Introduction

Ever since I first pondered how one might go about the task of creating a rifle barrel when I was just a lad, it has always seemed kind of like building a ship in a bottle. Just exactly how do you get tools in there to do some work? And how do you see what you're doing? At least when you build a ship in a bottle, the interior of the workspace isn't a dark and mysterious unknown. Making the hole wasn't the part that puzzled me. I knew what drills were and how to use them, although I must admit that I couldn't imagine drilling a hole *that* deep. But the rifling was a different sort of animal and I had absolutely no idea how you could cut grooves inside such a small hole, much less make them wrap and curl around the bore as they progressed forward. In those days, my ignorance and befuddlement concerning machine shop practice were so complete that I had no choice but to chalk the whole thing up to some sort of black voodoo magic and get on with my life as best I could.

As the years passed, I didn't give the matter too much thought because there really wasn't any pressing need driving me to learn the secrets of the barrel maker's art. And let's face it, despite the fact that rifled barrels have been in production for more than two centuries, there is precious little *useful* information that has been written down on the subject. Over time, I became a fair to middling deer hunter. By the time I had reached my mid-twenties, it was a foregone conclusion that I was going to put as much venison in the freezer each fall as I wanted. Success breeds knowledge and I began to form some very definite opinions concerning what did, and didn't, work well in the field. One of the strongest opinions that I formed during those years was the conviction that 50 caliber muzzleloaders aren't always the best medicine for big game; they are seriously lacking in penetration on angled shots and the blood trails their wounds induce aren't always reliable. It's not that the 50 calibers aren't enough gun. They are, but just barely. And I never learned how to settle for just barely. So I began a search for a bigger, better charcoal-burner.

As many of you who have engaged in the same search will already know, my search was rather frustrating and bore little fruit. But then, when I was just about ready to give up hope, the Kodiak Express 12-bore (72 caliber) double-barrel from Davide Pedersoli came on the scene. It was love at first sight and I simply *had* to have one of those rifles, so I bought one. The rifle, while certainly not a tack-driver, proved to be accurate enough for typical woods-range shots out to about 100 yards. And with a nearly three-quarter inch, 550 grain round ball rumbling along at over 1,500 fps, the "just barely" character of muzzleloader penetration and blood trails changed abruptly to "more than adequate". I like more than adequate. As the seasons came and went, deer and hogs fell at a steady rate whenever and wherever the 12-bore spoke, because it spoke with unquestionable authority. But, as satisfactorily as the Kodiak rifle performed for me in the field, I couldn't help but yearn for a little more accuracy out there where the dandelions grow tall. Like I said, I never learned how to settle for just barely. I also realized that there are some hunts that would never be in the Kodiak's future simply because there are some states that do not allow the use of double-barreled muzzleloaders for the hunting of big game. What if I wanted to hunt elk in Colorado during muzzleloader season? I certainly couldn't use a 50 caliber for elk now that I had grown accustomed to the power and penetration of a 12-bore when hunting deer. That was absolutely unthinkable. So I began another search, this time for a *single-barreled* large-bore. I tried a few large-bores from custom makers, but those rifles with their Forsythe-rifling couldn't even *match* the accuracy of the Kodiak, much less exceed it. I even contacted Davide Pedersoli in Italy to see if they could be induced to build a single-barreled 12-bore rifle (at that time, they made only smooth-bores in single-barreled configuration), but they would not. As my frustration grew, a long-neglected but deep-seated question slowly began to work its way back to the surface: how are rifle barrels made? You see, my quest (obsession?) for an accurate, powerful, single-barreled, large-bore muzzleloader was inexorably leading towards the only possible conclusion. I was going to have to build the thing myself.

This is the Pedersoli Kodiak that indirectly inspired me to become a barrel maker. On this particular day, the rifle put a 550 grain round ball right between this boar's eyes as he faced me down at a range of 15 yards. I don't know if he was planning to fight or flee, but the 12-bore decided the issue for him.

After deciding that I was going to fabricate my own muzzleloader barrels, I began yet another search. This time I was looking for any tidbit of information I could find that pertained to the crafting of rifle barrels. At first glance, it seemed that there was a bountiful supply of information on the subject. But as I began to dig deeper and really examine the available nuggets of wisdom, I found that much of what had been written on the subject was rather vague and not too helpful for readers like me who wanted to actually *make* barrels, not just learn about the process in general. Eventually, I dug up enough information from several different sources that I was able to build my own machine, fabricate my own tools, and finally make my own barrels. Since then, I have learned far more through hands-on experience and practical application. But I haven't forgotten how difficult it was to scrounge together enough information to get the ball rolling. This volume of work is my contribution to the shooting world and it is intended to fill the glaring void in our collective, written knowledge on the subject of rifled barrels. This is the book that I wish had been available when I was taking my first few tentative steps down this road.

While this book does contain everything I know (well, almost everything- a guy's got to have *some* secrets) about the specific processes involved in fabricating rifle barrels from solid bars of steel, it is not a work that can stand alone. In addition to the information found here, you will need to know several volumes worth of information about general machine shop practice if you intend to build your own machine and make rifle barrels yourself. This type of general machining know-how is beyond the scope of this book. Fortunately, and in sharp contrast to the store of published information that deals specifically with rifle barrels, there is no shortage of information available concerning the proper use of machine tools. I have listed several very useful references in the bibliography. In combination with this volume, these references will provide the rest of the information needed to become a full-fledged barrel maker. The bibliography also lists other sources of information pertaining specifically to making rifle barrels. If you intend to make barrels yourself, I strongly recommend that you also consult these other sources. There are some alternate techniques described in them that either didn't work so well for me or weren't applicable to what I was trying to do, but you may find the techniques very useful in your own endeavors.

Note carefully that I did not say that you will also need to spend years in apprenticeship to an established barrel maker in order to learn the trade. The perception that the trade can only be learned through long apprenticeship is very old and very romantic, but it is simply outdated in the contemporary age of information. I, myself, have never spent a single day under the tutelage of another barrel maker. I learned everything through a combination of reading and trial-and-error. Having said that, if you do happen to know a barrel maker with whom you could learn the ropes, by all means, jump at the opportunity! Yes, you can learn everything that he knows on your own… eventually. But learning from his experience will make the trip a whole lot shorter and the learning curve a lot less steep.

For those of you who have no intention of building and using your own machine to drill, ream and rifle barrels, this volume will nonetheless provide you with a very intimate knowledge of the process. And knowledge for its own sake is not a bad thing. I hope that, by the time you have turned the last page, you will have a much deeper appreciation for what those of us who make barrels have to go through to put those sleek, shiny rifles in your hands. A riflesmith who truly takes pride in his work could ask for no greater gift than a customer who truly appreciates the finished product. This type of understanding creates a far deeper camaraderie between craftsman and sportsman than can be attained through a mere monetary exchange and the lives of both are enriched by the shared experience. I can't speak for every riflesmith, but, when my customers send me pictures of their hunts, I feel far more pride in their harvest of big game animals with barrels that I made for them than I have ever felt about the harvest of critters by my own hand. There's just something about seeing one of my creations out there on its own doing good deeds for someone else. It makes me feel as if I've accomplished something that was truly worth the time and effort. It is my sincere hope that this book will provide you with the knowledge and inspiration to take the time and expend the effort to do something that is truly worthwhile for yourself.

Charlie Moore
Oakland, MD
September, 2012

CHAPTER 1: The Barrel Maker's Machine Shop

Any barrel maker, especially one who is building his own barrel machine, will need to have, or at least have access to, a basic machine shop. Basic is the key word. You will not need several large CNC machines that each cost as much as a modest home. A few basic machines, coupled with sound manual machining practices, will fit the bill quite nicely.

The subject of machining practice and technique is beyond the scope of this book and, in fact, requires an entire volume of written work to cover thoroughly. The bibliography lists several very useful sources of information on the topic of machining practices. Unless you have been operating machine tools since you were knee-high to the proverbial grasshopper, you should purchase a few of these references (or others like them) if you plan to build your own machine to fabricate your own barrels. They will provide you with the machining information not covered in this body of work. However, I would be remiss if I didn't mention a few things about basic safety and competence in the machine shop before discussing the types of equipment your barrel shop will require.

Basic Rules

Always roll up your sleeves and remove watches, rings, necklaces, etc. to avoid getting tangled in the machine or workpiece. I once read an account of an engineer who was wearing a necktie while running a lathe. He would have been sucked into the machine when the lathe dog snagged his fashionable accessory if not for the extremely quick reaction of a coworker who turned the machine off. I don't have a clue what kind of thought process led him to believe that wearing a tie in a machine shop was proper and necessary, but it was a decidedly poor idea. Gloves are off limits too. Cold fingers are far easier to remedy than broken or severed fingers. This business about keeping garments and accoutrements out of the machine is an absolutely inviolate rule of machining. Seriously, when a machine snatches you up, it *will* have its way with you. If you've ever had a hand-held, ½" electric drill wind your arms around each other like a Twizzler when the drill bit got caught on a thick chip, you know exactly what I'm talking about. Unless treated with respect, machine tools will do far more damage to the operator than a hand-held drill ever could.

Always wear safety glasses. Even when a machine is running at low rpm's, the chips being cut are under considerable pressure and can travel quite some distance after releasing from the workpiece. I've never had a steel chip in my eye and I intend to keep it that way.

Before switching gears or belts to change thread pitch or motor rpm range, make sure that the machine is unplugged. Not just switched off, but completely disconnected from the power source. Your fingers will thank you for taking the time to do this when they're still attached to your hand at the end of the day.

When filing a workpiece in the lathe, always point the tang of the file away from your hand, forearm and midsection. You do not want any part of your body in harm's way when (not if) the workpiece or chuck catches the file and thrusts it violently in the direction of rotation. Putting handles on your files will alleviate this concern and we all know it, but, seriously, how many of us actually have handles on *all* of our files? And how many of us will walk all the way across the shop to get a file with a handle when there's a perfectly good file with a bare tang lying right next to the lathe? Files with bare tangs are completely safe to use with a lathe as long as you treat them like loaded guns. *Never* point a naked tang toward anything that you don't intend to punch a hole through.

Focus on the task at hand. This is easier said than done, especially near the end of the day. At times, machining can be very tedious and it's a sure bet that your mind will begin to wander during a long, monotonous series of cuts. If you're thinking about bills, cars, football, hunting, fishing, blondes, brunettes or redheads, do not even attempt to operate a machine tool. At best, you'll make a cut in the wrong place and ruin the workpiece. And, of course, you won't ruin it on the first cut. You will ruin it after investing hours, or even days, machining it to the state of completion it was in when you made the faulty cut. Even worse, if you try to push your luck and cut steel when you're not completely focused on the task, you may injure yourself simply because you forgot one of the other safety rules. I've never injured myself with a machine tool, but I cringe every time I think of all the wasted hours spent on workpieces that I've ruined while trying to make "one more cut" before taking a break or calling it a day. Trust me, you will be much further ahead and waste much less time in the long run if you shut down and walk away from the machine when your mind begins to drift.

Do a dry run under manual feed with the machine power off before completing a setup and starting a cut. This ensures that the setup will allow enough travel to complete the cut without running the cutting tool into the machine (chuck, vise, etc.). This simple procedure will save you the frustration of going through a complicated setup only to have to tear it down and start over because you can't complete the cut. It will also ensure that you never damage your machine because of absentminded carelessness.

Ensure that your setup and cutting tool are solidly fixed and absolutely rigid before beginning a cut. The process of cutting steel looks smooth and easy with a rigid setup. But if you attempt a cut with a shaky setup or loose cutting tool, you will quickly realize just how much pressure is involved in shaping steel to your will. Machining operations get very scary in a big hurry when sharp steel objects that are supposed to be fixed in position start flying about in a willy-nilly fashion.

As I mentioned above, there is far more to being a competent machinist than I've covered here. But these suggestions do cover, in my humble opinion, the most important "always do" and "never do" rules of operating machine tools. Now let's have a look at the type of machining equipment required to run a rifle barrel shop.

CHAPTER 2: Methods of Rifling a Barrel

In making a rifle barrel, the drilling and reaming operations are simple and straightforward. There's a right way to do it and that's that. But rifling is a horse of a different color. There are several ways to form those mesmerizing, spiraling grooves along the length of the bore. Each method of rifling has advantages and disadvantages. Each method has people who swear by it as well as people who swear at it. It's up to the individual barrel maker (and the barrel maker's bank account) to decide which method to use in his shop. The vast majority of contemporary firearms manufacturers use the hammer-forging method to rifle their barrels. The reasoning behind their choice is obvious- they need to produce as many barrels as they can in the shortest period of time at the lowest cost. Quite apart from the very real economic considerations, small custom barrel makers don't employ hammer-forging machinery simply because they have no need to produce so many barrels so quickly. So for most of us, the choice comes down to cut-rifling or button-rifling.

One of the primary considerations in deciding between these two methods is time. When a barrel maker decides on the cut-rifling method, he is obligating himself to invest a considerable amount of time in each barrel. If the barrels will be made only for the barrel maker's own rifles, then the amount of time required to fabricate the barrels is not really an issue at all. However, if the barrel maker intends to sell his cut-rifled barrels to paying customers, then he had better find a specific niche for his products or he won't be able to compete in the marketplace. Examples of such niches are bench-rest rifle barrels and, in my case, large-bore muzzleloader barrels. Neither of these items are readily available at bargain-basement prices because the market for them is not large enough to justify an investment in mass-production machinery.

The other option for the small-quantity barrel maker is button-rifling. This method of rifling requires far less time than cut-rifling, so it is a viable option for those who would like to sell more common barrel configurations. However, nothing in life is free. Button-rifling does impose the additional expense of mandatory stress-relief of the barrel after the rifling operation is complete. This extra requirement is not so much of a handicap to larger custom barrel makers who can afford a heat-treating furnace. But for the small-shop barrel maker, the additional expense must be carefully weighed against the time savings that button-rifling offers over cut-rifling. Quality barrels can be crafted with either method, so it really is up to the individual barrel maker to decide which he'd like to use in his shop. In the following pages, we will take a closer look at the various methods of rifling a barrel so that the decision you make will be an informed decision.

CHAPTER 3: Indexing the Twist Rate of Cut-Rifling

For a small-shop barrel maker, the cut-rifling method is certainly the most practical way to produce accurate rifle barrels. The machinery required to cut grooves in a barrel does not need to be as robust as the machinery for button-rifling (let alone hammer-forging) and can therefore be built less expensively. And the fact that cut-rifled barrels do not need to be stress-relieved also reduces the cost to the barrel maker. However, the barrels produced will be worthless if the twist rate of the grooves is incorrect or inconsistent.

There are several indexing systems that will produce the proper rate of twist in a rifled barrel. Each indexing system has both advantages and disadvantages, but all will produce accurate barrels if set up and used properly. There are several important considerations when choosing an indexing system for the rifling operation. Some systems are more suitable for certain rifling pitches than others because of inherent design limitations or component size requirements. Available floor space is another important consideration. For example, the rifling cylinder indexing system requires a longer machine bed, and more floor space, than other systems. And the sine bar method is best conceived on a purpose-built machine for rifling only. This necessitates enough floor space for two machines- one machine for drilling and reaming and another machine for rifling. These and other considerations will be covered in more detail during the discussion of each indexing system. There may be, and probably are, other twist indexing systems out there, but the indexing systems we will be looking at are the most common and best known.

While there are differences between the various twist indexing mechanisms, the basics are the same no matter which system is chosen. In all cut-rifling operations, a rifling cutter box that is just a whisker under the bore diameter (land-to-land measurement) is pulled and pushed through the bore a number of times to cut the grooves in shallow increments. Rifling cutter box design varies, but all cutter boxes have moveable cutters that are raised a bit at a time to cut the grooves deeper on each successive pass through the bore. And, of course, the cutter box must be mounted to a stiff rod that is well under bore diameter so that it may be pushed and pulled through the bore. These things are common to all cut-rifling systems. The difference between the various twist indexing systems lies in how they impart rotation to the cutter box so that the finished grooves spiral around the bore. And, as you will see, the exact mechanism of rotation has some serious implications for the overall design of the machine and the types of barrels that can be rifled with it. We will be looking at four different mechanisms to impart rotation to the rifling cutter box.

CHAPTER 4: The 3-in-1 Barrel Machine

The drilling, reaming and rifling of rifle barrels are all very specialized operations that are not required or typically encountered in general machining. Sure, machinists drill and ream holes all the time. But those holes are typically only a few inches deep, at most. Lathes and mills can handle the machining of shallow holes with little difficulty. The trick when it comes to making rifle barrels is to machine perfectly straight holes with depths measured in *feet*, not inches. This sort of specialized operation requires some very specialized equipment. In fact, the machines used to perform these operations are so specialized that they are of no use for anything other than making rifle barrels. This narrowly focused purpose allows the design of the machine's components to be very basic because they only have to be very good at doing one thing.

When building a rifle barrel machine, or any other kind of machine for that matter, it is very important to take some time to design all of the components of the machine before actually fabricating or purchasing any of them. The reason for this is simple- all of the pieces work together to make a functioning whole. Because of this interdependency, the size, shape and placement of each component will affect the size, shape and placement of every other component.

The components that you will be fabricating yourself can be made to any dimensions that you require (within practical limits). However, the dimensions of the components that you will be purchasing do not give you the same degree of flexibility in design. After roughing out the general size and layout of your machine, you will need to do some homework to determine the dimensions of the gears, pulleys, bearings, motors and other assorted items that will be outsourced to finish your machine. I'm not talking about the very basic dimensions, such as a 2 $^{1}/_{16}$" bore through the raceways of the bearings for the spindle, but rather dimensions such as the center height of the bearing race above the base of the bearing and the spacing of the bolt holes through the base. *These* are the types of dimensions that will affect the design of your machine. Note carefully that I did not say that you will need to purchase the components and have them in your hands while designing the machine. Just get the dimensions of the parts now so that you can incorporate them into your design. When the design is finalized and you're sure that everything will fit together as it's supposed to, then the time has come to start buying the components that you don't intend to make yourself.

But the first step is to sketch out the basic design of your machine. The starting point of the design is not the machine bed or even the tools for drilling, reaming and rifling. The only point at which to begin designing a purpose-built machine of this sort is at the finished product itself. In this case, this means that the machine's design *must* start with the barrels that you intend to make. The machine must be made to accommodate the barrel, not vice versa. I believe this is known as reverse engineering in some circles. I call it common sense. I will not be providing a detailed listing of the dimensions of my machine's components because that would be a very good way for me to get you into trouble. My machine is designed to make *my* barrels and the same component dimensions may not work for you. The specific form of every component of your machine must follow the specific function it will have to serve to achieve *your* specific end. Along the same line of thought, if your specific end is a button-rifling machine, this basic blueprint for a cut-rifling machine could be adapted to serve that function without much trouble.

To put it in a vastly oversimplified nutshell, you'd just need to add a pressure plate and a hydraulic press to my machine with its rifling cylinder twist indexing system. Just remember that the entire machine will need to be much more robustly constructed to handle the terrific forces involved with cold-swaging steel.

But before you can design the components and layout of your machine, you must know what each component is required to do, both individually and as an assembly in conjunction with other components. In this chapter, we will look at what kinds of components are required to perform the basic tasks of machining rifle barrels. Those basic tasks are work-holding, tool-holding and tool-feeding. Once you know the basic functions that your machine's components will be called upon to perform, you can begin designing the layout and dimensions of the machine. The last section of the chapter will provide a few helpful tips and techniques to align all of the machine components on the same centerline.

CHAPTER 5: The High-Pressure Oil System

High-pressure oil is injected into the barrel blank at the interface of the workpiece and cutting edge during the drilling and reaming operations for three purposes. The first job the oil has to do is to provide lubrication so that the cutting action will be smooth and chatter free. It will do no good to cut a hole through the barrel blank if the finished bore is so rough and uneven that it is not suitable for the intended purpose. The second purpose of the oil is to conduct heat away from the cutting edge. Not only does this preserve the cutting edge by reducing erosion, it also prevents the steel of the barrel blank from expanding. This would cause the cutting tools to bind and it would also cause the finished bore to be very slightly oversized when the steel cools and contracts. But the most important role of the cutting oil is to flush the chips out of the hole and away from the cutting edges. In the case of the reamer, keeping the cutting edges clean and free of chips ensures that the cut will be as smooth as it can possibly be. As for the deep-hole drill, it is absolutely imperative that the high volume of chips produced be flushed out continuously to avoid compaction of the chips in the V-groove of the drill and shank. If the chips are not flushed away with sufficient urgency during the drilling operation, the V-groove will very quickly become packed with chips and this will actually push the drill off-center. Since the objective is to drill the straightest hole possible, this sort of thing can't be tolerated.

Since the volume of chips produced during drilling so vastly exceeds the quantity produced during reaming, it is the drilling operation that sets the requirements of the high-pressure oil system for the machine. Deep-hole drill manufacturers provide charts to determine the amount of flow and pressure required for their drills based on the diameter of the drill and the speed and rate of feed used to accomplish the cut. There are also figures that can be used to determine a maximum speed for drilling when the oil flow and pressure can't be brought up to the recommended levels. It is strongly recommended that you use the charts provided by the manufacturer of your particular drill(s). The geometry of various brands of deep-hole drills is very similar, but there can be minor differences between them.

Unlike the motors used for the spindle and leadscrew, which don't require a lot of power because the load is relatively light, the motor used to drive the hydraulic pump has to work very hard to produce the kind of flow and pressure that this type of machining demands. Likewise, the pump should be sufficiently large that it doesn't have to be spun at breakneck speed to produce the output required. When building a machine like this, it seems that the most difficult challenge will be to fabricate and align all of the components that actually do all of the high-profile work. The high-pressure oil system almost seems like an incidental afterthought. But brother, in this case, appearances are definitely deceiving. While building the machine per se is in fact the most rewarding part of the project, getting the speed of the drill-cut properly balanced with the maximum output of the high-pressure oil system is, by far, the most frustrating quandary you are likely to face as a barrel maker. Actually, if you make only small-bore barrels, the high-pressure oil system may not impose any undue or unforeseen complications in your barrel making future. But once the bore size increases above 30 caliber, things can get interesting in a hurry. Even when using my smallest drill diameter of .5700", the sheer volume of chips produced taxes my oil system to its limits. However, there is a simple solution that allows me to drill holes far larger than this. I just have to reduce the speed of the cut so that the rate of chip production remains within the chip removal capabilities of my high-pressure oil system.

Because of the surprising importance of the high-pressure oil system to the overall performance of the machine, we will first look at the flow and pressure requirements to run various sizes of deep-hole drills at maximum cutting speed. Then we will look at the maximum practical flow and pressure that can be achieved in a small shop with limited resources and how to adjust the cut itself to compensate for any deficiencies in the available equipment. We will wrap up the chapter by looking at the plumbing required to get the oil to the cutting edge and then safely back into the reservoir to be recirculated.

CHAPTER 6: Barrel Tooling

The art of making rifle barrels really isn't about the barrels themselves. It's all about the tools. If the cutting tools are as they should be and they are used as they should be used, the only possible outcome is a well-made, accurate rifle barrel. If, on the other hand, the tools are *not* as they should be, then the only possible outcome is miserable failure. Barrel making, like other types of machining, is a lot like sculpting. The raw steel bar has a rifle barrel trapped inside of it and it is up to the barrel maker to liberate it from its prison by cutting away the bits that confine it. But few machining tasks require the level of precision and care that must go into the creation of a rifle barrel. In order to remove every last trace of steel that isn't part of the rifled bore, but not a molecule more, the cutting tools must be very nearly perfect. Their dimensions cannot be more than a couple *ten-thousandths* of an inch shy of absolute perfection. And in addition to the requirement that the entire tooling assembly be dimensionally beyond reproach, the cutting edges must be maintained in a perpetually razor-sharp condition. There is no such thing as a drill, reamer or rifling cutter box that is "good enough". These precision implements of the machinist's art are either just right, or they are just plain wrong.

Many barrel makers buy all of their tooling from commercial sources. Considering the very high standards that the tools must meet, there is certainly no shame in this approach. But some of us choose to make our own tooling, either out of necessity or a desire to meet the formidable challenge that fabricating our own tooling presents. I bought my deep-hole drills primarily because I don't have the type of equipment that would be suitable for pressing a V-groove into the very long shanks of the drills. I also like the fact that the commercial drills are made of tungsten carbide so that they will last a very long time between sharpenings. I made my rifling cutter boxes myself because I don't have a clue where to buy them ready-made, especially for the caliber of barrels that I make. I also made my own reamers. Now, I'm pretty sure that I could have gotten the reamers from a commercial source. But I'm very sure that the sizes I require would carry a hefty price tag. I also wasn't willing to take the chance that outsourced reamers would be easily adaptable to my machine. By making my own reamer assemblies, I was able to build my machine around the deep-hole drills and then adapt the reamer assemblies to the machine. I also made my own drill guide bushings for the exact same reason- I was able to adapt them to the design of my machine. There is one very important thing to remember before you decide to use my techniques to build your own tools. Because I make only large-bore muzzleloader barrels, my cutting tools are absolutely huge compared to the tooling required to make barrels for the vast majority of centerfire calibers. My *smallest* set of tooling (58 caliber) is large enough to make *ultra*-large-bore, centerfire elephant rifle barrels. Smaller tools will be considerably more challenging to fabricate and far more likely to warp during heat-treatment. And the smaller they are, the higher the degree of difficulty. I've toyed with the idea of making a set of tooling small enough to craft a barrel for the 10 Eichelberger Squirrel wildcat cartridge. Not because I have any particular desire for a rifle so chambered, but because making the tools would be so ridiculously difficult. So far, just thinking about the project gives me a headache of sufficient magnitude that common sense has prevailed. But, regrettably, I *have* done a few really dumb things in my life, so who knows? Maybe someday I will be the proud owner of a rifle perfectly suited for stopping the charge of any enraged bull chipmunks that might happen be lurking about the place with malevolent intent… all because I just *had* to ask “I wonder how hard it *would* be to make tools that small?”

Because the cutting tools are of paramount importance, this chapter will deal exclusively with purchasing or fabricating the proper tools for the job. We’ll also discuss which grades of tool steel should be used based on the heat-treatment capabilities of the available shop equipment. After that, in the next chapter, we’ll start making some chips fly by getting into the actually machining operations involved in turning an unremarkable bar of steel into a testament to the art of rifle barrel making that will outlive the craftsman who created it.

CHAPTER 7: Machining Operations

As with all machining operations, workpiece preparation and an accurate set-up are required when machining a rifle barrel. Workpiece preparation is the prerequisite insofar as it sets the stage for making an accurate set-up. If the surfaces of the workpiece are not true, then establishing a proper set-up that precisely locates the work in relation to the cutting tools will not be possible. A barrel blank with smooth, consistent surfaces and accurate angles can be mounted on the machine in perfect alignment with the machine itself and with the cutting tools. The barrel blank should be thought of as a temporary component of the machine, with its positioning and alignment being just as important as the positioning and alignment of every permanent component. The two major aspects of the barrel blank set-up are centering in the spindle and squarely interfacing with the drill guide bushing to form an oil-tight seal. If these two requirements are met, the drilling operation will proceed flawlessly and the finished hole will be perfectly straight.

Tools of the trade: 8-bore tooling on the left, 58 caliber tooling on the right. In the center lie two completed barrel blanks, one in each caliber.

With the barrel blank accurately mounted in the machine, there are three other factors that will determine the outcome of the drilling and reaming operations. These factors are speed, feed and oil flow (chip removal). If the speed of barrel blank rotation and tool feed are correct, the cutting tools will do their job efficiently and leave behind a very good surface finish when their work is through. Likewise, if the oil flow is set correctly for the rate of chip production generated with a particular combination of speed and feed, then the tools will cut true without binding. However, if one or more of these parameters is not as it should be, then the hole is not likely to come out very straight or smooth. A crooked, rough hole would suffice if the finished product was going to be used as a sewer pipe, but this condition simply won't do when the objective is to produce an accurate rifle barrel.

Of all the operations required to craft a rifle barrel from solid stock, cutting the rifling is undoubtedly the most challenging. Drilling and reaming, while important, are relatively easily accomplished when the parameters of the operation are balanced correctly. Rifling a barrel by the cut-rifling method, on the other hand, requires concentration and attention to detail. It also requires the barrel maker to be able to determine how the operation is proceeding based solely upon the feel of each successive cut. This is in stark contrast to drilling and reaming. With those operations, once the machine is set up and running, the barrel maker becomes little more than an interested spectator to an event that really isn't all that interesting. But the cut-rifling operation demands the barrel maker's complete and undivided attention. He must keep track of several different variables constantly and simultaneously. And again, this must all be done by feel because the cutting operation is entirely hidden from view. This is why most people who know anything at all about the subject have reckoned the cutting of rifling grooves an art, not a science. After learning this time-honored practice myself, I have to agree. Cut-rifling really is a cut above more common machining practices because it does indeed demand more from the machinist. While there are very real, very practical advantages to cut-rifled barrels, it is the finesse and care that go into making them that causes riflesmiths and shooters alike to hold them in such high esteem. Then again, all of that finesse and care also tend to make cut-rifled barrels very good performers on the range and in the field, so maybe that's why they're held in such high esteem. Regardless, this chapter deals with the nuts and bolts of actually making those coveted, cut-rifled barrels.

CHAPTER 8: Understanding Barrel Steel

The sole purpose of a rifle barrel is to accurately propel a projectile towards the target. The barrel accomplishes this feat by containing and channeling a tremendous amount of pressure behind the projectile. If the steel used to make the barrel can't handle the pressures involved, the high-pressure gas will find its path of least resistance out through the barrel wall instead of down the bore behind the bullet. Not only would this defeat the purpose of the barrel by resulting in a projectile that does not project from the rifle, but this situation is also extremely dangerous for the shooter and any hapless bystanders who find themselves in the wrong place at the wrong time. Because the pressures involved with firing a rifle are so potentially dangerous, the choice of steel used to make the barrel is not a decision to be taken lightly.

But strength is not the only property of barrel steel that matters. The barrel blank must also be springy enough to expand slightly under pressure and then snap back into shape after the projectile has exited the bore and pressures have returned to normal. This means that the barrel steel must not be too hard because it will then be too brittle to handle repeated high-pressure expansion. To really top things off nicely, a barrel steel should also be reasonably easy to machine. The strongest, toughest barrel blank in the world will do you little good if it's so ridiculously hard to cut that it's nearly impossible to machine smooth lands and grooves into it.

In this chapter, we will take a detailed look at several grades of steel that are appropriate for both muzzleloading and centerfire rifle barrels. But first, we need to know why we are looking at these steels and not others. So we will begin by determining the general physical properties required of any barrel blank. Then we will look at the hardening and tempering processes that allow our chosen alloys to exhibit these necessary physical properties. Finally, we will look at the chemical composition and physical properties of five different alloy types so that we can compare and contrast them during the process of selecting the best steel for our purposes. As we will see, the barrel maker is often left with some very tough choices to make when choosing a barrel steel alloy.

Physical Properties of Barrel Steel

Barrel steels must meet or exceed certain minimum physical property requirements to be deemed suitable for the intended application. As mentioned above, the steel must be simultaneously strong, tough, hard (but not too hard), and relatively easy to cut. For rifles that will be either blued or browned, the steel must also be fairly easy to oxidize or it will be very hard to color to the desired finish. If these general characteristics are to be anything more than subjective hogwash, we must quantify exactly how much strength, toughness, etc. we are talking about.

Minimum Requirements for Muzzleloading Rifle Barrels

The original, timeless standard for the physical properties required of a muzzleloader barrel is wrought iron. This was the first ferrous material used to make rifle barrels and there are still a few dedicated artisans who forge their barrel blanks from iron. Any modern steel alloy used to make a muzzleloader barrel must be able to measure up to, or exceed, the mechanical properties of wrought iron.

Mechanical Properties of Wrought Iron

Hardness, Brinell	105
Hardness, Rockwell B	62
Hardness, Rockwell C	Can't be measured on the C scale
Tensile Strength, Ultimate	34,000-54,000 psi
Tensile Strength, Yield	23,000-32,000 psi

Chemical Composition of Wrought Iron (percentage by weight)

Iron	99.0-99.8%
Carbon	0.05-0.25%
Manganese	0.01-0.1%
Silicon	0.2% max
Sulfur	0.1% max
Phosphorus	0.2% max

Obviously, wrought iron does not make a particularly hard rifle barrel. Nor is it particularly strong. But it doesn't have to be because typical pressure levels at the breech of a side-lock muzzleloader are under 20,000 psi. Modern in-line muzzleloaders can and do approach 30,000 psi with magnum loads and will require barrels made of stouter stuff than wrought iron. Of particular concern to the barrel maker is wrought iron's variability in tensile strength, both ultimate and yield. There are still quite a few wrought iron barrels in service that were forged in the proverbial days of yore. However, there were also many more wrought iron barrels that are no longer with us because they burst under pressure. Since we are setting minimum *safe* standards for muzzleloader barrels, we would be well advised to take the highest values of tensile strength obtainable with wrought iron (54,000 psi ultimate and 32,000 psi yield) as our minimum acceptable level of strength. And even these values aren't acceptable for in-line muzzleloaders.

It will be important later to remember that wrought iron is full of slag inclusions. Someone with a fancy microscope and more free time than I have ever had counted the number of inclusions in wrought iron and determined that there are, on average, about 250,000 inclusions per square inch… I'll take his word for it. Also note the percentages of sulfur and phosphorus contained in wrought iron. We will be looking at free-machining grades of modern steels for use as muzzleloader barrels, both side-lock and in-line, and these steels are characterized by inclusions of sulfur, phosphorus and even lead. The stringers produced by these impurities give the steel its free-machining qualities by allowing chips to fracture at the boundary between the martensite grains (ferrite grains in the low carbon and/or cold drawn grades of steel) and the inclusions. Since our gold standard for muzzleloader barrels, wrought iron, contains the same type of inclusions, there is no compelling reason not to use the free-machining grades of steel that will provide free cutting and longer tool life.

<u>Minimum Requirements for Centerfire Rifle Barrels</u>

The standard set for centerfire barrels during the last century was ordnance steel. Ordnance steel contained enough carbon to allow the alloy to harden through heat-treatment. It also contained a fair amount of manganese to increase the depth of hardening. By increasing the depth of hardness, a homogeneous steel is produced that isn't hard on the outside while remaining too soft for the intended application near the center, where it is more difficult for the quenching medium to remove heat quickly enough for martensitic transformation. So, the standard for centerfire barrels is homogeneous steel with the following characteristics:

Mechanical Properties of Ordnance Steel

Hardness, Brinell	275-305
Hardness, Rockwell B	104-107
Hardness, Rockwell C	28-32
Tensile Strength, Ultimate	130,000 psi
Tensile Strength, Yield	110,000 psi

Chemical Composition of Ordnance Steel (percentage by weight)

Iron	98.5-98.1%
Carbon	0.40-0.55%
Manganese	1.00-1.30%
Sulfur	0.05% max
Phosphorus	0.05% max

Because of the pressures produced by centerfire cartridges (up to 65,000 psi), the strength required of the barrel steel has increased tremendously over what is considered adequate for muzzleloaders. Remember that the values presented above for strength are *minimums*. Do not, under any circumstances, use a weaker grade of steel to make a centerfire barrel. Even if you're making a barrel for an old-timer like the .45-70 Government and you plan to use only black powder loads, use a grade of steel that can handle the pressure produced by smokeless powder. The rifle will eventually fall into someone else's hands and, if you use a weaker grade of steel, they may get themselves into some serious trouble with high-pressure smokeless loads. Depending on what type of action that .45-70 barrel is screwed into, they may get themselves into trouble with smokeless loads anyway- but at least it won't be *your* fault. Also, note the amount of carbon present in the steel. This level of carbon is required to harden the steel all the way through without causing embrittlement. Yes, more carbon would make the steel stronger, but it would also make it more likely to fracture. For example, the tensile strength of O-1 tool steel (both ultimate and yield) is nearly twice that of ordnance steel, but a barrel made of O-1 could very well burst when fired because its carbon content of 0.85-1.00% makes it far too brittle for this application. Barrel steel needs to be elastic.

Another difference between the steel used for centerfire barrels and the wrought iron used for muzzleloader barrels is the nearly surgical cleanliness of the alloy. Only trace amounts of sulfur and phosphorus are considered acceptable for centerfire barrels. As previously mentioned, stringers of impurities in the steel make it easier to machine, but they also create potential points of weakness where barrel fractures can begin to form. Those of you who are familiar with the alloys used for modern centerfire barrels will likely have heard that 416R stainless steel barrels can fracture at extremely high or low temperatures. This weakness is due to 416R's increased sulfur content of 0.13%. The suitability of this alloy for centerfire barrels is a valid concern and we will discuss 416R in more detail later. We will also look at two alternative grades of stainless steel for rifle barrels that do not have a high percentage of sulfur.

Speaking of stainless steels, only the mechanical properties listed above apply to the stainless alloys. The chemical composition of stainless steels is far more complex than what is presented in this section. We will look at the exact chemical composition of suitable stainless steel alloys later.

CHAPTER 9: Proof-Firing

Rifles impart motion to their projectiles by igniting a violent deflagration beneath them in an enclosed space. This causes, by necessity, very high pressures. The high-pressure gas generated by the burning gunpowder is able to launch the bullet from the barrel at high velocity by applying considerable force to the base of the bullet. This is all well and good, but the gas also pushes with the exact same amount of force against the breech of the rifle and the walls of its barrel. And if the barrel is not strong enough to stand up to this force, the barrel bursts and sends shrapnel flying indiscriminately across the landscape. This is a very dangerous situation that should be avoided at all costs. The only way to be reasonably certain that a particular rifle barrel will not fail when fed a steady diet of normal loads is to feed it a load that has intentionally been made far more powerful than any other load the barrel will ever be asked to digest. This procedure is called proof-firing and its goal is to cause a faulty barrel to burst, or at least swell to the point of becoming completely unserviceable, before anyone ever fires a round through it from the shoulder.

With the firing of a single proof load, you are verifying: the strength of the raw material, the thickness of the barrel walls, the integrity of the installation of the receiver or breech plug and, to a certain extent, the dimensional accuracy of a centerfire barrel's chamber and bore. There is no means other than proof-firing to know for certain that a particular rifle will be safe to fire from the shoulder. Sure, measuring instruments and gauges can be used along with the yield strength of the steel to, theoretically, determine whether or not the barrel is sound. You can even use X-ray or ultra-sound to have a peek inside the barrel to determine if any internal flaws are present. But, even in the technology-filled 21^{st} Century, the only way to be absolutely certain that a specific barrel is structurally sound is to subject it to a ridiculously heavy load that generates forces of equally ridiculous magnitude. The reason it is called "proof-firing" is because it *proves*, beyond any reasonable doubt, that the barrel is satisfactory for its intended use.

While the need for proof-firing is universally accepted among all cultures (at least those cultures which are civilized enough to trust armed citizens), the standards of proof do vary somewhat in different regions throughout the world. Standards of proof can also vary depending upon the caliber of rifle being tested and the normal pressures to which it is subjected. I am not employed at a ballistics research facility, nor do I have the sensitive instrumentation necessary to conduct my own ballistic testing. So, as far as I can say with any measure of credibility, it doesn't matter which set of proofing standards you choose to follow. The important thing is that you do follow *some* standard. The standard of proof that you choose to follow will be largely dictated by the equipment you have on hand to measure your compliance. However, it is probably wise to at least attempt to use the standard that was originally established for the caliber and chambering of the specific barrel that you are proving. For example, if you are proof-firing a barrel chambered for the 7 × 57mm Mauser cartridge, it would make sense to use the Commission Internationale Permanente (CIP) standards for proving that particular barrel because that is the original standard for the cartridge. However, without the sophisticated equipment needed to conduct internal ballistic testing, it may not be practicable to use a particular proofing standard because you won't be able to tell whether or not you are in compliance. Most proofing standards are based on maximum chamber pressure produced by the proof load, but these standards do you no good if you don't have loading information for the proof cartridges or a pressure measuring device to determine when the specified pressure has been reached. Fortunately, there are other alternatives for assembling proof loads that do not require verification by a ballistics laboratory.