IN THIS CHAPTER

- Introducing basic metalworking processes
- Understanding the difference between bending and forming
- Comparing fabrication to other manufacturing processes
- Taking apart the machine for a peek inside

Chapter 1
Manipulating Metal

It is not knowledge, but the act of learning, not possession but the act of getting there, which grants the greatest enjoyment.

— CARL FRIEDRICH GAUSS

In 1987, ex-Beatle George Harrison released the hit song, "When We Was Fab," in which he lamented the loss of his youth and the subsequent breakup of the original boy band from Liverpool. In spite of his poor grammar (or perhaps in part because of it), Harrison's tune caught on. Although it might sound silly, I can't listen to the late musician's hit single without thinking about the fabrication, or fab, shop where I once worked, the sounds of stamping presses and laser cutters rattling about behind my ears. Am I crazy, or is that a sign of too many years making parts?

It's certainly not the latter. Metalworking is an awesomely cool profession (albeit one that's a bit noisy), and I wouldn't trade the memories of those sounds and smells for anything. Walk into any fab shop and you'll immediately know what I'm talking about — the boom . . .boom . . . boom of the heavy stampers reverberating through the floor like the footsteps of a not-so-distant giant.

From the other side of the factory comes the machine-gun sound of the turret presses, the crackle of the welders, and the hiss of lasers and waterjets and high-density (also known as high-definition) plasma cutting machines patiently slicing through steel. It's an awesome experience. Yes, it can be a loud place (be sure to wear your hearing protection), but there are some wondrous things going on here; metal is being shaped and stamped and sliced and bent into parts that are used all over the world and held to tolerances finer than the thickness of a human hair.

Defining the Processes

Even more so than those shops that cut metal on lathes and machining centers each day (that is, machine shops), every fabrication shop is different. Where some specialize in welding large metal structures like electrical distribution towers and railroad trestles, others cater to customers looking for hydro-formed parts or millions upon millions of stamped-metal widgets.

The term *fabricating* covers a diverse set of technologies, some performed on generic machine tools that might accommodate dozens of distinct processes, others on specialty equipment that does only one thing. I dive more deeply into the more common of these processes in Part 2, but for now, let's take a 30,000-foot view of all that it might mean to be a fabricator, starting with *cutting,* a generic term that includes cutting metal with a stream of high-pressure water, a high-powered laser, or a jet of super-hot plasma, and is one of the primary operations performed on sheet metal, plate stock, angles and shapes, and billets.

Cutting up

Look up the word "cut" in the dictionary and you'll see it described as "using a sharp instrument to sever, slice, or chop" something, as in "I cut my big toe on the doorjamb last night." Ouch. When it comes to sheet metal, however, cutting generally means fracturing the material — no sharp edges are needed, at least not like the tip of a kitchen paring knife.

TECHNICAL STUFF

Punching and shearing operations usually require two precision-ground edges to be slid past one another, often at a high rate of speed but not always so. As they pass, the material trapped between these opposing forces deforms momentarily and then fractures, whereupon a section of raw material literally breaks away from the sheet, plate, or angle from which the workpiece is being made. Examples include the punch and die set used to punch out millions of shiny new pennies, or a huge scissors-like machine tool known as a *shear* (something I *slice* into shortly).

To be completely accurate, much of the "cutting" done in the fabricating world is actually a shearing operation of some sort, although that's not to say you can't cut a piece of material with a bandsaw — it's done all the time but is generally reserved for materials too thick to shear using conventional means, or by shops that don't have a heavy-tonnage shear.

Even though the mechanisms are fundamentally different, the term *cutting* has also come to encompass newer technologies such as abrasive waterjet machines and laser cutters, both of which are giving their centuries-old shearing counterparts a run for their money (see Figure 1-1).

FIGURE 1-1: Abrasive waterjet machines can quickly and cleanly cut virtually any material in any thickness, from the hardest steel to the most friable stone.

Courtesy: WARDJet, Inc.

Shearing specifics

My wife owns a set of heavy-duty kitchen shears. She hides them in the drawer behind the Ziploc bags, and occasionally inside her nightstand drawer. I love those shears, and even though she yells at me for doing it, I use them to cut everything. Aluminum foil, cardboard, rope, that nearly-impossible-to-open plastic packaging that once contained my latest Captain America figurine — you name it, they cut it.

But shears do far more than create domestic disputes in the kitchen. Industrial shears are just as important to those who process sheet metal for a living. They function in much the same manner as their smaller household counterparts, by passing a blade of hardened steel past a stationary but similarly shaped blade below. This fractures the metal, and if all has been set up properly, will leave a straight, clean edge with minimal burr. (Burrs are those annoying, ragged, and often sharp edges that can send the incautious among us to the emergency room for stitches.)

TIP

Suppose you want to make a replacement electronics cabinet for your vintage Elvis Presley pinball machine. You might start with a 4-x-8-foot sheet of aluminum, shear off a piece to match the cabinet's "unfolded" dimensions, notch out the corners (perhaps using a punch press), bend it up on a press brake, and then spot weld the corners together. The King is back in business. (I talk more about these operations in Part 2.)

Slitting success

Pretend it's your favorite nephew's birthday and you want to wrap the *For Dummies* book you're giving to him as a gift. The roll of paper is 36 inches across — far too wide for that yellow-bound work of art — so you decide to slice the paper in half lengthwise. If the gift wrap were made of steel, you would have just performed a slitting operation, and it's the first step in the process that turns coils of steel perhaps six feet wide, thousands of feet long, and weighing tens of thousands of pounds into more manageable pieces of raw material (check out Figure 1-2).

FIGURE 1-2: Every day, metal coils weighing more than a school bus are slit, sheared, stamped, and formed into millions of different parts.

mady70/Shutterstock

Slitting is a type of shearing operation, except it's usually done continuously, lengthwise down the coil. A single coil might be unwound, slit into whatever widths are needed, then rewound again on the opposite side of the slitter in one continuous process. It could also be used to feed a stamping line — flattened and sheared into short lengths to make sheet stock for use on a turret punch or laser cutter — or sent to a blanking line as the first step in the production of the door panel for the new sports car you're planning to buy next year.

Punching out

The mechanics of punching are much like those of shearing in that the metal is first deformed and then fractured in rapid succession as the tool moves past. But where shearing uses a set of opposing blade-like tools to get the job done, *punching* relies on a punch and die set (hence the name) that fit together precisely, one within the other (Figure 1-3 shows a photo of one such tool).

FIGURE 1-3: As the name implies, these multitools contain multiple punch and die sets, which can be indexed to whichever tool is needed. They are a favorite of turret punch-press operators who've run out of tool stations.

Courtesy: Wilson Tool International

Suppose you want to make a series of Mickey Mouse–shaped holes in a sheet of aluminum. (I'm unsure why you would want to do this, but you get the idea.) Accomplishing this task would require a punch made of hardened tool steel or tungsten carbide (sometimes simply called "carbide"), which in all likelihood was cut using a wire electrical discharge machining (WEDM) machine to resemble everyone's favorite rodent. (I talk about EDM and other toolmaking processes in Chapter 12.)

The punch will be mounted in the top station of a punch press or possibly in the upper half of a stamping die. In either case, a mating female die must be positioned directly below it. Some small amount of clearance (less than a hair's width, most likely) between the punch and die is required for machine misalignment and to allow the slug to pass through, with thicker materials requiring commensurately more clearance than when punching thin materials. Slide the material between the two halves of the mating tools, give the punch a whack, and there's Mickey.

Perforating

Here's another punching example. Most of us who live in the desert Southwest have a security screen door on the front of our house to allow fresh air in while keeping critters such as coyotes and javelinas (which look like wild pigs) out. These doors are made of perforated metal — it resembles a window screen but is thicker and strong enough to withstand inquisitive noses. Perforated metal is also used for washer and dryer drums, screens for separating materials in food processing, and as decorative panels in architecture.

Perforated metal is produced in a variety of ways. The most common employs a device that looks similar to a rolling pin that has a series of sharp needle-like punches around its circumference. As this "perforation roller" rolls over the metal, it continuously punches round, square, or whatever-shape holes are desired along its surface. Now take this concept one step further. Rather than a cylindrical roller, it's quite feasible to produce the holes en masse via a metal plate that looks like a bed of nails and a matching die set. Just give the sheet a good whack as it passes beneath and thousands of perforations can be made in one shot.

IMPORTANT DETAILS

Expanded metal is a close cousin to perforated metal. Like chicken wire on steroids, it's great stuff for non-slip surfaces on industrial walkways and running boards on monster trucks. And to borrow another example from the desert Southwest, expanded metal lath is commonly applied to the outside of houses before slathering them with stucco. Rather than simply punching holes and diamond shapes as with perforated metal, however, expanded metal is made by simultaneously stretching the metal while punching small slits into it, much like the process we once used to make paper snowflakes as children. (It's perfectly okay if you still do so.)

Blanking

As I mention a few pages back, sheet metal starts out as humungous coils of material that are delivered from the mill to a metal processor. These are then sliced into narrower coils or sheared and flattened into manageable pieces approximately the size of the plywood sheets you've probably purchased at one time or another from the local lumber yard.

In either case, the sheet stock is often "blanked" into a variety of shapes that are sent on to secondary processes. For high-volume applications such as automotive door panels, this is usually accomplished using a punch and die on a dedicated blanking line. A punch of the desired shape is forced through the sheet and into a mating die. This shears the door panel out of the sheet, causing it to fall through.

What's the difference between a blanking operation and, say, cutting an oblong-shaped window or punching a hole in a workpiece? Easy. With blanking, the piece that falls through the sheet *is* the workpiece, whereas in a normal piercing or punching operation, that leftover chunk of material is scrap.

REMEMBER

For higher-volume shops, blanking is often done with a punch and die set, but shops could also use a laser, waterjet, or shear to knock out whatever shape is needed for the forming press or press brake. The decision as to which is most cost-effective largely depends on job quantity, edge quality, material thickness and type of material, and which machine is most readily available.

Boarding the Bending Express

Virtually all sheet metal is bent or formed into some sort of shape eventually. If not, it would just lie there being flat for its entire life, good for little more than a gasket or shim. Boring, right? Most of the time, bending operations belong to the press-brake department, but that doesn't mean you can't bend a bracket with a die set in a stamping press, or fold a short, shallow louver using a special tool in a turret punch press. Fabricators are clever people, and they are constantly coming up with ways to make their equipment work for them.

Putting on the brakes

Bend a piece of metal too far or too fast and it will *fracture,* which is the same mechanism involved in shearing. But by controlling it carefully (and by selecting metal that boasts sufficient plasticity), precise, high-quality bends can be made in a variety of metals.

I get into the nitty-gritty details of press brakes in Chapter 5, but for now, you can think of one as a big paper airplane folding mechanism with a V-shaped (usually) punch on the upper side of the press and a mating female die on the bottom. Squeeze a sheet of metal between the two halves and a variety of shapes can be formed.

There's way more to the story than this. Accurate tonnage and bend calculations, the types of tooling used, blank size, corner radii and part dimensions, and the order in which bends are made all play a role in the success of any bending operation. Check out Figure 1-4 for an in-process photo.

FIGURE 1-4: Bending complex parts like this is all in a day's work for a modern computer numerical control (CNC) press brake.

Courtesy: LVD Strippit

Forming opinions

Step out to the garage for a moment to groove on the sleek lines of your 1991 Yugo GV. The quarter panels, hood, roof, doors, and even some parts of the frame were made on a stamping press larger than a studio apartment. (Sadly, the Serbian plant that once made the Yugo was destroyed by NATO bombs in 1999.) Heavy stampers work much like press brakes, except that rather than bending up a box one edge at a time, the heavy stamper would form the entire box in one shot: BOOM!

Just kidding — it would be impractical to form a box shape in this manner, as the corners are too sharp and the metal would buckle. But heavy stampers can form very complex shapes. Just drive down the street and admire the far sexier curves of cars thirty years newer than the boxy, Yugoslavian automotive marvel tucked away in your garage.

Thinking progressively

Stamping presses go up and down. Build a die set that can perform multiple operations "per stroke" and you have the ability to make some pretty complex stuff and do so very quickly. Consider a tiny electrical connector or a clamp for a radiator hose. A progressive die might perform a dozen discrete operations on parts like these. Punch a hole, bend a tab, cut a window, form a flange. With each stroke of the press, the part advances to the next station until the final step: separation from the strip of leftover material, known as a *remnant.*

Progressive dies are expensive, and they might take months to test and develop. Most are designed to crank out tens of thousands of parts per minute — a high-speed stamping press can exceed 2,000 strokes per minute, dropping one complete part per stroke (that's 120,000 pieces each hour). Check out Chapter 6 if you want to find out lots more about stamping technology; until then, you'll have to settle for Figure 1-5, which shows a sideways view of a progressive die mounted in a stamping press.

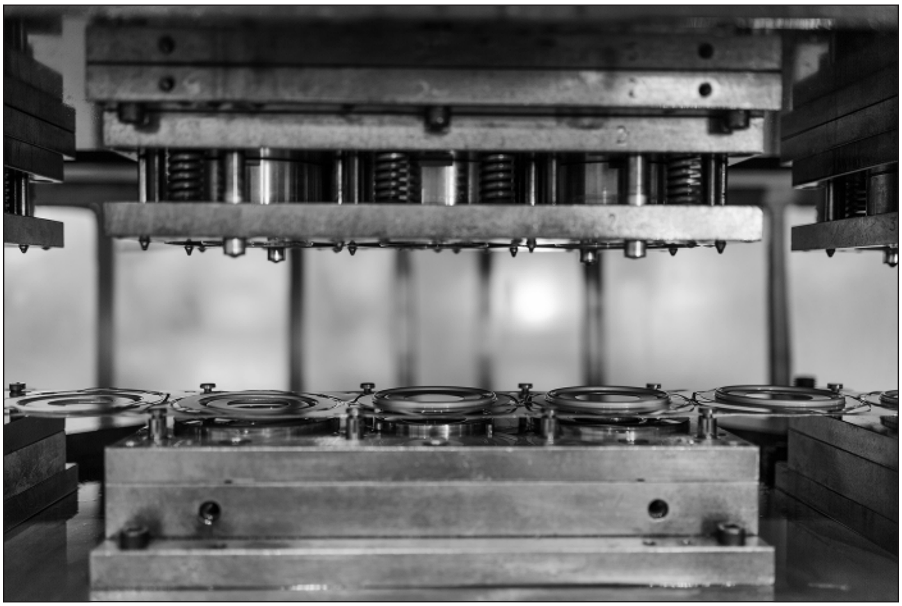

FIGURE 1-5: Progressive dies perform multiple successive stamping operations with each stroke of the ram.

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Spinning in circles

Here's another type of forming, one far different and much more limited than a stamping press, but capable of some whiz-bang shapes nonetheless. Ever seen the nose cone on a rocket? How about a stainless-steel bowl big enough for the massive amount of potato salad you're being forced to make for the upcoming family reunion? These and other thin, dome-shaped parts are produced by spinning, which, like other forming processes, relies on the ductility of many metals for shaping complex parts to close tolerances. (I discuss ductility and other metallurgical properties in Chapter 3.)

TECHNICAL STUFF

A spinning machine is like a big lathe without the metal cutting tool. The operator starts by clamping a mandrel that's shaped like the inside of the nose cone or salad bowl to the lathe spindle. A flat disk of material is then pinched between the end of the mandrel and a pressure pad. The spindle starts up and a "spoon" made of hardened steel or brass is used to apply pressure to the metal, which gradually bends and takes the shape of the mandrel beneath.

Peeking at the Neighbors

These were but a few examples of all that fabricating makes possible. But what is this thing called *fabricating*? How does it work, and what makes it different from machining, injection molding, three-dimensional (3D) printing, and all the other manufacturing technologies in existence today? Read the rest of the book if you want a more complete answer, but here's a sneak peek at what goes on beyond the walls of the fabrication department every day in shops near and far.

Touring the machine shop

Machining is an important part of fabricating, which is why I cover it more deeply in Chapter 12. For now, though, you should know that without machining, none of the punches, dies, and other tooling needed to fabricate parts could be made, never mind the fabricating machinery itself.

MACHINING VERSUS FABRICATING

You machinists who are secretly reading this book hoping that none of your coworkers catch you studying the fabricating dark side might be thinking, "Can't some of this stuff be done with drills and milling cutters?" The answer is yes, it certainly can, but there's one thing to consider: Sheet metal is hard to hold onto. This isn't a problem when you're stamping a hole on a punch press or laser-cutting a window because those cutting forces push down on the sheet (or in the case of lasers, create virtually no cutting forces at all). If you were to try that on a milling machine, the bit would grab and lift the material, quite possibly turning it into a razor-sharp windmill. A vacuum chuck (or even a piece of double-backed tape) is able to grip thin, flat materials, but this is far less practical (and much slower) than knocking those shapes out on a press.

It's also a subtractive metalworking process (as opposed to an additive one, something I talk about a little further along in this chapter). It uses chunks of very hard metal such as tungsten carbide or high-speed steel (which are also used in fabricating) that have been precision-ground into drills, end mills, reamers, and dozens of other types of cutting tools.

WARNING

Cutting tools are dragged across or through a bar or billet of material to accurately remove small bits of metal from it. These are called *chips*, and if you get one in your eye or wrapped around a finger, you'll have an opportunity to chat all about machining with a doctor at the emergency room as he administers first aid.

Depending on the type of machine tool you stand in front of each day, you might perform any or all of these machining operations in order to complete a given workpiece:

- Drilling
- EDM
- Grinding
- Milling
- Sawing
- Threading
- Turning

I admit, those are some pretty broad categories. Turning, for example, comprises dozens of unique operations, including profiling, grooving, boring, drilling, cut-off, and more. If you want to learn more about these and other machining processes and technologies, you can check out my book, *Machining For Dummies*, where, as you might have guessed, I go into the meat and potatoes of all things machining.

Wake up, it's time to get vertical

For now, though, let's look at some of the other cool things you can do as a manufacturing person. Some of them have literally nothing to do with fabricating, but as my Uncle Ted once told me, "Knowledge is power, young man." He then punched me in the shoulder and told me to go get him a beer.

The old coot's wise words notwithstanding, you'll find that fabricating shops tend to be more "vertical" than most manufacturers, which is an industry term that means these shops try to do whatever is needed to complete a part or assembly.

This might mean they're cheap and don't wish to share any work with the paint shop or welding business down the street, but it could also mean they're smart.

TIP

Want to get ahead as a fab shop? Vertically-oriented manufacturers have more control over their products (which usually translates into better quality), greater flexibility, shorter lead times, and — probably — higher profit margins as a result. In the fabricating world, this means you'll do the usual bending, shearing, and forming, but are also happy to paint, powder coat, weld, assemble, *and* machine parts (all of which are discussed later in this book).

Reviewing the Rest

Here are a few additional metalworking (and plastic working) processes. Some are as old as Roman times; others were invented around the time Ronald Reagan was huddled with his advisors, dreaming up trickle-down economics. Again, these are typically not performed at most "fabricating" companies, but if you're power-hungry and want to be the Amazon.com of manufacturing, you'll embrace these processes with equal aplomb.

Thinking additively

You might know it as 3D printing. This process works by electronically slicing a 3D CAD (computer-aided design) model into paper-thin layers and then *growing* the part from the bottom up (although some newer printers start at the top). There's no material waste, part accuracy competes with other manufacturing processes, and 3D printing is widely used to make a wide array of prototype and low-volume production parts. Nine distinct 3D printing technologies exist, with these three leading the pack:

- **SLA (stereolithography):** Developed in the early 1980s, SLA is the grandfather of commercial 3D printing. It uses a UV laser beam to cure layers of photosensitive liquid resin. As each layer is completed, fresh material is scraped over the top of the developing workpiece and the process begins again.
- **SLS (selective laser sintering):** SLS is a powder bed fusion technology that uses a laser to fuse layers of plastic or metal (this is often referred to as *selective laser melting* or SLM) contained in a heated powder bed. As with SLA, a blade or roller spreads material over the top of the workpiece after the completion of each layer.

- **FDM (fused deposition modeling):** Similar in operation to a hot glue gun, FDM deposits molten material one layer at a time, tracing the outline and then the interior of each layer until complete. It is one of the few additive manufacturing technologies that allows multiple materials to be used in a single "build."

Additive manufacturing offers many benefits. Some use materials with physical properties equivalent to their forged or cast counterparts. Virtually any shape can be printed, even those (or rather, especially those) previously considered un-manufacturable — or which at least required the assembly of many parts.

3D printing is, however, relatively slow, and a part the size of a breadbox might take days to manufacture. There are several new technologies coming online right now that claim to drastically increase production speeds. If successful, these new technologies promise to change the landscape of manufacturing substantially, especially in the machining world. Feel free to skip forward to Chapter 16 for some additional details on this revolutionary technology.

Casting away

If you were lucky enough to take industrial arts (also called "shop" class) in high school, you might have made a pair of cast aluminum candleholders to give to Mom for her birthday. Casting is a lot like plastic-injection molding, used to make everything from Tupperware to toothbrushes, except that *casting* denotes metal, while *molding* refers to plastic (unless you're talking about metal-injection molding, which is another story entirely).

TECHNICAL STUFF

The casting method we former industrial artists are most familiar with is called *sand casting.* It works by pouring molten metal into a mold formed by compacting fine, powdery sand around a master part (the pattern) that is held between the two halves of the mold (the cope and drag). The mold is gently separated and the pattern(s) removed, then hot metal is poured into the sprue (a hole in the top of the mold). Once cool, the mold separates, hot, smelly sand goes flying all over the place, and presto! Mom gets a shiny new pair of candlestick holders that she'll treasure forever.

There's also *investment casting.* This uses a wax or foam pattern that is melted or "lost" during the casting process (which is why it's also called *lost wax casting*). Many aerospace and similar high-tech components are made using investment castings, thanks to its ability to create accurate parts with fine features.

Die casting uses a set of hardened metal dies, into which molten metal is forced at high pressure. If you played with Matchbox cars as a kid (or still do today), you are familiar with die-cast parts. It's also used to make a variety of high-volume automotive and consumer products, including the transmission body in your car, the faucets in your bathroom, and the compressor housing in your refrigerator.

Forging partnerships

Forging is as old as metalworking itself. Start with a chunk of steel (or bronze or iron), stick it in a fire until red hot, and start whacking. If you're strong enough and patient enough, you might make a nifty set of horseshoes for old Bess or some armor to defend yourself against marauding Huns. And as I mention in Chapter 2, repeatedly pounding some metals makes them tougher and more wear resistant (see Figure 1-6).

FIGURE 1-6: Blacksmithing was among the first metalworking processes and was used to not only shape metals but also make them stronger.

Ermolaev Alexander/Shutterstock

But because people's arms inevitably get tired, some clever blacksmith eliminated the grunt work of forging by inventing a machine called a *drop hammer.* And because pounding metal with the consistency of super-taffy into an accurate shape is quite challenging, some equally clever blacksmith invented the *forging die.*

Like the molds used to make castings, these contain the inverse shape of whatever wrench handle, cabinet hardware, gear blank, or other mechanical component is desired. Simply set the hot metal blank into the die, spank it once or maybe a dozen times (depending on the type of forging process, the part geometry, and the metal used), and out comes a part ready for final machining.

Honorable mentions

These brief descriptions pay short shrift to the complexity and capabilities of casting, forging, and their far more modern counterpart, 3D printing. Nor do the preceding sections mention any of the other important metalworking processes such as powder metallurgy, swaging, explosive forming (yes, they really do that), ultrasonic machining, photochemical milling, and others.

Some of these fall under the umbrella term *fabricating,* which is why I revisit many of them in later chapters — punch presses, for example, are discussed in Chapter 7. But since this book is mostly about sheet-metal fabrication techniques with some segues into welding, plate processing, and automation, I'd best avoid my editor's wrath and stick to those topics, saving the rest for another time.

Embracing Mechanics

Whether a punch press, laser cutter, swaging machine, or ironworker (a multipurpose machine tool that I explain in Chapter 8), all fabricating machinery shares some basic mechanical similarities. Each machine has a frame made of metal (usually cast iron). Each has bearings and sliding surfaces. Most are driven by computers and servo systems, known as computer numerical control (CNC). Here are a few of the most important components along with some brief descriptions of each to mentally arm you for the chapters to come:

Bearing witness

Without bearings, your car wouldn't roll. Fidget spinners wouldn't spin, and the garage door would be permanently shut. That's because bearings allow surfaces to slide freely against one another (see Figure 1-7). Most of the bearings you find in such everyday devices are donut-shaped, with inner and outer races and metal balls or needles contained between the two. Some bearings are flat and use a similar arrangement of balls or needles (the drawers in a toolbox are one example). And some bearings are actually known as "ways," with two precision-ground metal surfaces separated by a thin film of oil.

It's this last approach that is used in many machine tools. So-called "box ways" are able to support massive loads while still maintaining extreme precision and have long been used in stamping presses, shears, and press brakes. And linear guideways, which contain specially-shaped rails and ball-filled "trucks" that ride atop them, provide smooth, accurate motion and excellent load-bearing properties even at very high rates of speed. This makes them a favorite in machine tools that move very quickly, such as laser cutters and turret presses.

AnnaElizabeth Photography/Shutterstock

FIGURE 1-7: Whether round, flat, or angular, bearings allow machinery to operate smoothly and accurately.

Motoring about

At the risk of leaning on the automobile metaphor one too many times, your car would do nothing but take up space in the driveway without a motor. But unless you own a Tesla, the motor in your car is completely unlike the ones used to power virtually all machine tools. Electric motors turn turrets, drive rams, power hydraulic pumps, and are what make the flying optics in laser cutters fly with purpose-filled abandon.

Most of today's CNC machines use highly efficient alternating current (AC) motors that take orders from onboard servo systems, which are in turn controlled by the machine's computer program. They make press brakes go up and down and turret punches move side to side and in and out, and they can do so accurately, even when bending or punching a chunk of steel thicker than your hand.

Controlling motion

The servomotors described in the previous section require a way to convert their rotary motion into the linear motion needed to actually perform work. In most cases, this means attaching a "ball screw" to one end of the motor. A ball screw looks like a super-long bolt with roundish threads that fit inside a ball-filled nut that rides up and down the length of the ball screw as it rotates. Because this may be tough to visualize, take a peek at Figure 1-8 to see what a ball screw looks like.

FIGURE 1-8: Ball screws are responsible for quickly and accurately transmitting motion in CNC machine tools.

v1875/Shutterstock

TECHNICAL STUFF

Some newer, very high-speed machine tools have linear motors. These are essentially "flattened" electric motors that eliminate the need for ball screws entirely. They can accelerate and decelerate very quickly and achieve speeds far greater than what's possible with traditional ball screw–equipped machines. If you've ridden the rollercoaster, Superman: The Escape at Six Flags Magic Mountain in Valencia, California (or are a fighter pilot on an aircraft carrier), you're familiar with the power of linear motors.

Mulling over the miscellany

The list of components needed to build a precision CNC machine tool costing more than a three-bedroom house in the suburbs is far longer than the meager list discussed in the previous paragraphs. Aside from the ball screws or linear motors just described, pulleys and gears and crankshafts are also used to transmit motion. Sheet-metal enclosures and safety glass are needed to protect human operators from injury. Lasers are used to cut metal, but they're also an important part of operator safety, shutting off the machine when unwary or overconfident hands are placed too close to moving parts by intercepting a ray of light paired with a receiver. Then there are shafts, seals and O-rings, pins and washers, and of course, the nuts and bolts that hold the thing together. To say it's complex is like saying Bill Gates is moderately wealthy.