THE FIRST BOOK OF MACHINES

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The FIRST BOOK of
MACHINES

THIS BOOK is about the story of modern machines, and how they do the world's work. We shall see how raw materials, such as metals, wool and cotton fibers, and wood, are turned into automobiles, ships, typewriters, fabrics, and other useful products. Our machine age has made this possible, for only by machines can these many products be made cheaply and quickly.

We shall also see how machines are able to do such varied jobs as threshing grain, machining engine blocks, or multiplying long rows of numbers. And later on, we shall learn how automation, the newest marvel of the machine age, teaches machines almost to "think" for themselves.

A World Without Machines

IN ORDER for us to compare the wonders of our modern machine age with the days of hand tools, let us take an imaginary trip back through medieval England. How was work done in that age?

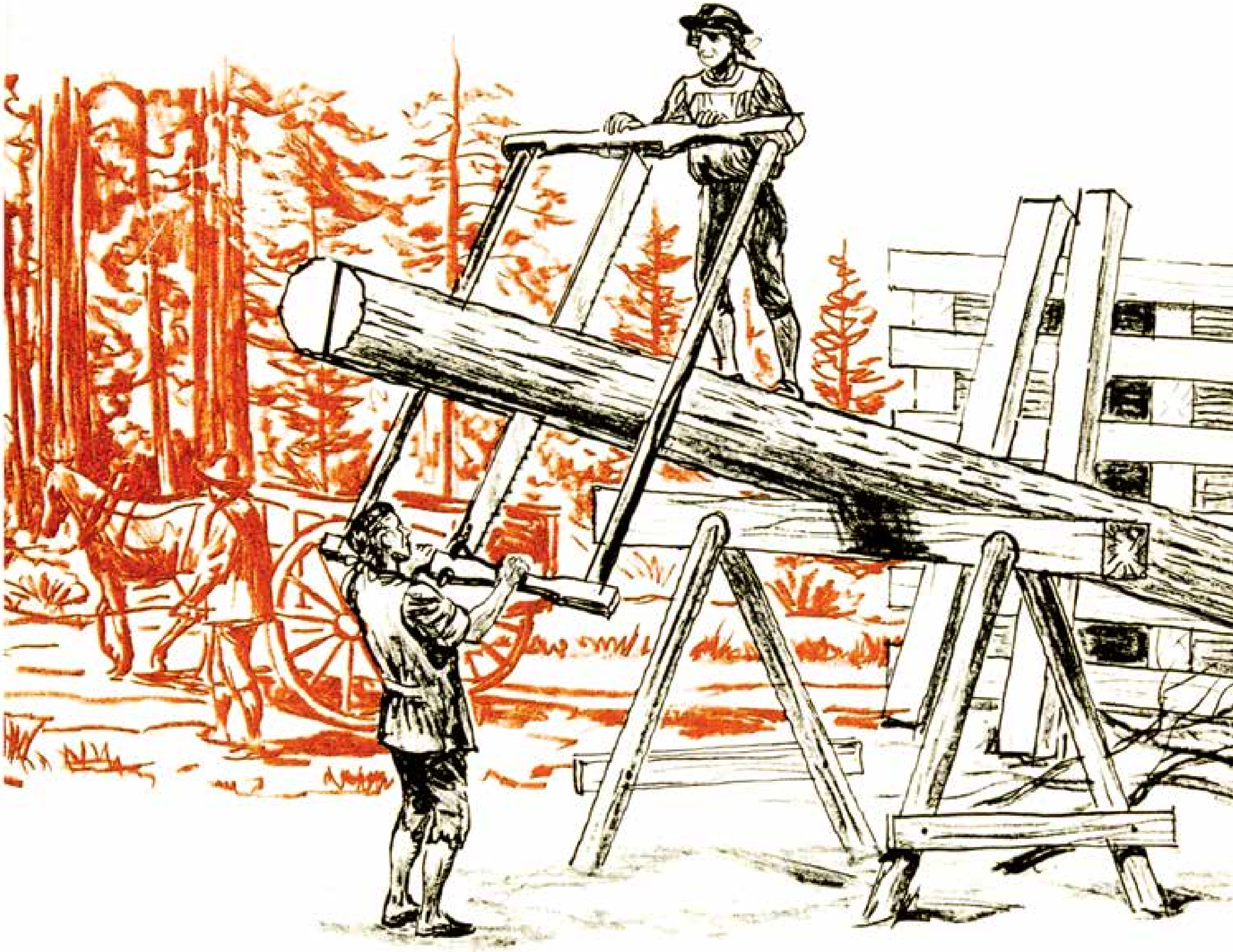
We find ourselves following a rough pathway between green hedges that leads us to a field where peasants are preparing the soil for spring planting. One man loosens the earth with a kind of broad-bladed pick, called a *mattock*. Other men follow behind, breaking up the lumps and smoothing the ground with rakes and hoes. Then the sowers, carrying bags of seed hung around their necks, cast handfuls of seed about them as they stride across the field.

When harvest time comes, other peasants will cut the grain with hand sickles, and tie it into bundles which they will carry to the barns on their backs. In the barnyard they will beat the kernels from the stems with long, hinged sticks called flails, toss the straw into the air with forks for the wind to carry away, and then shovel the kernels into sacks.

When flour is needed to bake bread, the medieval housewife pours a handful of grain kernels into a hollowed-out stone slab called a *mortar*. Then she grinds them into a coarse flour with a rounded stone called a *pestle*.

As we approach a medieval sawmill, two men are sawing boards from a big log that is lying across a high framework. One man stands on top of the log holding one end of a long saw, while the other stands beneath it and pulls the other end. It is slow, hard work - it will take them many hours to saw out just one plank.

Farther on, we pass some medieval "traffic"--groups of men, women, and children carrying great loads on their backs, as well as donkeys,



horses, and even dogs, straining under heavily loaded pack saddles. Sometimes a rough, two-wheeled cart passes, its solid wheels screeching on ungreased axles. It is pulled by oxen or horses at a rate of two miles an hour.

At the edge of a small market town, we pass a new house being built. The walls have timbered frames, filled in with stones or bricks; the roof is thatched, built of tight bundles of straw wedged together. The carpenters are making door and window frames, using crude saws, planes, and chisels. The windows have only wooden shutters, for there are no glass blowers as yet in England to make windowpanes.

In an open doorway a shoemaker sits at his bench, cutting cow-hides into boot soles and uppers; these he will put together with needle and thread and wooden pegs. A woman sits before a clacking hand loom, patiently passing a shuttle back and forth between the *warp*, or vertical threads, and crossing them with the *woof*, or horizontal threads. It is the only way she knows to make cloth.

Loud hammering is coming from another doorway. Here a copper-smith is beating copper sheets into pots, pans, and jugs. Next door a tailor sits cross-legged on his table and stitches a sleeve into an armhole.

In medieval times all work, whether in field, forest, village, or town, had to be done with crude hand tools. Handwork was slow, for human muscles soon tired. There was no way of speeding production beyond what human fingers could do.

The First Machines

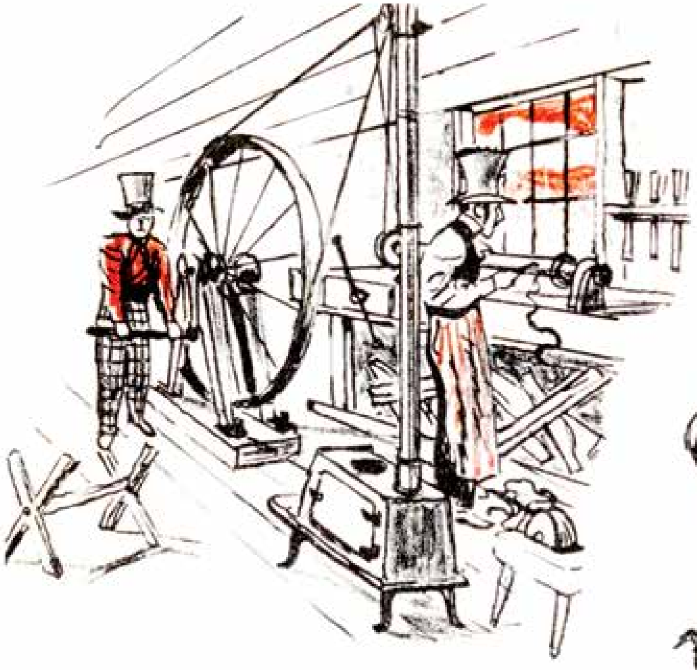
NO ONE knows exactly how long ago it was that the first simple machine was invented. Perhaps it was a rough grindstone mounted on an axle and turned with a crank, or a potter's wheel, worked by a foot treadle, to turn a chunk of clay into a jar or pot. Whoever invented that first machine started a new era - an era in which men would slowly but surely be relieved of the back-breaking toil of making things solely by hand.

Exactly what is a machine? A machine is any device that helps you do work faster and with more power than by using your hands alone. It does this by using any one of, or any combination of, the following six basic aids: the inclined plane, the wedge, the lever, the wheel and axle, the screw, and the pulley. These six could really be considered four, because the wedge is just another form of the inclined plane, and the screw is an inclined plane wrapped around a cylinder, or drum.

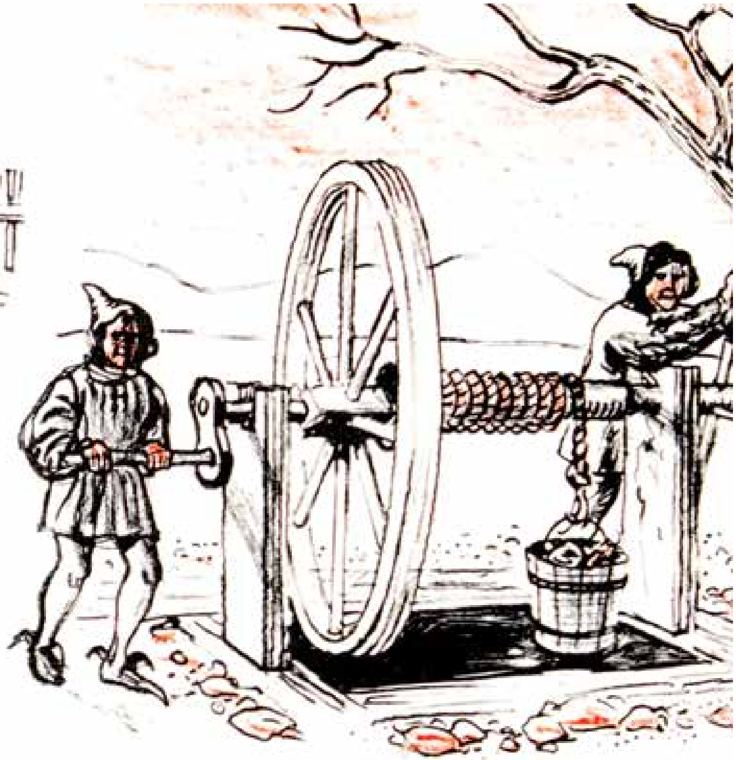
These aids are often called *simple machines*. Combinations of several simple machines are called *complex machines*. With a simple machine like a lever, a man can multiply his lifting power so many times that he can easily lift a weight that ten men couldn't lift without the lever. With a wedge he can split great logs or even rocks. With pulleys and a rope tackle he can lift great loads into the air without help - loads that a whole gang of men couldn't lift an inch with their muscles alone. In other words, a simple machine can multiply the amount of force applied to a task.

The speed of a machine can also be increased by connecting a large wheel to a smaller one by means of a belt, chain, or gears and applying power to the large wheel. The smaller wheel will turn much faster, speeding up the action. The old-fashioned spinning wheel, the sprocket and chain of a bicycle, or the transmission of an automobile are examples.

But the speed with which such a machine does its work depends upon the *kind of power* applied to that big wheel. In the earliest machines, man power was used to turn a crank, to work a foot treadle, to haul on a rope tackle, or to push the bars of a *windless*, a kind of drum which winds up a rope as it turns.



HAND CRANK TO POWER
EARLY WOOD LATHE

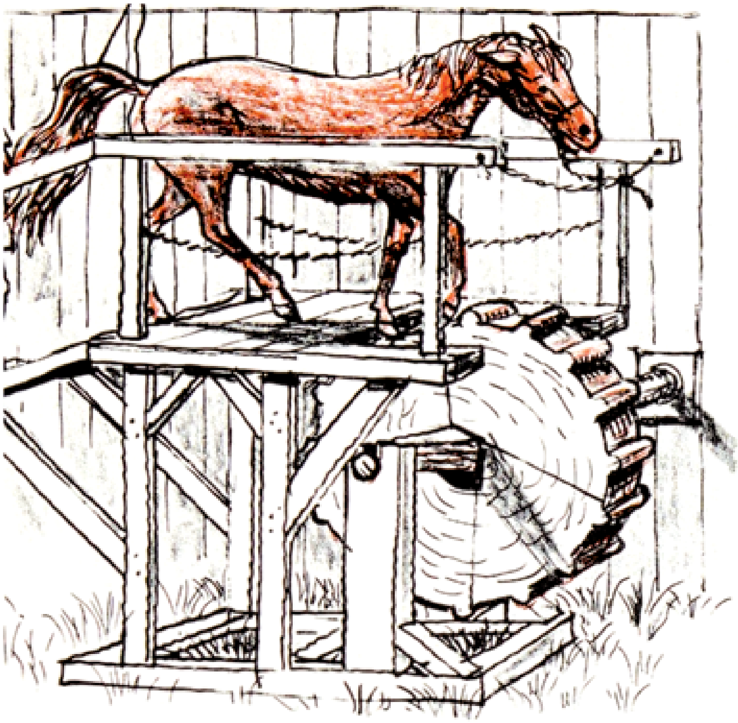


WINDLASS OVER EARLY MINE SHAFT

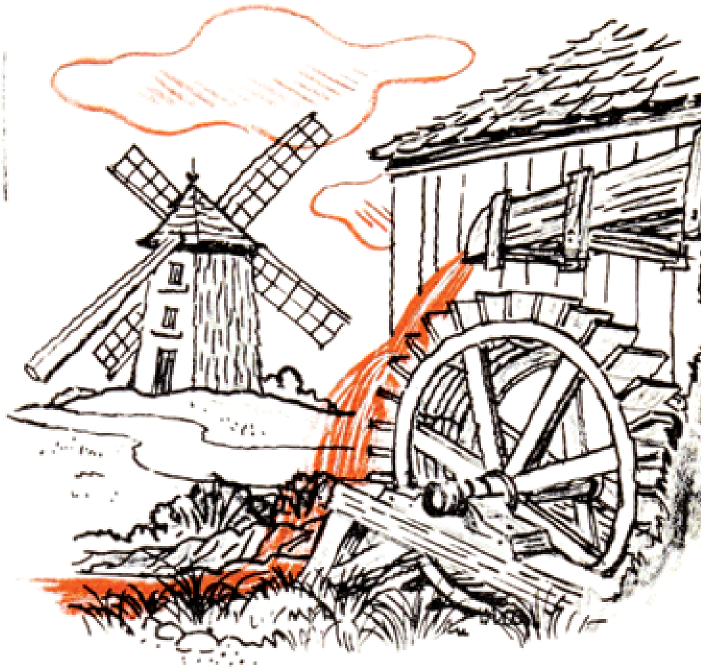
Because those early machines depended upon manpower, they naturally slowed down as soon as the human muscles got tired. Later horses, cattle, and even dogs were used to turn treadmills and windlasses, but even though they had more endurance than men they, too, were living creatures and also grew tired. This is why some other kind of power than flesh and blood had to be found if machines were ever to reach their full usefulness.

Then someone thought of harnessing the power of wind and water. Windmills and water wheels became the chief sources of power until well into the nineteenth century. They were used to pump water, saw lumber, grind grain, press oil, and turn the machines of factories.

Water and wind power were a big improvement over men and animals, but they also had their limitations. When the wind died, the



ONE HORSE POWER TREADMILL



WINDMILL WATER WHEEL

arms of the windmills stopped turning; so did the machinery in the mill below. If a rainless period dried up the streams, soon there was not enough water in the millpond to turn the wheel. Thus, the mill was out of business until it rained.

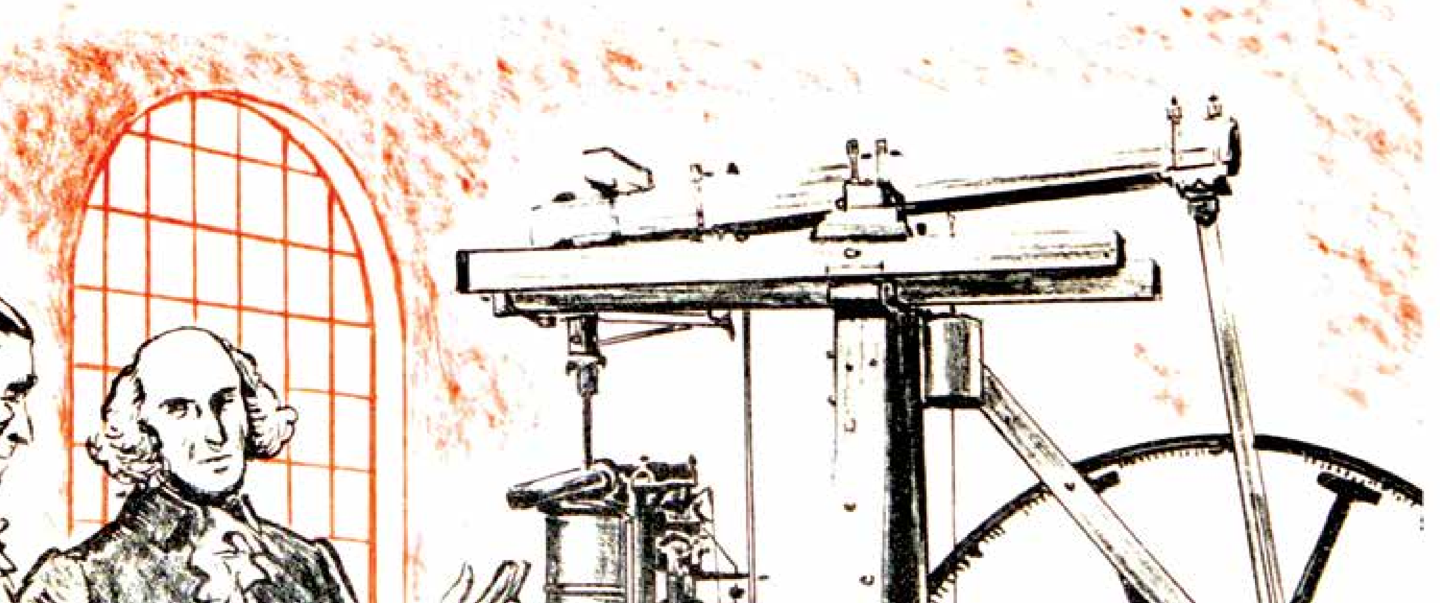
Then, early in the 1700's, a Scottish boy named James Watt, while watching the steam rising from his mother's teakettle, thought of a new source of power. Why couldn't steam power be used to run machines? As he grew older this idea kept him experimenting. Finally he succeeded in inventing a steam engine that could do many things. It was used to pump water from the tunnels of coal mines, turn machines in factories, and work the grindstones in flour mills. When the steam engine was mounted on wheels it would pull cars along a track - the first railroad.

With the steam engine it was possible to build factories even where there were no rivers to turn water wheels. The steam engine was always ready to go. If more power was needed, bigger engines could be built to supply it.

Then, in the last half of the nineteenth century, an entirely new source of power - electricity - came into use. Following the lead of the early pioneers of electricity - men like Alessandro Volta, Michael Faraday, Benjamin Franklin, and Thomas Edison - engineers began building electric dynamos which made electric power - power that could be sent out over wires to wherever it was needed.

Now the time was really ripe for the machine age. Men had begun to learn how to design machines able to do all sorts of things; moreover, there was always a dependable supply of steam or electric power to run them. People everywhere needed and wanted the products that machines alone could produce.

WATT'S ROTATIVE ENGINE



The Modern Machine

WHAT do we demand of our modern machines - how do they do their jobs? To begin with, machines can be broadly divided into the following three classes:

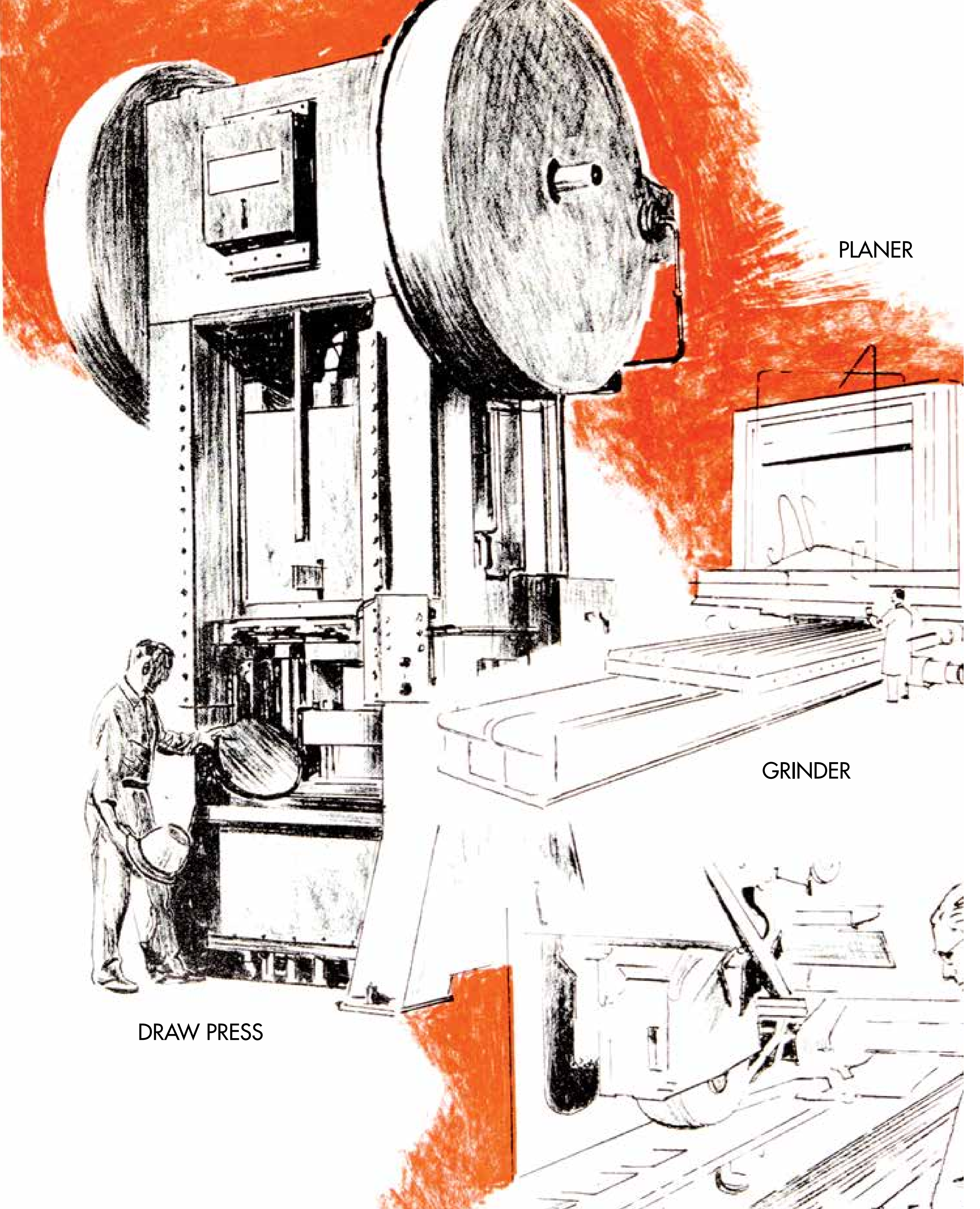
1. Machines that make the machines that turn out the products everyone needs and wants.
2. The machines that make these products.
3. The machines that are themselves products, like automobiles, typewriters, and bulldozers.

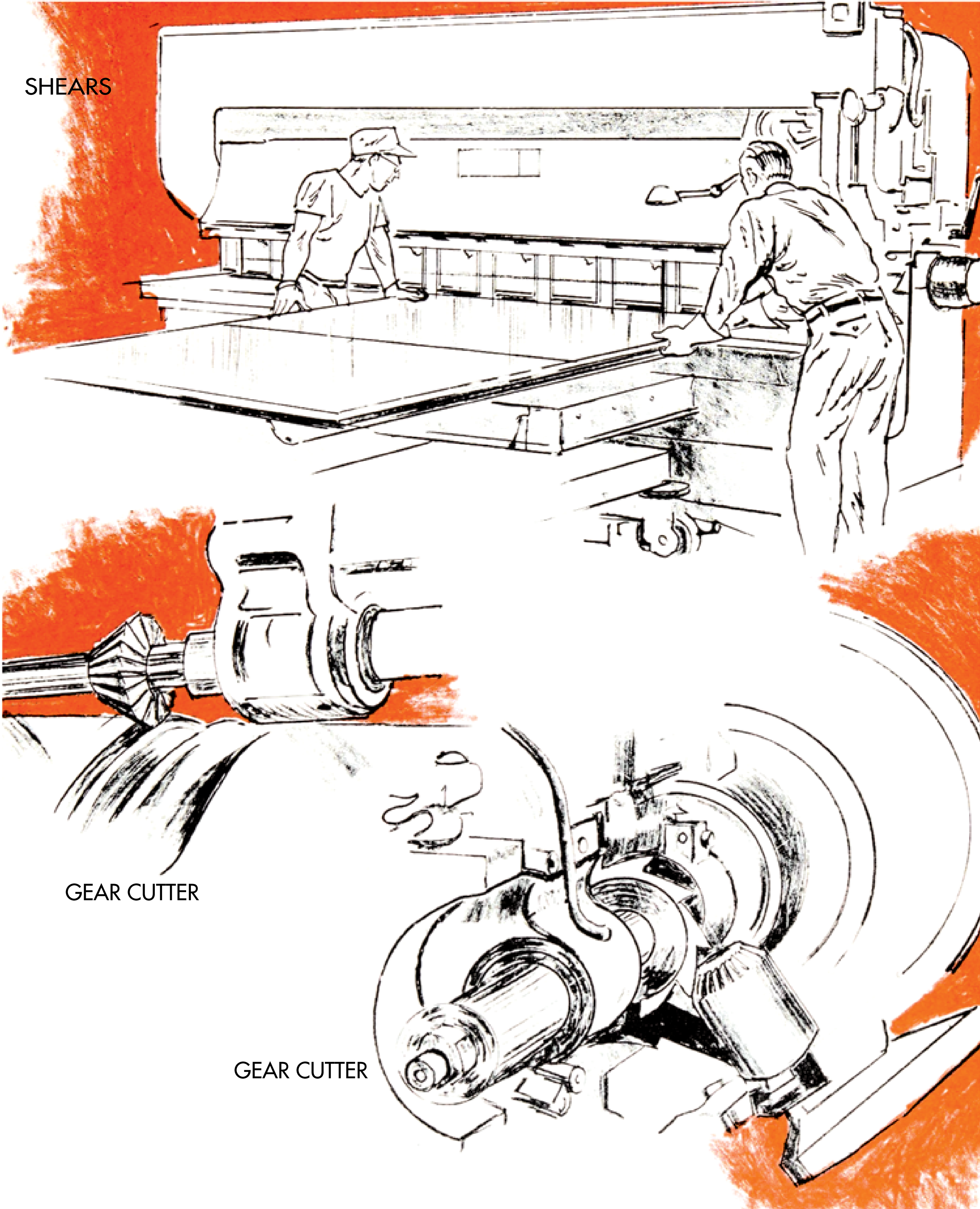
Machines That Make Other Machines

At the beginning of the long process of turning raw materials into useful products are the steel and other metal mills. *Smelting plants* melt down the iron, copper, and other ores in great furnaces to recover the metals.

To make steels of different kinds, crude iron is combined with various chemicals at high temperatures. *Rolling mills* squeeze these rough steel chunks into flat, workable shapes; then great drop hammers and presses change them into useful shapes such as sheets, wire, beams, rails, and rods. From these shapes, called *stock*, the machines in a shop turn out their products.

Large factories usually have their own *foundries*, buildings in which metal castings are made. Here chunks, or *ingots*, of iron or steel are remelted and poured into molds made of special sand compounds where they harden into the shape of the molds. Then the molds are knocked off and a rough metal object, called a casting, is left. This now goes to the machine shop to be machined. Many smaller factories buy their *castings*, sheets, and rods from the foundries and rolling mills.


PLANER
GRINDER
DRAW PRESS


SHEARS
GEAR CUTTER
GEAR CUTTER

To make the thousands of parts which will eventually be assembled into lawn mowers, adding machines, or motor trucks many special machines are needed. Here is a list of machines usually found in a well-equipped machine shop:

LATHES - Generally used to turn and shape rounded, or *cylindrical*, stock.

BORING MILLS - Used to finish holes where great accuracy is required.

DRILL PRESSES - To drill holes where less accuracy is required.

PUNCH PRESSES - To punch out shapes from flat steel as a cooky cutter does.

SHEARS - To cut apart sheets of steel.

GRINDERS - Used to smooth surfaces and grind down edges.

PLANERS - To plane down metal surfaces to proper thickness.

MILLING MACHINES - To cut grooves and gear teeth and to bevel edges.

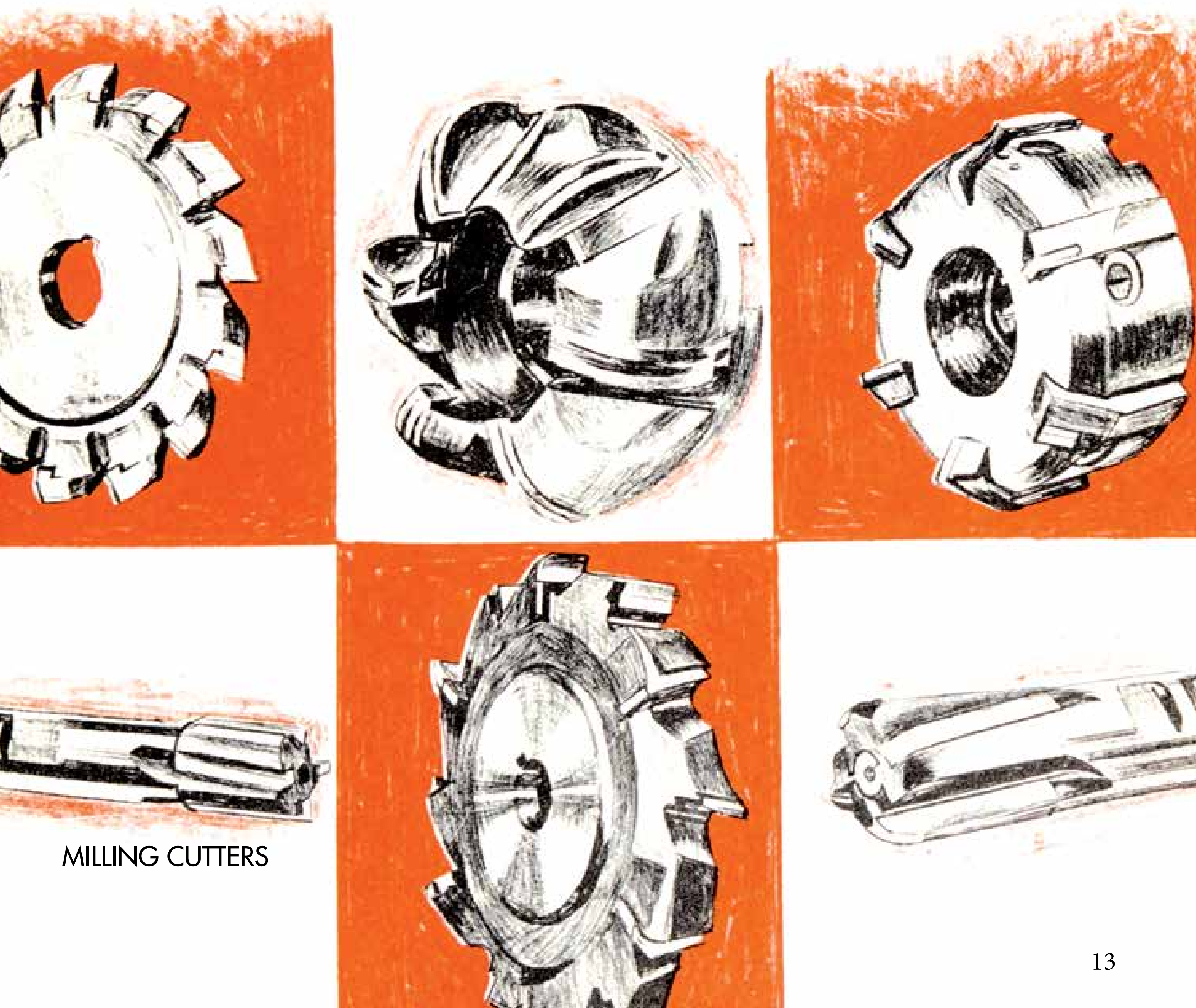
SCREW MACHINES - To cut spirals in blank cylinders, making screws of them.

SAWS - Band or circular, to saw through metal.

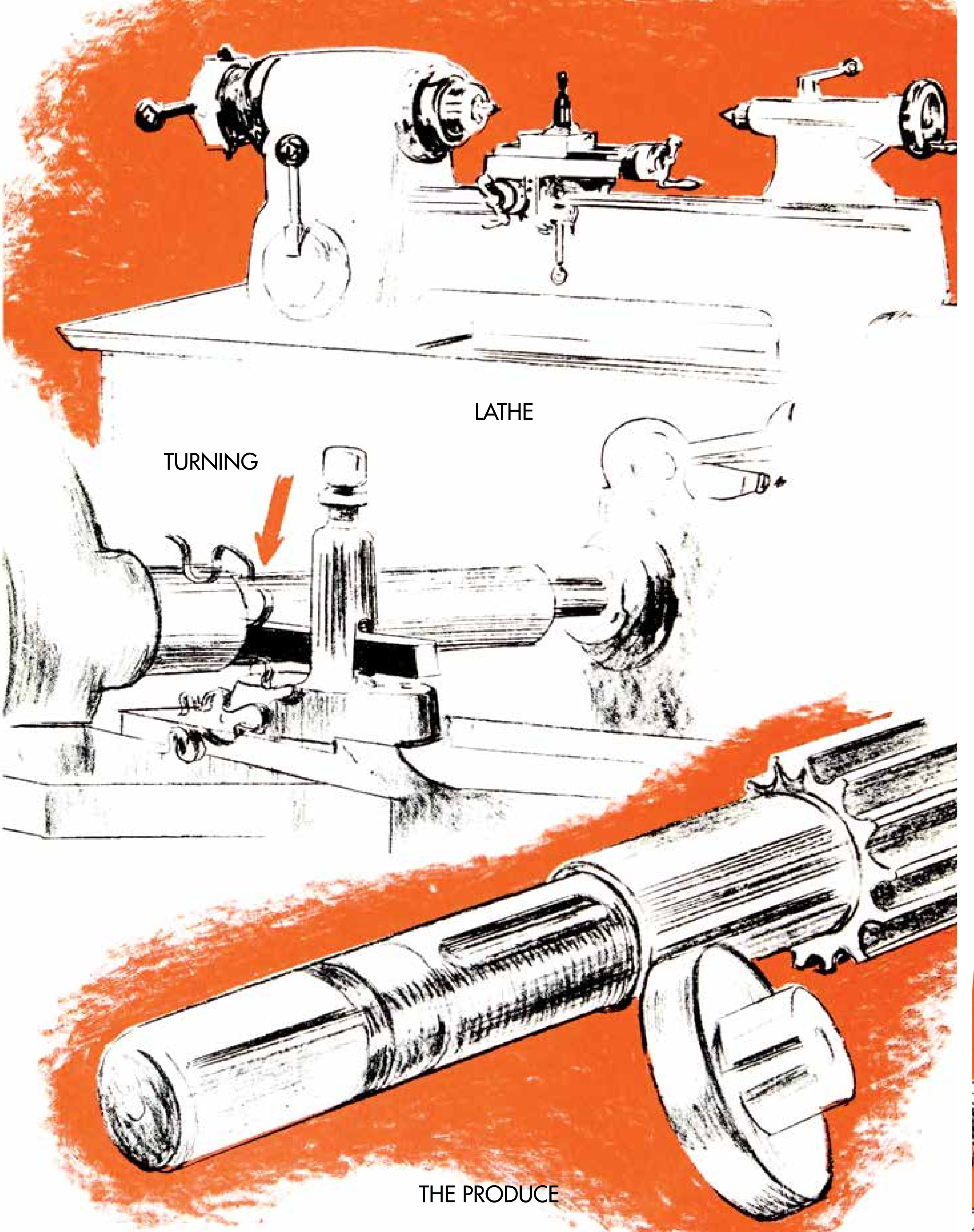
However, *only when they are properly guided and directed* can any of these machines do its job of boring holes, cutting threads and gear teeth, milling grooves, or grinding down cylinders. Unless every hole and groove on the part is cut in exactly the right place - sometimes to an exactness of one ten-thousandth of an inch - the part will be useless.

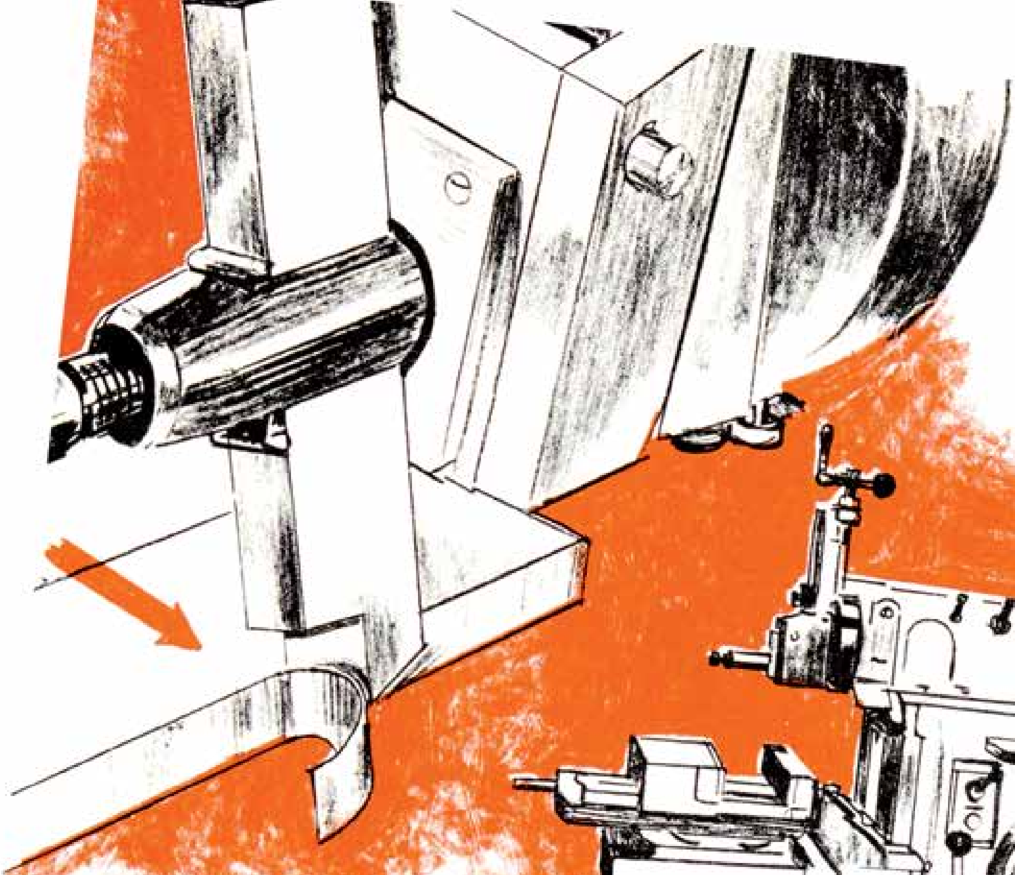
But how can the stock be held in place - sometimes at an angle - and the drill or milling cutter guided to do its task at just the right place so that each part turned out will exactly match every other one? This is done with devices called jigs, fixtures, and dies. *Jigs* and *fixtures* are specially designed devices in which the part to be worked on can be held rigidly in position in the machine. Then the boring or cutting tool, held in place by a contrivance called a *chuck*, will strike the part at just the right place.

A *die* is a specially made part of very hard steel that acts as a pattern or guide. Perhaps a part has to have a shallow groove pressed into the center of a flat surface. The die maker makes his die in two halves. He



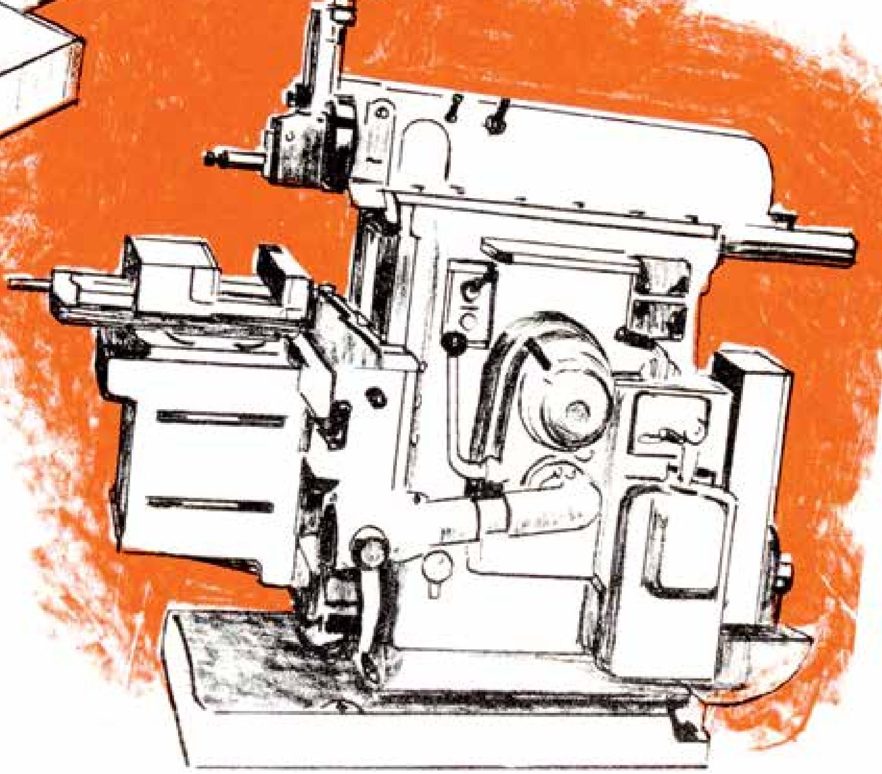
MILLING CUTTERS

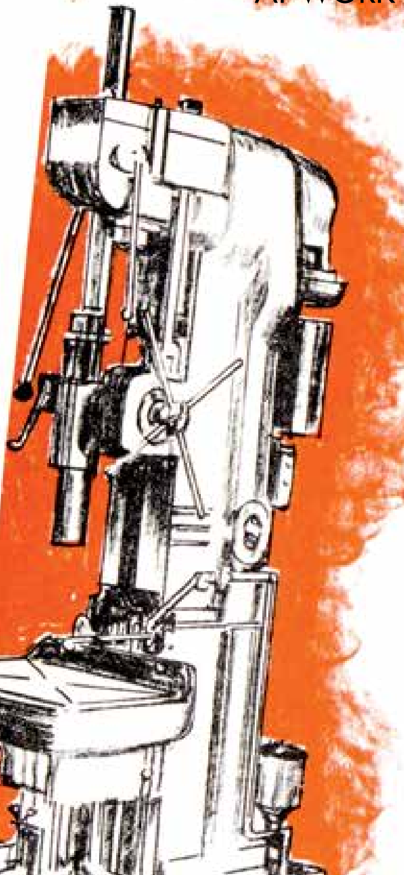

LATHE
TURNING
THE PRODUCE



AT WORK

SHAPER





DRILL PRESS

cuts out a groove in the lower half, then carves the upper half so that a ridge remains sticking up. When the two halves are joined, this ridge will fit exactly into the groove below. Then the lower half of the die is bolted to the table of the machine, the stock is placed on top of it, and the upper part of the die is bolted to the press above it. When the press comes down, the ridge is pressed down on the stock, forcing it to bend into the groove in the die underneath.

When a new part is to be made, the tool designer is given a rough sketch of it by the department head. From the sketch the designer works out on paper the exact design of the jigs and dies which will be needed to make the part.

Then his plans, called *mechanical drawings*, are turned over to the tool room.

In the tool room a tool and die maker will reproduce the drawing in hard steel. The toolmaker is "king" of the shop mechanics. He has served a long apprenticeship to learn exactly how to use every tool, and he must be able to make dies with almost unbelievable accuracy. His measuring instruments, called *calipers* and *micrometers*, are able to measure the thickness of a piece of steel so precisely that by comparison a sheet of tissue paper would seem thick.

Machine designers are constantly trying to improve their machines so that they can turn out work better, cheaper, and faster. For example, a certain piece of work may need one hole bored through the center of it, two smaller holes drilled in at an angle, and a double groove cut along one edge. Normally this would take three machines, one to bore the center hole, a drill press to bore the smaller holes, and a milling machine to cut the groove. Doing it this way, however, makes the job slow and costly. So the designer gets busy and plans a machine that can do all three operations at once.

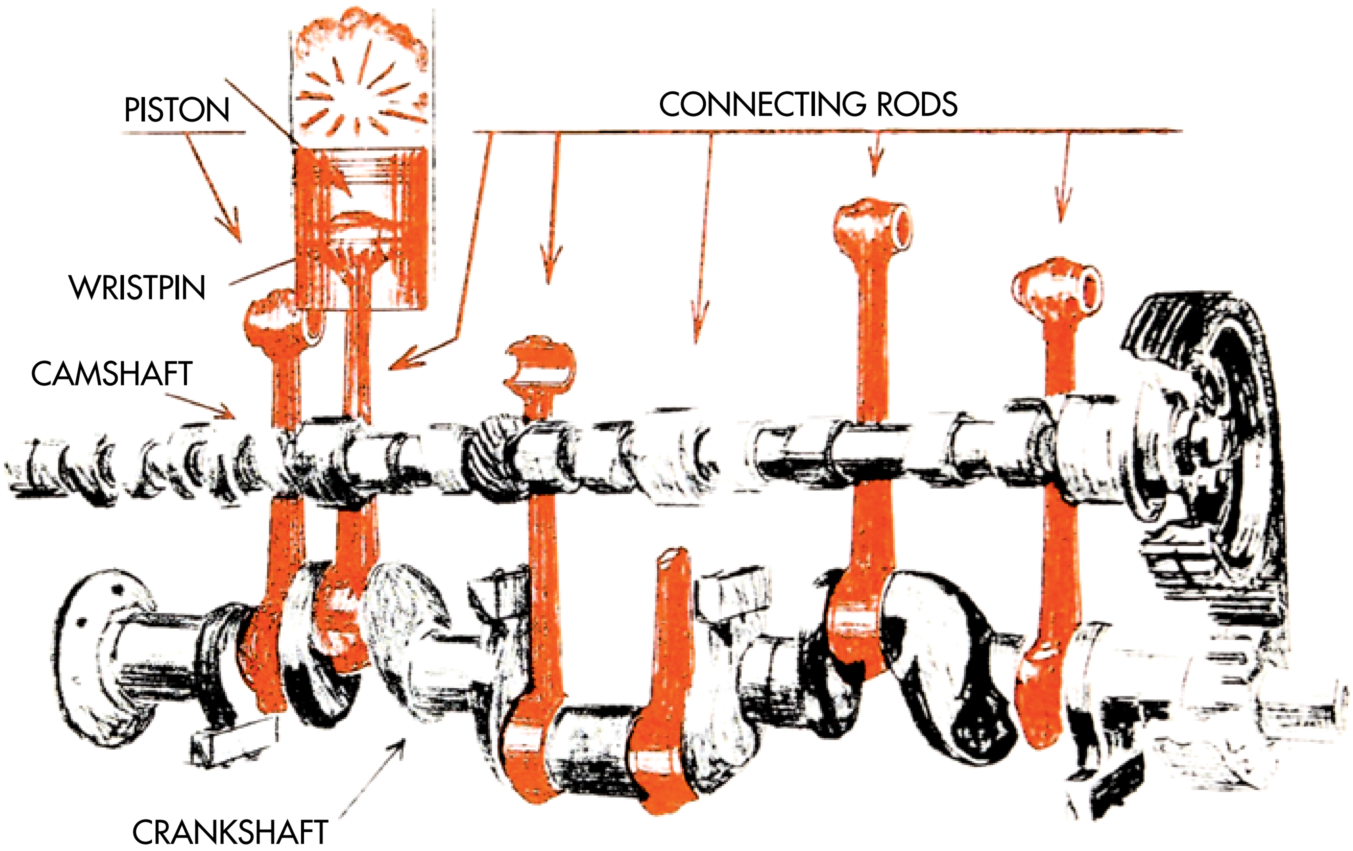
Today there are turret lathes and other machines capable of working on a part from all sides and from any angle all at once. In early machine shops it took a good deal of moving from one machine to another to make an automobile engine block. Today one single machine bores out cylinders and valve ports, drills holes for bolts, and does all the other necessary operations at one time.

How Power Is Applied to Machines

A BIG problem in designing any machine is how to apply power where and how it is needed. Power reaches the machine by way of a belt drive or an electric motor, constantly turning in one direction at the same speed. Yet one gear may have to revolve five times faster than another, or a rocker arm must move up and down and sideways, while a valve must open and close. How can the steadily turning motor translate its power into all these different movements? This is done by the use of cams, valves, clutches, belts, ratchets, cranks, linkages, and gears.

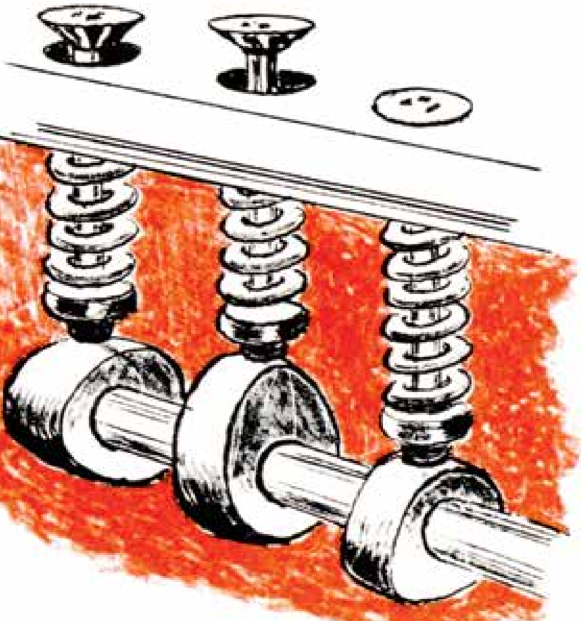
How a Gasoline Engine Works

Look at the drawing of a gasoline engine which has been cut away to show how the parts work. The power comes from an explosion in the cylinder head, which in turn drives the piston down in a straight line. However, a revolving motion is needed to make the automobile's wheels turn. To accomplish this a connecting rod is suspended from a pin, called a wrist pin, in the piston, so that the rod can swing from side to side like the clapper of a bell. The bottom end of the connecting rod ends in a ring which fits around a bearing of the crankshaft. This crankshaft is held firmly in place by bearings in several places so that its cranks can revolve around the center of the shaft.

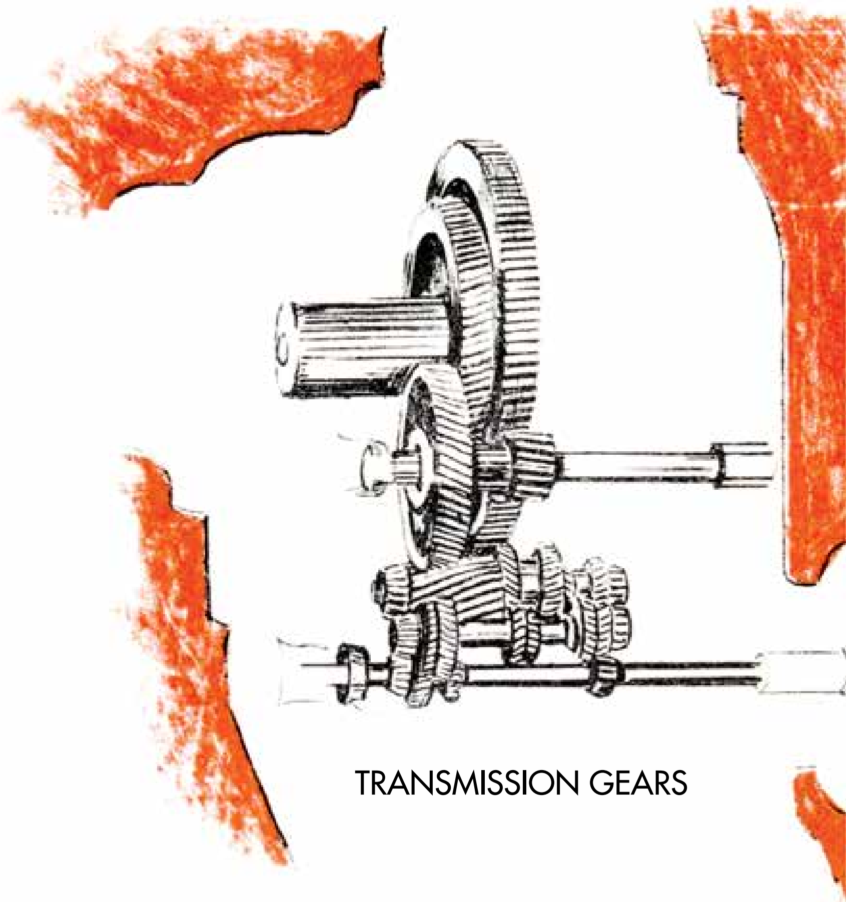


When the gasoline from the car's tank is mixed with air in the carburetor, it forms a vapor, which is sucked into the cylinder head and exploded by a spark from the spark plug. The explosion forces the piston down, and then the connecting rod pushes against the crank and makes it turn. When you ride a bicycle, your muscles are the " explosion, " or power impulse, your legs are the connecting rods, and the pedals and sprocket are the crankshaft.

Now look at the picture of the cams and camshaft. One of the many uses of cams is to open and close the valves on a gas engine. When they are open, vapor is sucked into the cylinder. Next the valve must close tight so that the vapor can be compressed and exploded. Then it must



CAMS AND CAMSHAFT

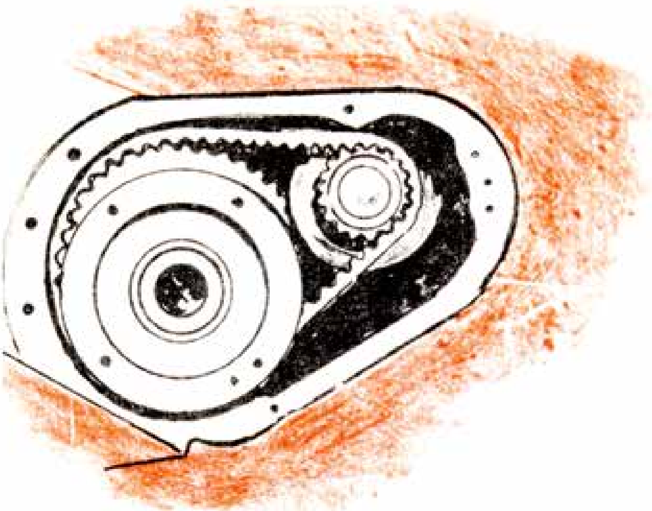


TRANSMISSION GEARS

reopen to let out the burnt gases and be ready to suck in more fresh vapor. All this must happen with split-second timing.

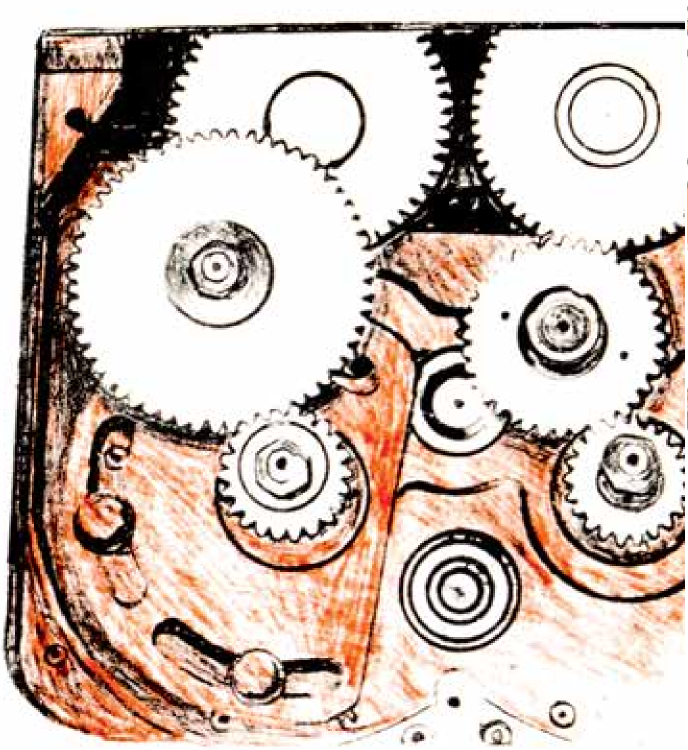
The bottoms of the valve stems rest on the cams, each one held down tightly by strong springs. As the camshaft turns, the high part of the oval-shaped cam forces the valve stem up and holds it open just long enough. Then, as the cam revolves, the spring pushes the valve stem down, closing the valve.

Look at the accompanying picture of an automobile transmission. This is a good example of applying power when it is needed. A car needs a lot of power to get started or to climb a steep hill, but much less after



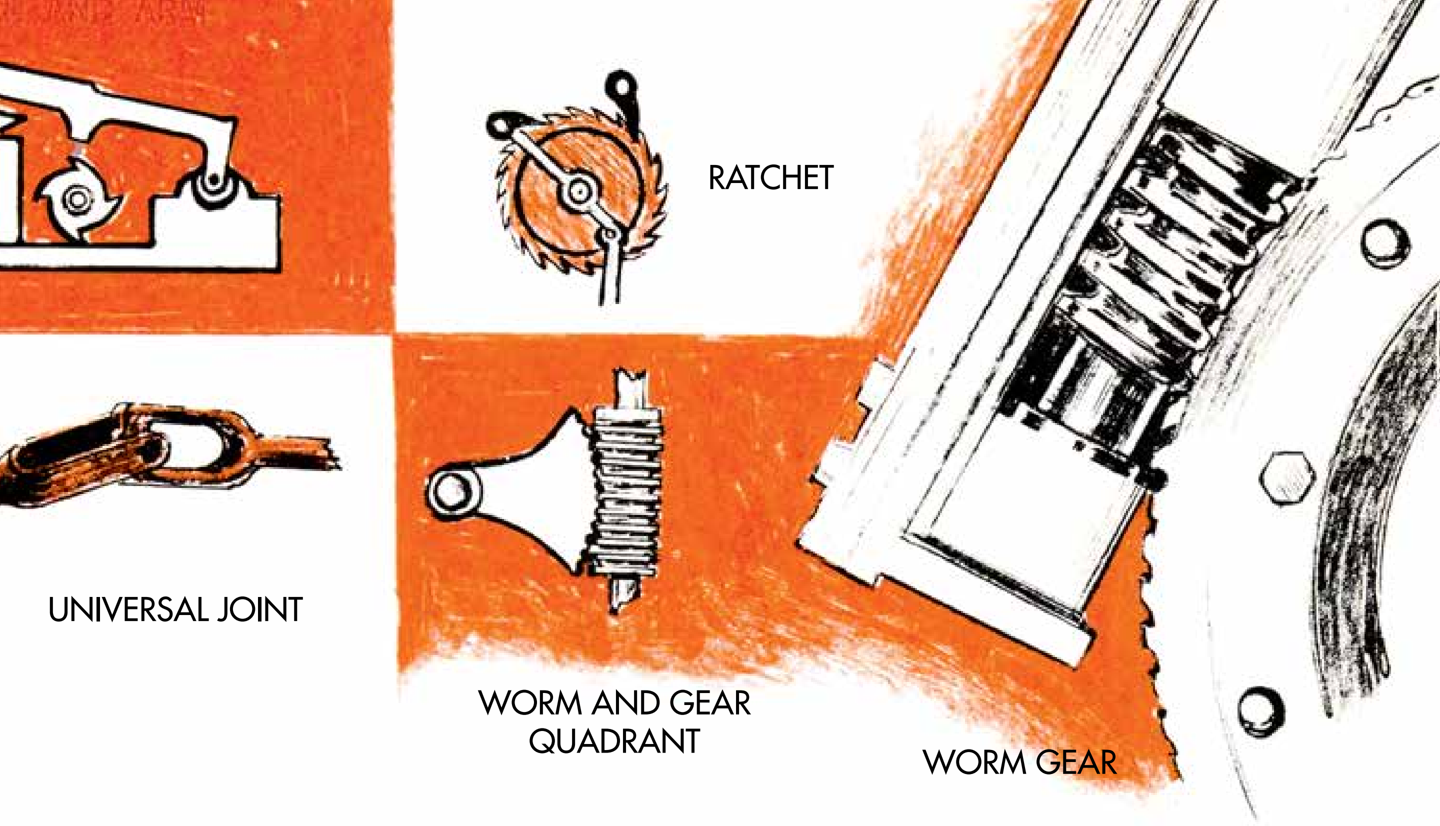
DRIVE CHAIN

GEAR DRIVE



it is moving fast on a level stretch. The engine would overheat, wear out faster, and use too much gas if it always had to run as fast as when it was starting. The transmission makes it possible to turn the rear wheels faster without speeding up the engine. This is how it works.

The crankshaft of the engine is connected to one shaft that ends in a gear in the transmission. Another shaft geared to the rear axle runs forward into the transmission, and also ends in a gear. As soon as the engine starts, the gear at the rear end of its shaft turns, but the car won't move until the gear on the rear-end shaft is connected to the engine shaft. To start the car, the gearshift lever must be turned to low speed. This slides a large gear into place so that its teeth *mesh* (engage) with those of the gears on the two shafts; then the car begins to move. When second gear is engaged, it pushes a smaller gear into mesh. And when the smallest, or high, gear is engaged, the drive shaft revolves even faster,



although the engine is still turning at the same rate. To back the car, a reverse gear is meshed into place.

Now look at the picture of a drive chain. When for some reason the teeth of two gears cannot be made to mesh, the power may be transmitted by a chain, whose links fit over the teeth of the gears. On a bicycle the power applied to the sprocket through the pedals is carried back to the teeth of the rear-wheel axle by the bicycle chain. Because this axle is much smaller than the sprocket, the rear wheel revolves many times while your feet on the pedals turn only once.

The picture of the clockwork-gear train shows gears of many different sizes, all meshing. While the motor or spring which drives them always turns at the same speed, the gears turn at different speeds, according to their sizes.