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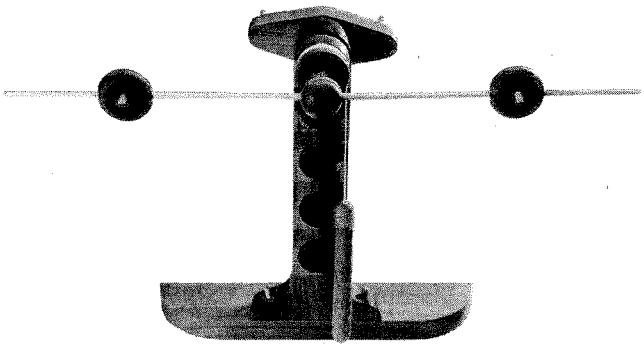
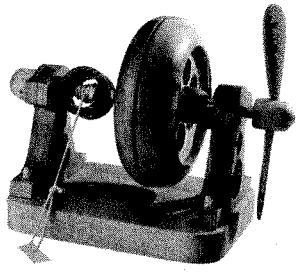
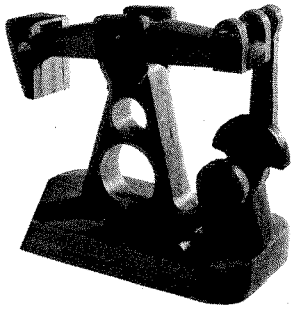


CIRCULAR MOVEMENT MACHINE



FLYWHEEL PROPELLER MACHINE



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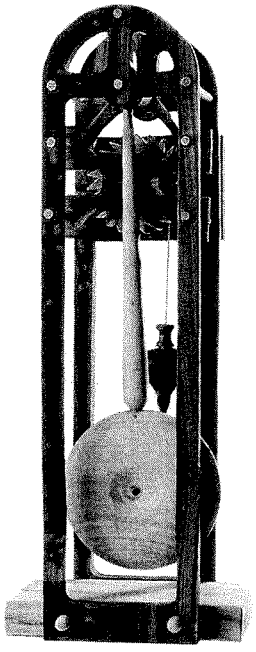

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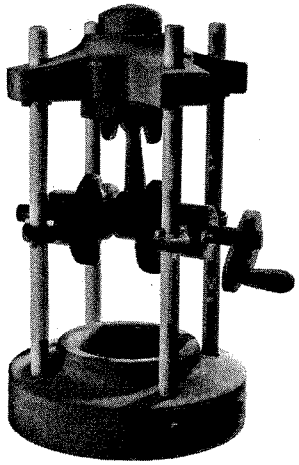
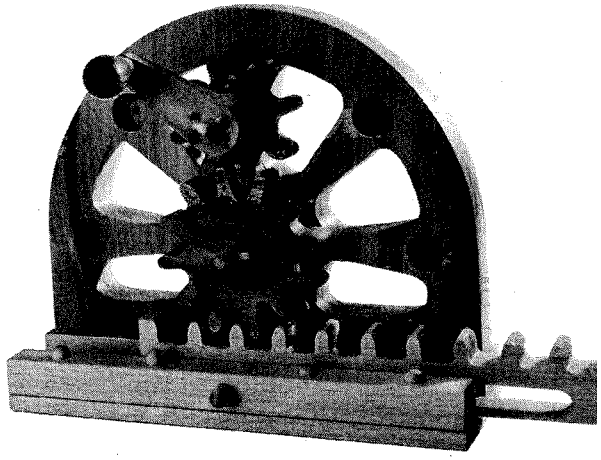
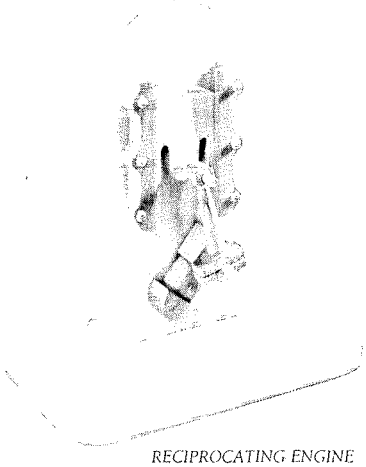


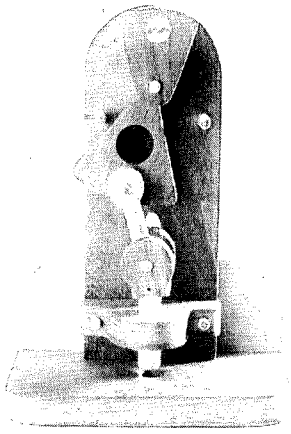
IN-THE-ROUND COMBUSTION ENGINE



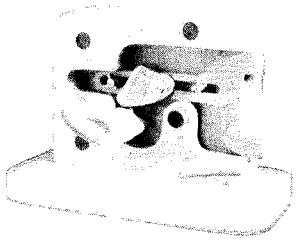
RACK AND PINION MACHINE



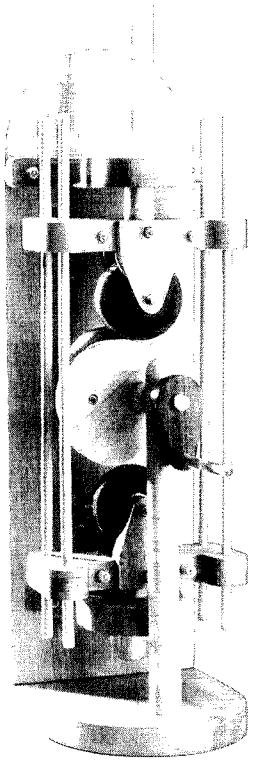
RECIPROCATING ENGINE



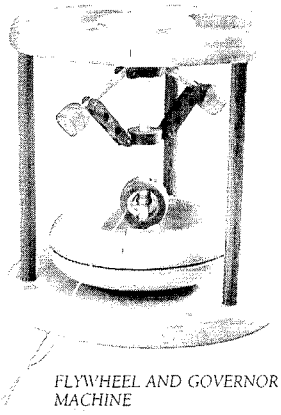
HARMONIC OSCILLATION PUNCH MACHINE



WARD LOCK AND KEY

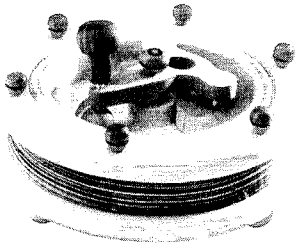


CAM MACHINE

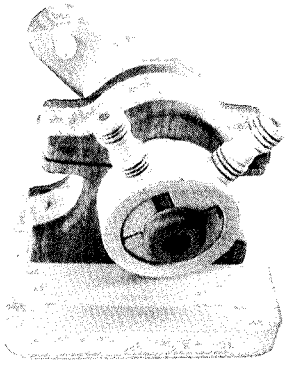


FLYWHEEL AND GOVERNOR MACHINE

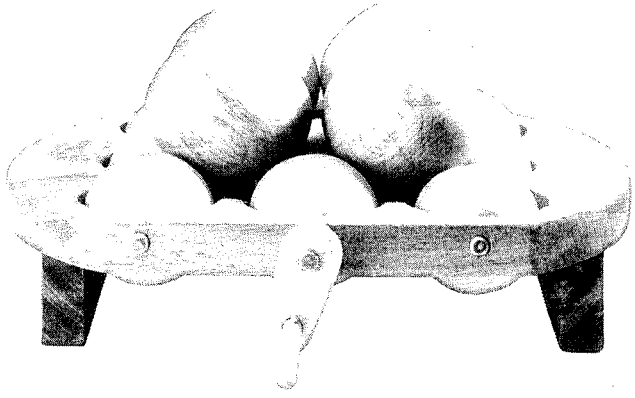
CAM AND FORK MACHINE



SECTOR WHEEL BEARING MACHINE



CENTRIFUGAL IMPELLER PUMP



PYRAMID ROLLER-BALL MACHINE

INTRODUCTION

When I was a child—I must have been about eight years old—I was forever trying to make some sort of weird and wonderful wooden machine or other. One time it was a very complicated and slightly dangerous weight-wheel-and-see-saw mechanism that linked my alarm clock to the bedside lamp, and then another time it was a catch on the shed door that was operated by the weight of the person approaching the shed, and so the list goes on. Well, of course, when I now look back, I see that my interests were twofold: On the one hand, I enjoyed playing around with mechanisms—weights, levers, wheels and the like—and on the other hand, I simply enjoyed the pleasures of handling and shaping wood.

The intention of this book is to explore and demonstrate the use of all the skills and techniques involved in producing what might best be described as key mechanisms and machines in wood. Machines made from wood? OK, so in many ways it might be thought that wood and machinery make for an odd couple, but that's not so. History tells us that if we could go back in time to, say, Leonardo da Vinci's workshop, Galileo's observatory, Benjamin Franklin's laboratory, Samuel Colt's gunmaking workshop, Isambard Kingdom Brunel's shipyards or wherever, we would almost certainly see people beavering away variously whittling, sawing, shaping wood, and making small-scale working mechanisms and machines.

Occasionally, when I am comfortably ensconced in my small, cozy workshop—with the sun shining through the window, my dog dozing on a pile of wood shavings, and my tools and piles of timber surrounding me—I take one or other of my little wooden machines and spend time running my eyes and fingertips over its forms and textures—it's an amazingly satisfying feeling! To see the way the grain flows through the structure; to wonder as the light catches the colors within the wood; to marvel at the characteristics of the various wooden component parts that make up the project—say a piece of silky, butter-colored lime or maybe a piece of plum with its deep, rich, honey-brown hues—to study the way the wooden components link, relate and operate one to another; and then to remember the many happy hands-on hours spent cutting, shaping and working with wood—these are, without doubt, uniquely beautiful experiences that should not be missed.

The intention, or you might say ambitions, of this book involves sharing with you all the pure playtime pleasures of building and creating small machines and mechanical prototypes from wood. With each and every project, we take you through the procedures of drawing out the designs, of making decisions as to the best type of wood to use for the task in hand, and of choosing the best tools for the job. We tell you how to use the tools and machines, we show you with scaled, gridded working drawings what goes where and how, we illustrate with photographs and pen drawings how best to achieve such and such a cut; in fact, we take you through all the stages of designing, making, constructing and finishing. We do our level best to describe all the procedures that go into making our working wooden wonders.

Each project relates to or is inspired by a specific mechanism or machine. There are such juicy delights as a circular movement machine, a pendulum recoil escapement machine, and a flywheel and governor machine. There are fifteen projects in all.

Making Wooden Mechanical Models does not require a workshop full of complex and expensive tools or shelves stacked high with rare and exotic woods (our wish is that you only use renewable species); it requires only that you become involved in the close, physically satisfying and therapeutic experience of working with wood—our most beautiful natural material.

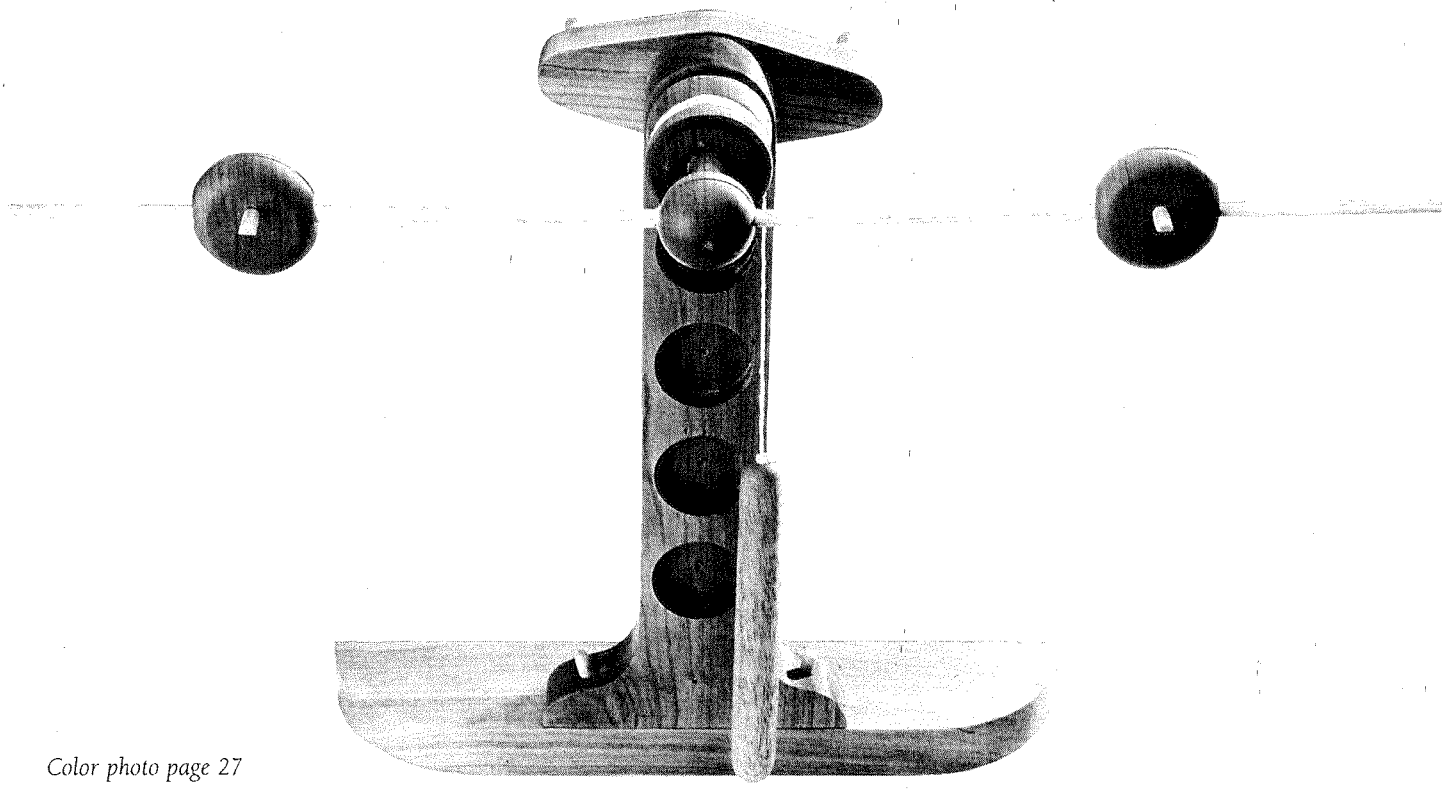
Making Wooden Mechanical Models is about personal involvement, working with your hands, and the joy and pleasure of using your mind and body to create uniquely beautiful machines in wood. What else to say except "Best of Luck!"

TOOLS & MATERIALS

- Scroll saw.
- Band saw.
- Bench drill.
- Forstner drill bits.
- Rotary power tool.
- Small drum sander.
- Pencil and ruler.
- Back saw.
- Pair of compasses or dividers.
- Sharp whittling knife.
- Adjustable angle square.
- Lathe.
- Good selection of lathe tools.
- Four-jaw chuck to fit your lathe.
- Screw chuck to fit your lathe.
- Tailstock drill chuck.
- Tracing paper.
- Teak oil.
- The usual workshop tools and materials—sandpaper, calipers, dividers, etc.
- Good selection of clamps.

PROJECT ONE

Circular Movement Machine



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PROJECT BACKGROUND

This machine is amazingly interesting in that it beautifully illustrates one of the key principles of horology. It shows how, in the context of a traditional grandfather-type clock, a pulley drum, length of cord and weight are able—like a coiled spring—to store up and provide energy.

The movement is handsomely direct and uncomplicated. As the weight falls at a constant rate, so the drum-and-beam flywheel spins at a uniform speed on its pivot. The fascinating thing is that the position of the pill weights on the beam dramatically alters the speed of spin.

To set the machine into motion, the cord is wound up with the crank handle, the two flywheel weights are adjusted so they are equidistant from the center of spin, and the weight is allowed to descend. If you have a yen to play around with flywheels, crank handles and pulley weights, and if you enjoy a good working mix of wood turning, fretting on the scroll saw and drilling, this might well be the project for you.

PROJECT OVERVIEW

Have a look at the project picture (above), the working drawing (Fig 1-1a) and the template design (Fig 1-1b), and see that we have designed the machine so it can be easily positioned on the edge of a surface. The idea is that the machine can be located on a mantle shelf or the edge of a table in such a way that the weight can fall three or four feet lower than the base of the machine.

Although at first sight this project may look almost too simple to be true, I think it fair to warn you that turning the beam boss with its integral pulley wheel and spindle, plus turning, drilling and fitting out the long, sausage-shaped bob weight, are all procedures that call for a deal of patience and expertise. There are several points along the way that require delicate work if you are to avoid mess-ups. For example, the fit of the spindle needs to be just so—not too loose, not too tight. Also, the bob weight hole has to run straight and true. If the drill bit veers a little off-center, you've got a dowel with a gash in the side—not a pretty sight!

PROJECT ONE: WORKING DRAWING

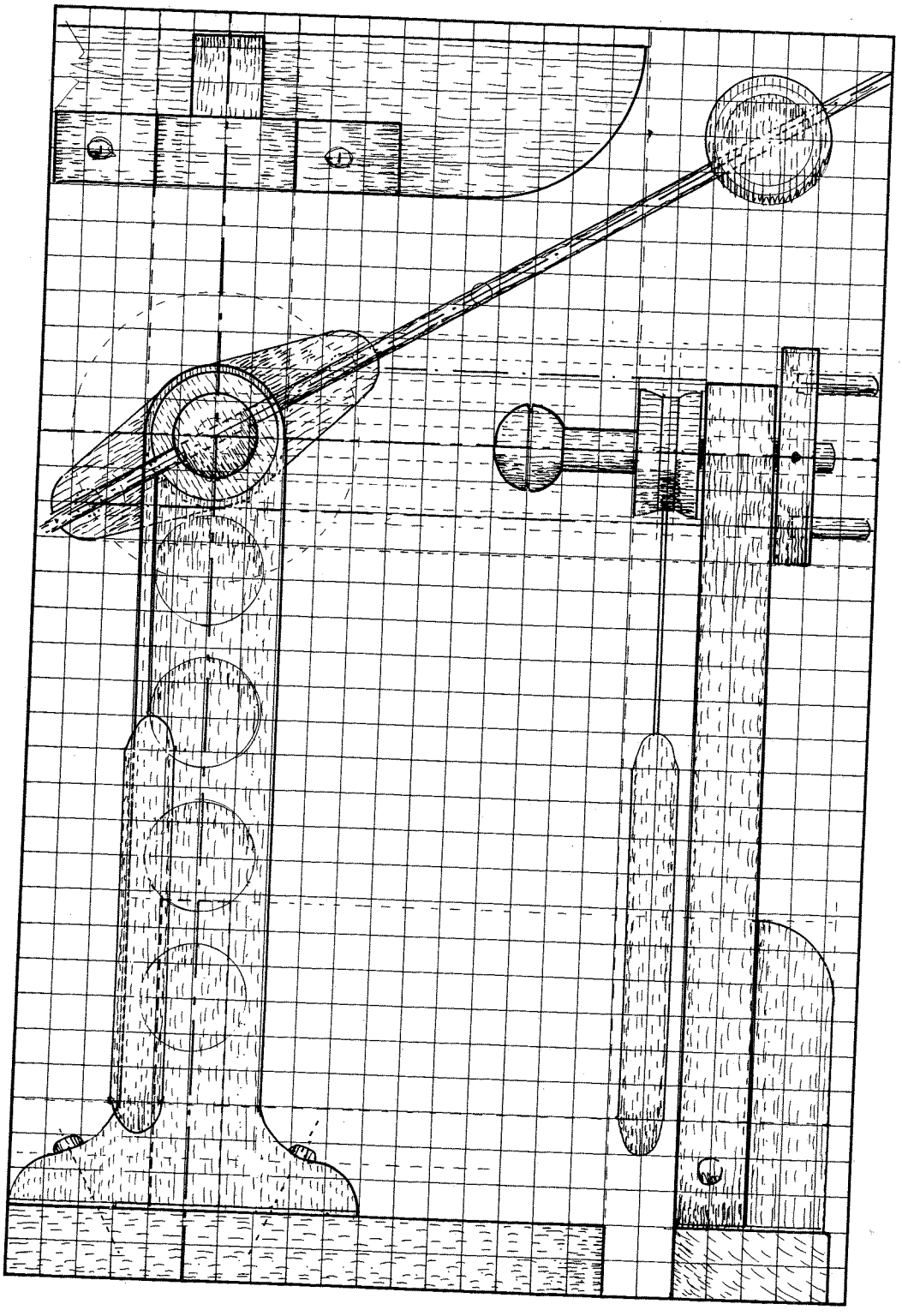


FIGURE 1-1A
At a grid scale of two squares to 1", the machine stands about 13" high and a little over 24" wide across the span of the beam rod.

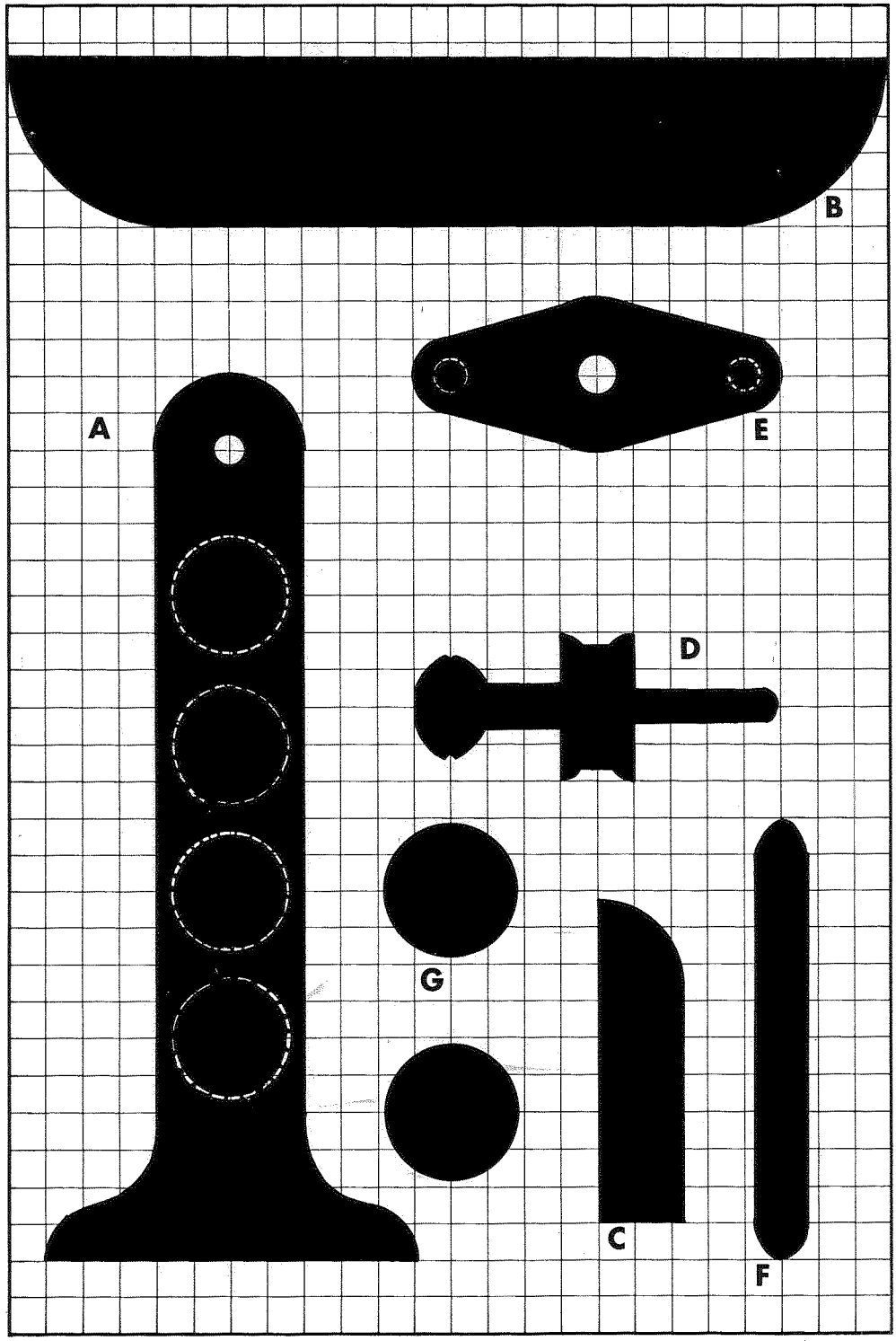


FIGURE 1-1B
The scale is two grid squares to 1".
A *Stand.*
B *Base.*
C *Buttress support.*
D *Boss spindle drum and flywheel cam disks.*
E *Crank handle.*
F *Weight.*
G *Beam weights.*

CUTTING LIST—PROJECT ONE

A	Stand	1 × 5½ × 13½ cherry
B	Base	1 × 2¼ × 12 cherry
C	Buttress support	1 × 1¼ × 4¼ cherry
D	Boss spindle drum and flywheel cam disks	2 × 2 × 12 cherry
E	Crank handle	1 × 2 × 6 cherry
F	Weight	6″—¾″ dark wood dowel
G	Beam weights	2 × 2 × 8 cherry
	Beam	24″—¼″ dowel
	Handles, fixing pegs	White wood dowel pieces

CHOOSING YOUR WOOD

Although we went for North American cherry for the base, stand, beam weights and crank, a length of off-the-shelf dark wood dowel for the weight, and odds and ends of various white wood dowel for the handles and fixing pegs, this is not to say you can't go for almost any wood that takes your fancy. There are two provisoes: The bob weight is best made from a heavy, dense wood, while the boss spindle needs to be made from a wood that is straight grained and easy to turn. That said—and being mindful that we all ought to be using nature-friendly, sustainable timbers—you could go for a variety like lime, jelutong or perhaps even beech. My overall thinking is that if the wood is easy to work; not too expensive; free from knots, splits, warps and stains; and from a reputable source, it's the right timber for the task.

MAKING THE BASE, BACKBOARD AND CRANK HANDLE

1 Study the working drawing (Fig 1-1a) and template design (Fig 1-1b). Draw the profiles to size and make clear tracings.

2 Set to work carefully cutting out the profiles.

3 Take the two cutouts—the stand and crank—and make sure the position of all the holes is clearly established with punched center points (Fig 1-1b). You need center points for the ½″-diameter spindle bearing at the top of the stand, the four 1½″-diameter blind holes that decorate the front of the stand, the ½″ hole at the center of the crank for the spindle, and the two ⅜″-diameter holes at the ends of the crank for the handle dowels.

4 With all the center points clearly fixed, drill them out with the appropriate bit size. Warning: For safety's sake, if the bit size is greater than ½″, have the workpiece held with a clamp (Figs 1-2 and 1-3).

TURNING THE BEAM WEIGHTS

1 Having established the end centers by drawing crossed diagonals, mount the wood on the lathe, draw up the tailstock, set the tool rest at the correct height, and generally see to it that all your tools are within reach.

2 Take the large gouge, either square ended or round nosed, and swiftly turn down the 2″ × 2″-square section of wood to the largest possible diameter. With the wood roughed out, take the skew chisel and bring the wood to a smooth cylinder.

3 Starting with the two beam disks, or pucks, and working from right to left along the workpiece,

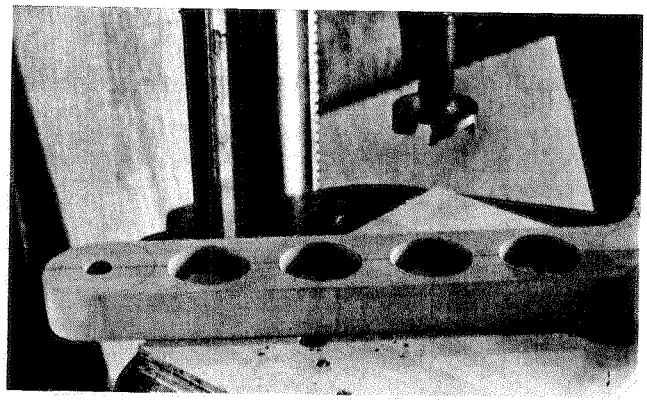


FIGURE 1-2

Clamp the workpiece securely to the worktable, and run the blind holes in to the depth of the head of the Forstner bit.

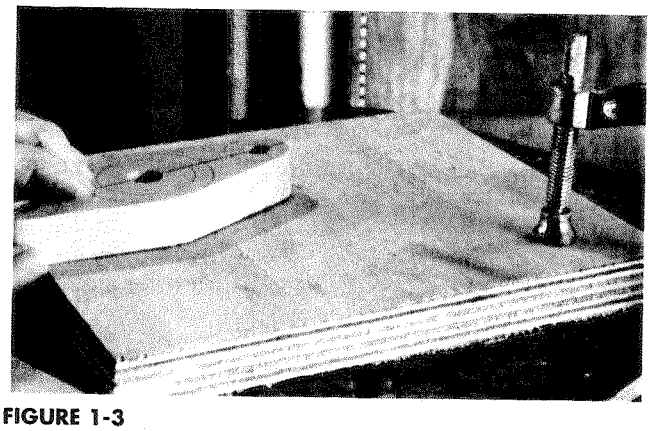


FIGURE 1-3

Have a piece of waste wood under the workpiece—we use a sheet of plywood—so you can drill right through the workpiece without doing damage to the bit. The waster also ensures that the exit hole is crisp and clean edged.

meaning from the tailstock end, take the dividers and mark all the step-offs that make up the design. Allow about ½" for tailstock waste, 1" for the first disk, ¼" for part-off waste, 1" for the second disk, and then a final small amount for part-off waste.

4 With the two disks carefully marked, take the parting tool and sink the waste areas to a depth of about ½" so that you are left with a core diameter of about ½".

5 Take the skew chisel and use the toe, or point, to swiftly mark in the midlines of each 1"-wide disk. Then flip the tool over, and use the heel to turn away the corners of waste. Aim for a nicely rounded profile. I first cleared the parting waste, then trimmed off the sharp corners, and then rounded each of the shoulders (Figs 1-4 and 1-5) and so on, all the while trying to match up the mirror-image forms.

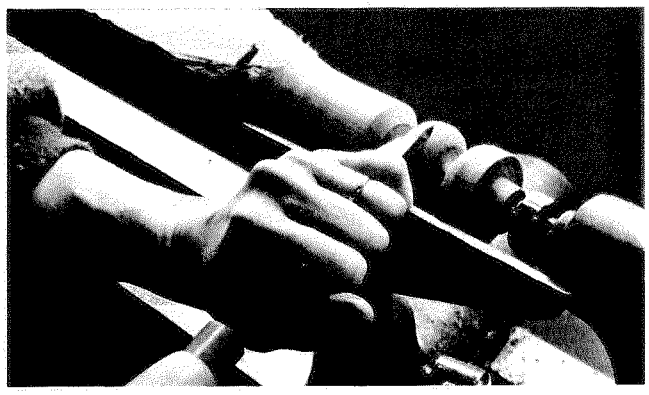


FIGURE 1-4
To turn off the round shoulder, set the skew chisel flat on the workpiece, slowly twist the tool until the back or heel of the blade begins to bite, and then run in a continuous sweep down and round into the valley.

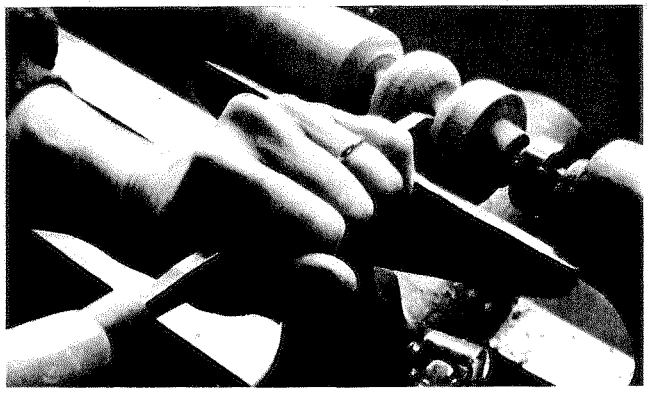


FIGURE 1-5
Having turned off facing shoulders, take the parting tool and deepen the parting waste to reveal and define the flat face of the disk.

6 Finally, when you have what you consider is a well-matched pair of disk weights, bring them to a smooth finish with the skew chisel and a piece of fine-grade sandpaper, and part off.

TURNING THE INTEGRAL SPINDLE, CORD DRUM AND BOSS

1 Check your wood over for faults and mount it securely on the lathe.

2 Having used the square- or round-nosed gouge to achieve a roughed-out cylinder and the skew chisel to bring the wood to a smooth finish, take your ruler and dividers and mark all the step-offs that make up the design. Working from the tailstock end, allow a small amount for tailstock waste, 2" for the spindle, 1" for the drum, 1" for the length of spindle between the drum and the boss, 1" for the boss itself, and the rest for chuck waste. Mark the 1" drum with a midline.

3 Take the parting tool and lower the waste between the various step-off points to achieve the required core diameter (Fig 1-6). For example, if we take it that you are starting out with a 2"-diameter cylinder, then you need to lower the spindle by ¾" for a ½" core, the drum by about 1/16" for a 1⅞" core, the area of spindle between the boss and the drum by a little over ⅝" for a ⅝" core, and the boss by ⅜" for a 1¼" core (Fig 1-7).

4 With each of the step-offs lowered to the required depth, take the tool of your choice—I like using a skew chisel—and set to work shaping up the various profiles (Fig 1-8). No problem with the boss and the drum and the length of spindle in between—they can more or less be turned to any shape that takes your fancy—but the spindle shaft must be turned down so it is a smooth fit in a ½"-diameter hole. Note: If you can't use a ½" drill

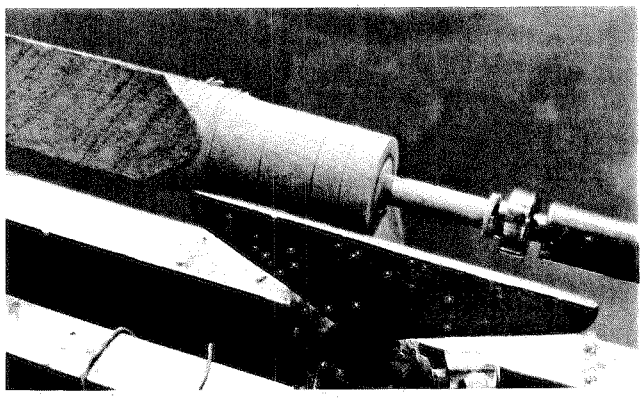


FIGURE 1-6
Take the parting tool and establish the main core diameters.

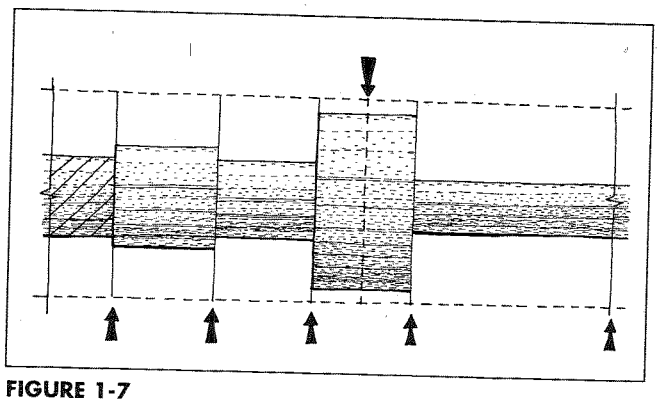


FIGURE 1-7

Lower the step-offs until you reach the core diameters of ½" for the spindle, 1⅞" for the drum, about ⅝" for the length of spindle between the drum and the boss, and 1" for the boss.

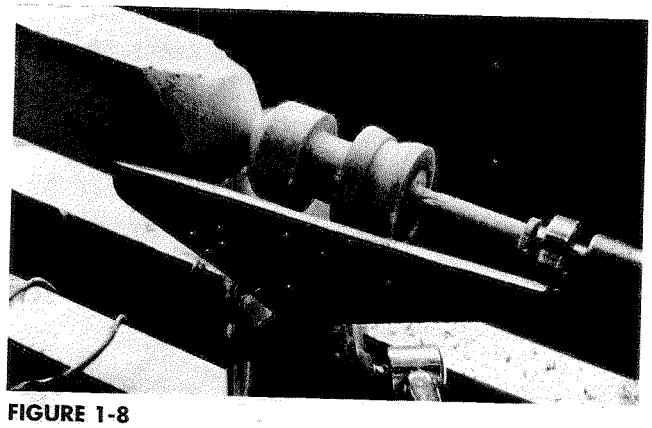


FIGURE 1-8

The partially turned workpiece, showing—from left to right—the boss, length of decorative spindle, drum and spindle shaft. Note that at this stage, we were still undecided as to how we wanted the boss to be finally shaped.

bit, settle for turning your spindle shaft to the nearest available size, say ⅜" or ⅝".

5 When you have turned the various profiles to size and shape and rubbed them down to a smooth finish with a scrap of sandpaper, carefully ease the tailstock center out of the way, and have a trial fitting of the spindle through the bearing hole at the top of the stand. Be mindful that it needs to be a good, smooth-running fit (Fig 1-9).

6 To part off, hold and cradle the workpiece in one hand, and carefully nip it off with the toe of the skew chisel (Fig 1-10).

7 Finally, set the rag-muffled spindle in the jaws of the chuck—the rag being used to protect the spindle from crush damage—and sand the part-off point down to a smooth finish.

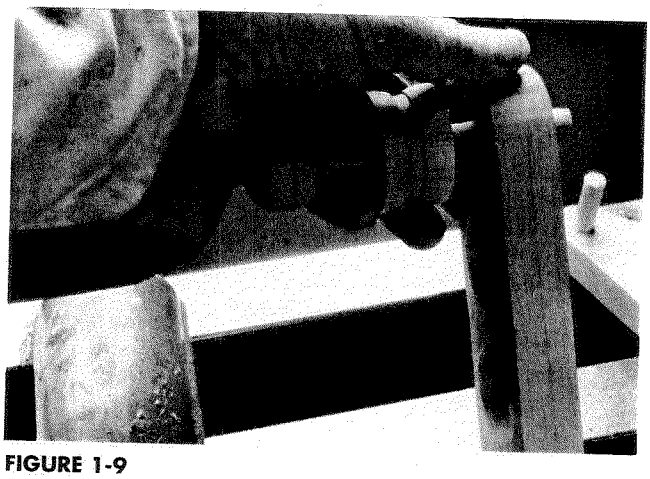


FIGURE 1-9

With the workpiece still secure in the jaws of the chuck, draw back the tailstock and have a trial fitting of the spindle shaft through the bearing hole. Be very careful not to jolt the turning off-center.

MAKING AND LOADING THE BOB WEIGHT

1 Before you put tool to wood, have another look at the working drawing (Fig 1-1a) and template design (Fig 1-1b). Note how the weight needs to be long and thin so it can pass between the stand and the spinning beam weights, while at the same time, it must be heavy. Consider how we drilled out a length of ¾"-diameter dowel and loaded it with lengths cut from a 6" nail.

2 Take your 6" length of ¾"-diameter dowel and check it over for faults. If it is warped, split, stained, or in any way less than perfect, select another piece.

3 Make a jig that allows you to stand the dowel on end at right angles to the drilling table and hold the dowel securely in place. If you look at the step-by-

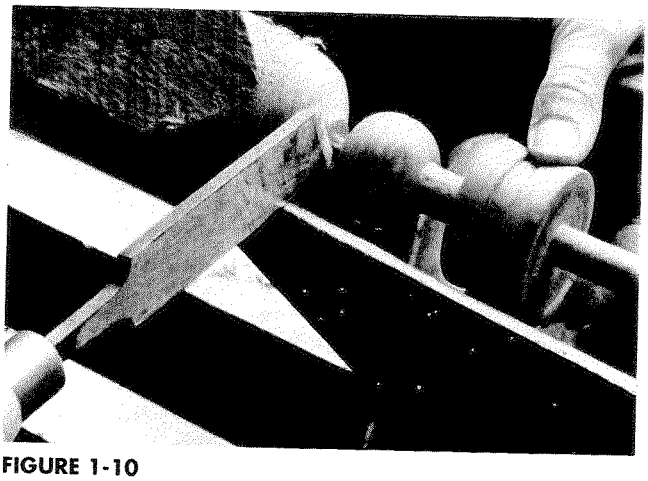


FIGURE 1-10

When you have achieved what you consider is a good, well-finished turning, use the toe of the skew chisel to part off from the lathe. Be careful that the toe of the chisel doesn't slip between the workpiece and tool rest.

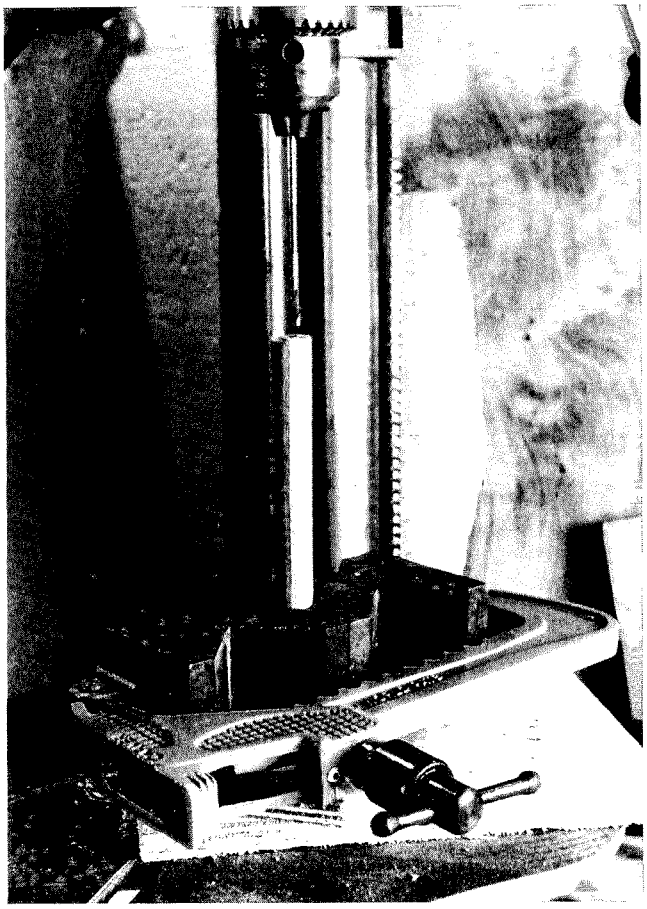


FIGURE 1-11
Secure the dowel so it is perfectly aligned with the drill, and run a ⅜"-diameter hole down to the full depth of the bit. Do this from both ends of the dowel.

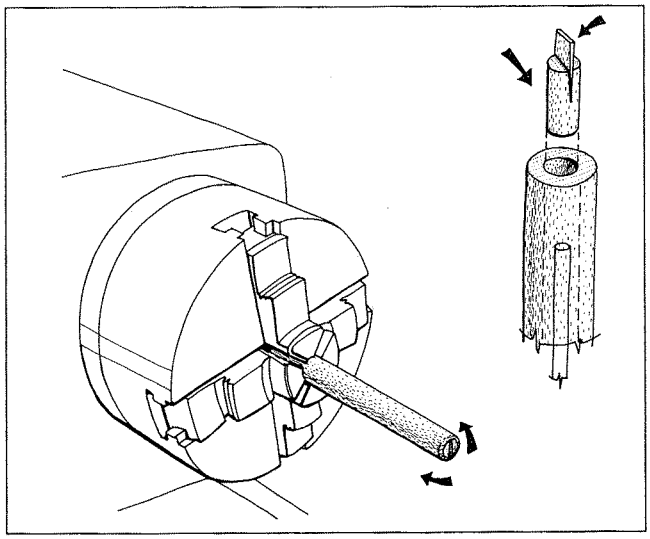


Figure 1-12
(right) Cut a length from a 6" nail, and push it down into the cavity; aim to finish up with a space of about ½" at the top of the hole. Plug the hole with a short length of wedged dowel.
(left) When the glue is dry, set the workpiece in the jaws of the chuck, and carefully turn down the end to a round-nosed finish.

step photographs, you will see that we solved the problem by clamping the wood between a couple of heavy, steel V-blocks.

4 Run a ⅜"-diameter hole down through the length of the dowel. Bore the hole down into one end—to the full length of the bit—and then turn the wood over and repeat the procedure for the other end (Fig 1-11).

5 With the holes in place—either right through the dowel or at least a good way into each end—cut one or more lengths from a 6" nail, and load it to within about ⅜" of the ends.

6 Push a length of split and glued ⅜" dowel into the end hole—both ends—tap a shaved wedge into the little stopper, and put it to one side to dry (Fig 1-12 right).

7 One end at a time, secure the loaded dowel in the jaws of the lathe chuck, and use the skew chisel and the graded sandpapers to turn it down to a round-ended shape—like a torpedo (Fig 1-12 left).

8 Finally, cut and finish all the secondary components: the buttress at the back of the stand and all the little pins and pegs.

PUTTING TOGETHER AND FINISHING

1 With all the component parts meticulously cut and worked (Fig 1-13), and with all unglued surfaces lightly oiled, set the stand on the base so it is flush with the front edge and aligned with the center line, and draw in a couple of discreet alignment marks.

2 Clamp the stand lightly to the base, and run ¼"-diameter peg-fixing holes down at an angle—

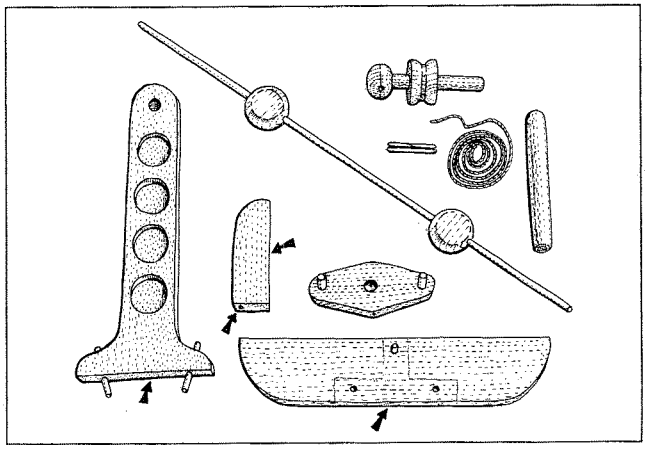


FIGURE 1-13
Note that the areas to be glued, on the base, the underside of the stand, and two sides of the buttress, are not oiled.

through the feet and on into the base. The best procedure is to drill one foot, secure it with a peg, and then repeat the technique for the other side. Be aware that because the feet are short grained, they are relatively fragile. Note: Don't glue the pegs at this trial fitting stage.

3 Take the buttress piece and set it firmly against the back of the stand. When you feel there is good, tight, right-angle coming-together of the three components, fit with a dowel (Fig 1-14).

4 Take the boss spindle and the beam weights and one piece at a time, secure them in an appropriate clamp-and-block jig. Drill out the ¼"-diameter holes for the beam rod. Make sure the holes are aligned at right angles to the run of the grain. Drill two 1/16"-diameter holes—one into the drum for fixing the cord and the other through the side of the crank and into the spindle (Fig 1-15).

5 When you have fitted the stand to the base and the spindle is sitting comfortably in place at the top of the stand, push fit the ¼" beam dowel through the boss (Figs 1-16, 1-17 and 1-18), set the weights on the beam, fit the length of fine cord and the weight, and then have a trial run.

PROBLEM SOLVING

■ The whole success of this project hinges on the spindle shaft being a smooth, friction-free fit through the top-of-stand bearing hole. Try waxing the contact surfaces.

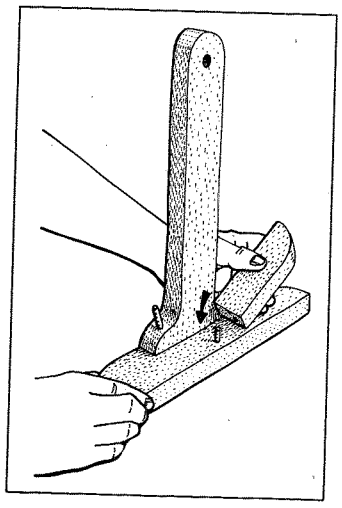
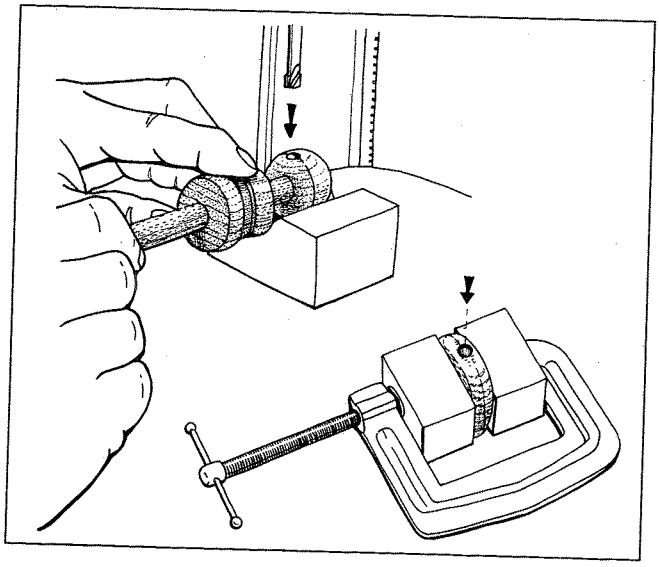


FIGURE 1-14
Fit and fix the stand to the base, and then brace with the buttress.

FIGURE 1-15
Build clamp-and-block jigs for the various difficult-to-hold components that need to be drilled. Minimize the risk of splitting the wood by having the holes set across the run of the grain.



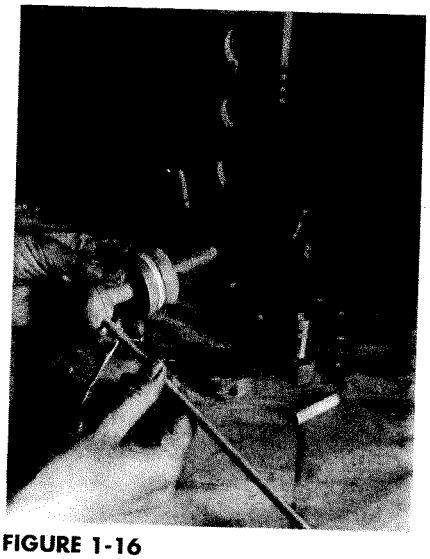


FIGURE 1-16
The beam rod needs to be a tight push fit through the boss hole, while at the same time a loose push fit through the disk weights.

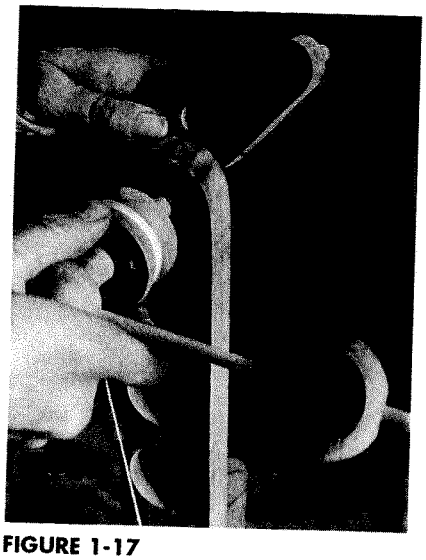


FIGURE 1-17
Pass the shaft through the bearing hole, set the crank on the shaft, and fit and fix with a round toothpick.

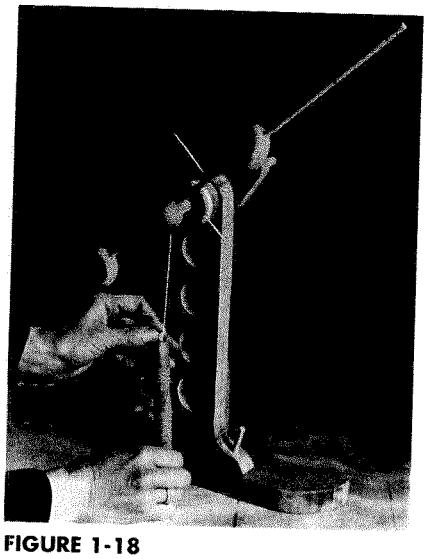
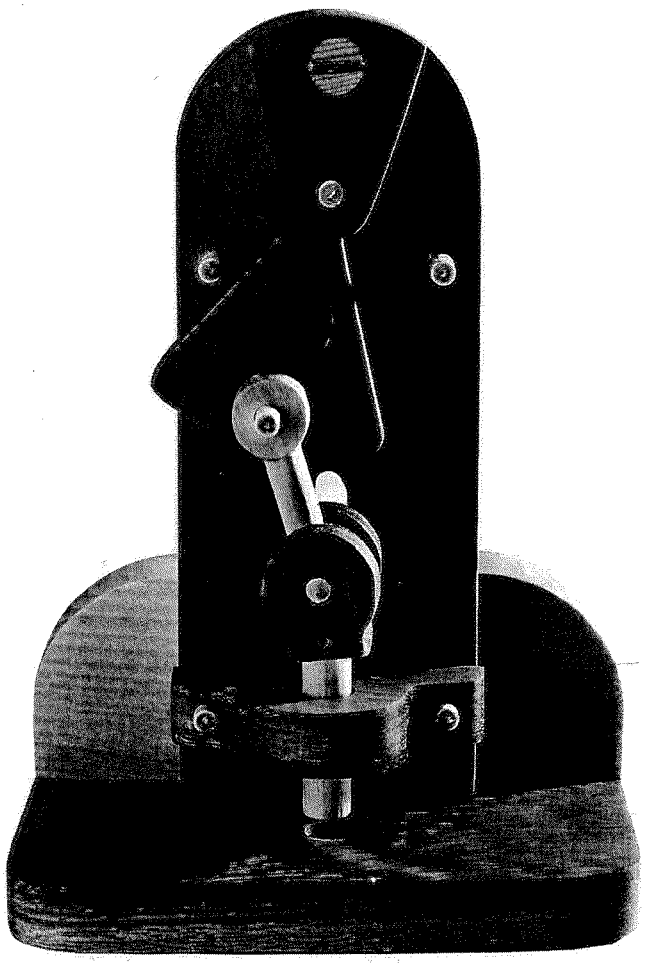


FIGURE 1-18
Fit the weight on the end of the cord, and have a trial run. If need be, reduce the friction by waxing the shaft and all the other moving mating faces.

PROJECT TWO

Harmonic Oscillation Punch Machine



Color photo page 28

PROJECT BACKGROUND

The oscillation punch machine is a gem to make. With its intriguing movement and attractive structure, it is the sort of machine that is just asking to be set into action!

As to the name of this machine, it is not so easy to come up with a clear-cut definition or meaning. OK, no problem with the term *oscillation punch*—it simply describes the up-and-down punch action that is created by the oscillating, or side-to-side, movement of the sector weight—but the term *harmonic* is a bit of a stickler. I reckon it has something to do with symmetrical, harmonic frequency, but I'm not so sure. Have you got any ideas?

The best way to operate this machine is to put your forefinger in the sector weight hole and to flick it rapidly from side to side. If everything is right, the swift side-to-side movement should result in the punch joggling up and down.

PROJECT OVERVIEW

Have a look at the working drawing (Fig 2-1a), the template design (Fig 2-1b) and the various photographs, and you'll see that this project is somewhat complicated in that it is made up of a large number of small moving parts. This is not to say that each component is in itself difficult to cut—far from it—but rather that the sum total of putting all the parts together does require a lot of thinking and a lot of fine adjustment.

Study the working drawing (Fig 2-1a), and consider how the machine is made up of the primary units: a base with a low, glue-fixed backboard, a high, round-topped backboard with a pivot rod location slot and various pivot holes, a plate and spacer to hold the sector, the swinging sector weight itself, the connecting rod, the pivoted crosshead joint and punch, and the bracket.

In action, as the sector weight swings to the side, the connecting rod rises, which in turn lifts the punch in its supporting bracket. And, of course, as the sector comes to rest in the midposition, the punch goes down in its bracket. The best bit about the action, meaning the way the parts move, is the way the loose-fit crosshead joint at the bottom of the connecting rod is kept in place by the pivot pin that passes through the unit and into the backboard slot.

PROJECT TWO: WORKING DRAWING

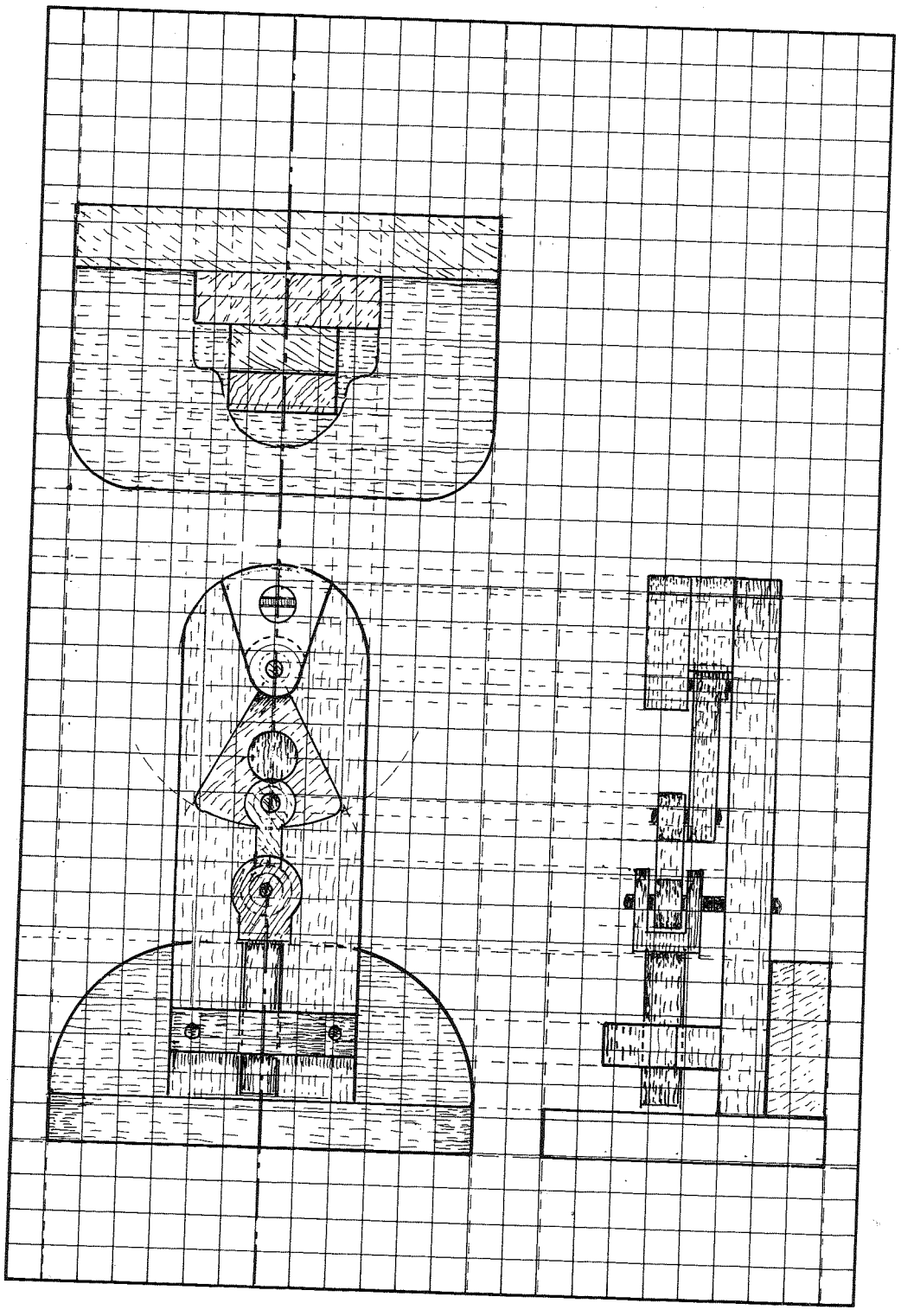


FIGURE 2-1A
At a grid scale of two squares to 1", the machine stands about 8½" high and 6" wide across the span of the base.

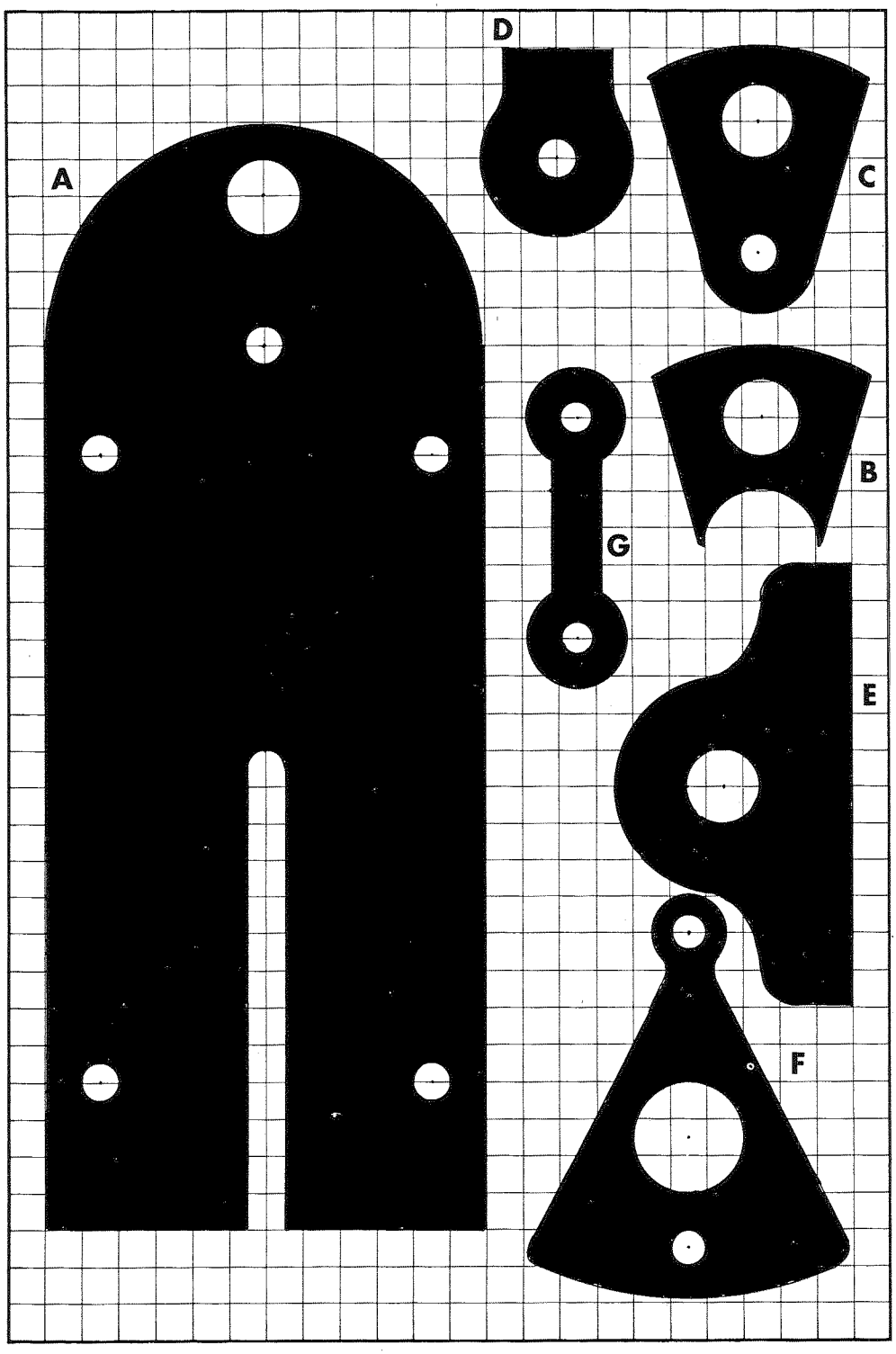


FIGURE 2-1B
The scale is four grid squares to 1". Note that we have only illustrated the difficult-to-visualize components.

A *Tall, round-topped backboard.*
B *Spacer.*
C *Front plate.*
D *Crosshead joint.*
sides.
center.
E *Bracket.*
F *Sector weight.*
G *Connecting rod.*

CUTTING LIST—PROJECT TWO

A	Tall, round-topped backboard	5/8 × 3 × 7 1/2 oak
B	Spacer	5/8 × 1 3/4 × 2 oak
C	Front plate	5/8 × 1 3/4 × 2 oak
D	Crosshead joint sides	1/4 × 1 1/2 × 2 oak
	center	1/2 × 1 1/2 × 2 olive
E	Bracket	5/8 × 2 × 3 oak
F	Sector weight	1/4 × 2 1/2 × 3 oak
G	Connecting rod	1/2 × 1 × 2 1/2 olive
	Base	5/8 × 4 × 6 oak
	Low, horizontal backboard	7/8 × 2 1/4 × 6 olive
	Pegs and pivots	18"—1/4" dowel
	Wedged dowel and punch rod	8"—1/2" dowel

CHOOSING YOUR WOOD

We decided to emphasize and draw attention to the various parts by using two strong-grained, fancy woods. We used Spanish olive for the horizontal backboard, the connecting rod, and the middle layer of the laminated crosshead joint and a piece of uncharacteristic English oak for the rest.

MAKING THE BASE AND BACKBOARDS

1 Having carefully studied the working drawing (Fig 2-1a) and template design (Fig 2-1b), take the two 6"-long pieces of wood—the oak at 5/8"-thick and 4"-wide, and the olive at 7/8"-thick and 2 1/4"-wide—and the 7 1/2"-long 3"-wide board, and use the pencil, ruler, square and compasses to mark all the lines that make up the design.

2 Spend time carefully marking in the position of the center lines, the main peg and pivot holes, and any other guidelines you think will help you on your way.

3 When you are sure all the guidelines are well placed, use the tools of your choice to cut the three boards to shape and size.

4 Peg and glue the low backboard to its base, check with a square, secure with clamps, and put it to one side until the glue is set.

5 Having cut the tall backboard out on the scroll saw, establish the position of the two top holes—the 1/4"-diameter pivot hole and the 1/2"-diameter wedge-peg hole—and drill them on the drill press.

6 Finally, when you have achieved what you think is a good fit and finish of the three boards, set the tall backboard on the base and draw in a couple of alignment marks (Fig 2-2).

MAKING AND FITTING THE SECTOR PLATES

1 Have a good, long look at the working drawing (Fig 2-1a) and photographs, and note how this project is perhaps slightly unusual in that all the small parts are cut out on the scroll saw.

2 When you have a clear understanding of how the parts fit and relate to one another, take the two 5/8"-thick pieces of oak that make up the sector support—the spacer and the front plate—and use the compasses, ruler and soft no. 2 pencil to draw the design on the best-looking piece.

3 With the two pieces of wood clamped securely together, establish the position of the sector pivot hole, and drill with the 1/4" drill bit.

4 Push a length of 1/4" dowel through the pivot hole to hold the two pieces of wood together, and cut the wedgelike shape out on the scroll saw (Fig 2-3).

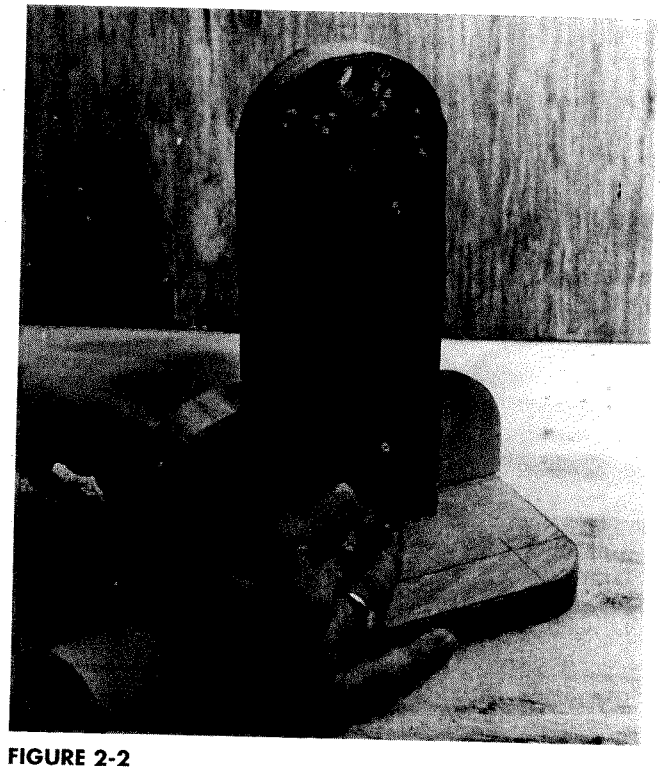


FIGURE 2-2
Make sure the backboard is set at right angles and aligned with the center line.

5 Have a trial fitting of the two cutouts on the backboard (Fig 2-4). Fix the position of the wedge-peg hole center point, and mark on the spacer plate the area that needs to be cut away.

6 With the pivot pin still in place, use the ½" drill bit to run the wedge-peg hole through the two pieces of wood. Note: Don't forget to back up the workpiece when drilling with a piece of scrap wood to prevent tearout.

7 Having achieved two identical cutouts, take the one that is to be sandwiched between the front plate and the backboard and cut away the waste, the whole ¾"-diameter circle with the ¼"-diameter pivot hole.

8 Cut a piece of ½" dowel to length—so it passes through the sector plate, the spacer and the backboard—saw a slot about ½" down into the end of the dowel, and knife cut a shaving of waste to fit.

9 Align the dowel so the wedge slot runs across the grain, and have a trial fitting just to see if the wedge holds the tenon in place in its hole (Fig 2-5).

CUTTING AND LAMINATING THE CROSSHEAD JOINT

1 Take the three pieces of wood that make up the crosshead joint—the two pieces of oak at about ¼"-thick and the piece of olive at about ½"-thick—and sandwich them together so the olive is the filling and the grain runs vertically up and down. Mark the three layers "top," "middle" and "bottom."

2 Draw the design on the top board, fix the position of the center point, and then tap a pin through the waste area to link all three layers.

3 Run the ¼"-diameter pivot hole through all three layers, and push home a generous length of ¼" dowel (Fig 2-6).

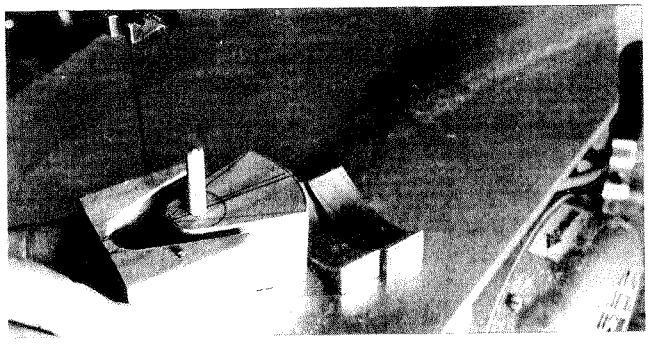


FIGURE 2-3
Saw through both layers so as to achieve two identical cutouts.

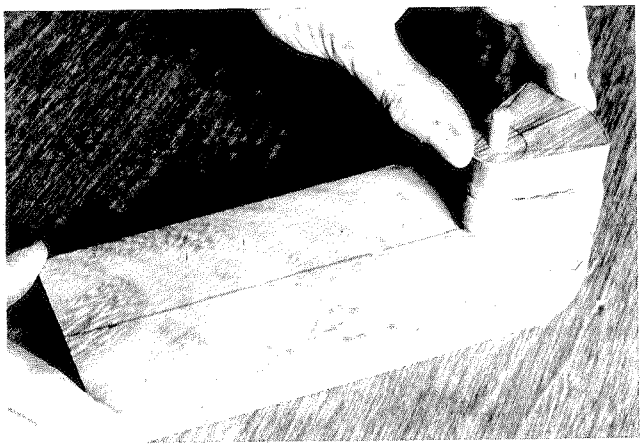


FIGURE 2-4
Set the cutouts in place on the backboard, make sure the arrangement is symmetrical, and then draw a couple of registration marks.

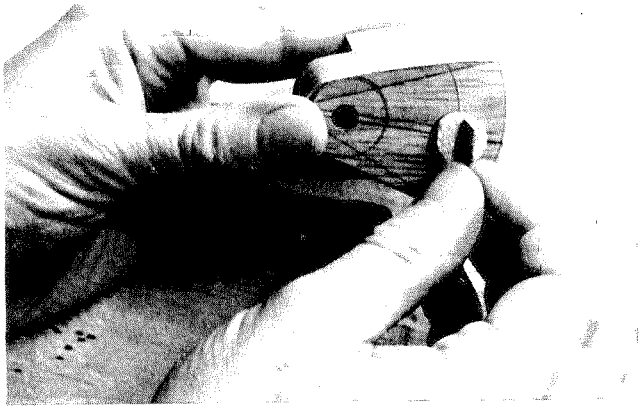


FIGURE 2-5
Align the slot so it runs at right angles to the grain, and have a trial fitting of the wedge. If all is correct, a push fit should be enough to hold the tenon firm.

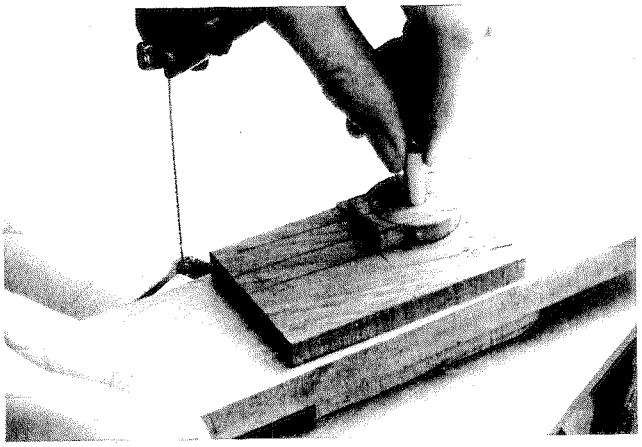


FIGURE 2-6
Saw through the three-layered stack to achieve three identical cutouts. Note how my heavy-handed nail fixing very nearly resulted in a complete mess-up—with a split running along the grain.

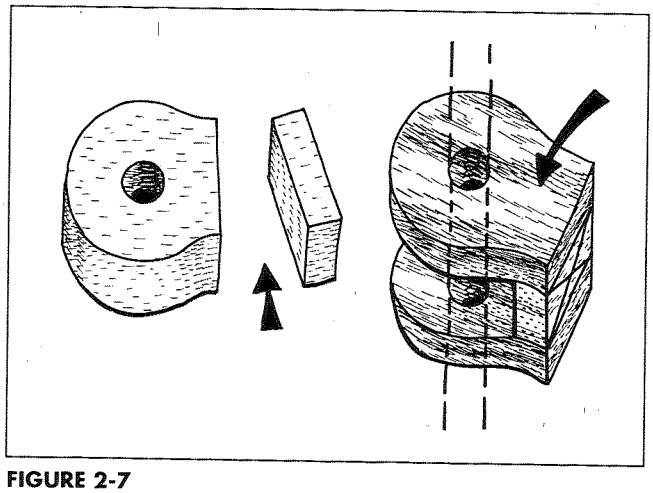


FIGURE 2-7
Cut away the top half of the middle layer so you are left with a ¼" slice.

4 With all three layers of wood held secure by both the pin and the dowel, fret out the shape on the scroll saw.

5 When you have achieved the cutout and carefully removed the dowel so you have three layers, mark on the middle layer the area that needs to be cut away (Fig 2-7).

6 Cut away the waste, replace the dowel, and then glue and clamp the three layers to make up the unit (Fig 2-8). When the glue is dry, run a ½"-diameter hole through the base of the component, and have a trial fitting of the punch rod.

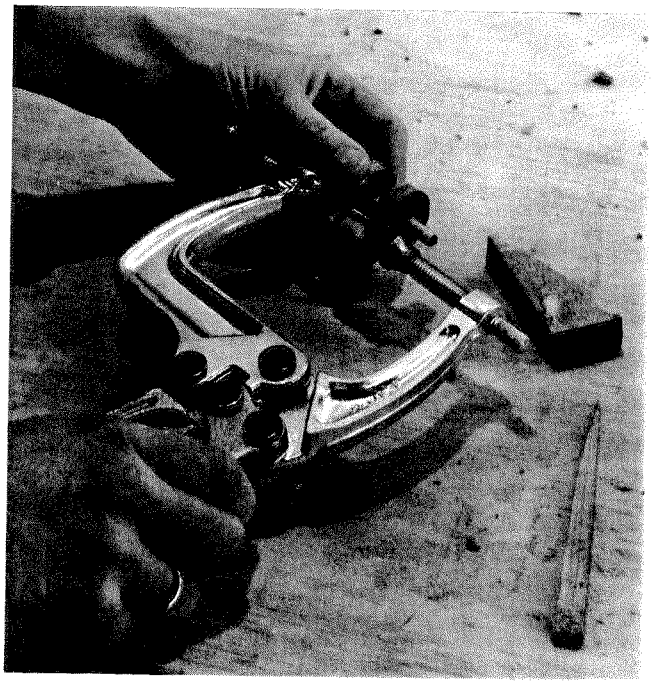


FIGURE 2-8
Smear glue on mating faces, align the holes with the pivot dowel, and then carefully clamp up.

MAKING THE BRACKET AND SECTOR

1 Have a look at the working drawing (Fig 2-1a) and template design (Fig 2-1b), and see how the two components—the bracket and the sector—are simple flatwood profiles that are cut out on the scroll saw.

2 Take the ⅝"-thick piece of wood you've set aside for the bracket and use the pencil, ruler and compasses to mark all the lines that make up the design.

3 Establish the position of the punch rod hole, and run it through with the ½"-diameter drill bit. Note: Be mindful that the precise position of the bracket hole, meaning its distance from the backboard, will relate to the finished thicknesses of the sector, the connecting rod and the crosshead joint. If you are at all unsure as to the finished sizes, you can make the bracket at a later stage, or you can allow extra depth to the bracket, and then trim back to fit.

4 When you have double-checked that all is correct, cut out the bracket on the scroll saw.

5 Take the piece of wood for the sector weight—all marked out and measured and with a clear center line—and give it another look-over, just to make sure the three holes are well placed. No problem with the ¾"-diameter finger hole—it can be just about anywhere on the center line—but the two ¼" pivot holes need careful positioning. The top pivot hole must be at the center of swing, meaning at the center of the ½"-diameter circle of wood, while the connecting rod pivot hole must be centered about ⅜" up from the bottom of the arc.

6 With all the lines and center points in place, and having carefully checked for accuracy, drill the three holes on the drill press—¼"-diameter for the two pivot holes and ¾"-diameter for the finger hole (Fig 2-9). Lastly, cut out the profile on the scroll saw.

MAKING THE CONNECTING ROD

1 Take the ½"-thick piece of olive you've put aside for the connecting rod and mark it with a center line that runs in the direction of the grain. Mark the line with two center points that are 1½" apart, and draw in all the lines that make up the design—the two ¾" circles and the ⅜" width to the rod.

2 Run the two center points through with a ¼"-diameter drill bit, and then have a trial fitting to link up the sector and the crosshead joint (Fig 2-10). If

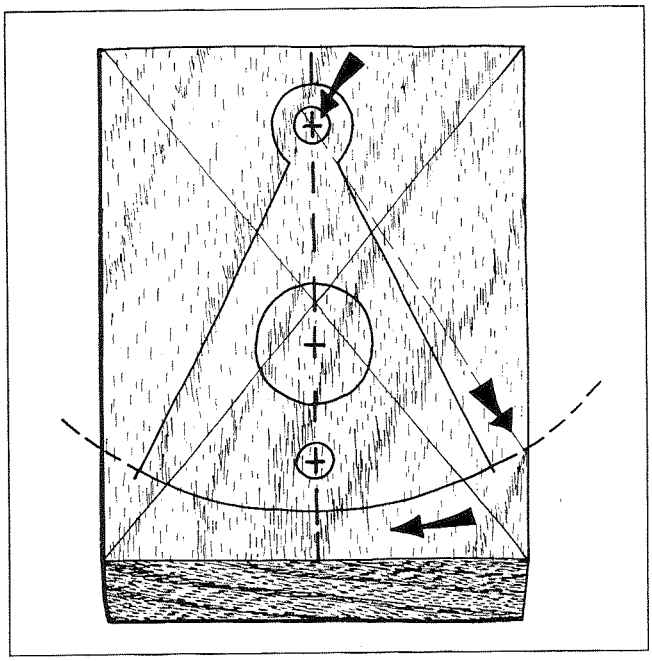


FIGURE 2-9
Avoid weak, short-grained areas by having the design arranged and centered so it is set symmetrically with the run of the grain.

need be, reduce the thickness and diameter of the bottom end of the rod so it is a good, loose fit between the ears of the crosshead (Fig 2-11).

3 Having cut the profile out on the scroll saw, take a small, sharp knife and set to work whittling the straight part of the rod to a roundish section. The best technique is to set the circle line in with a stop-cut—on both sides of the wood and at both ends—and then to carefully slice the blade into the stop-cut so the waste falls away. If you work with a careful, thumb-braced paring cut, you won't have any problems with the knife slipping (Fig 2-12).

4 When you have rounded and slightly lowered the round section so the flat faces of the end circles stand slightly in relief, take a scrap of sandpaper and rub down the knife-worked area to a smooth finish.

5 Take the tall, round-topped backboard and mark, drill and cut the various holes and the crosshead pivot runner slot.

PUTTING TOGETHER AND FINISHING

1 When you have completed all the component parts that make up the project (Fig 2-13), then comes the fun of trying to get everything together so it works!

2 When you are happy with the overall finish, glue and peg the low backboard to the base so it's at

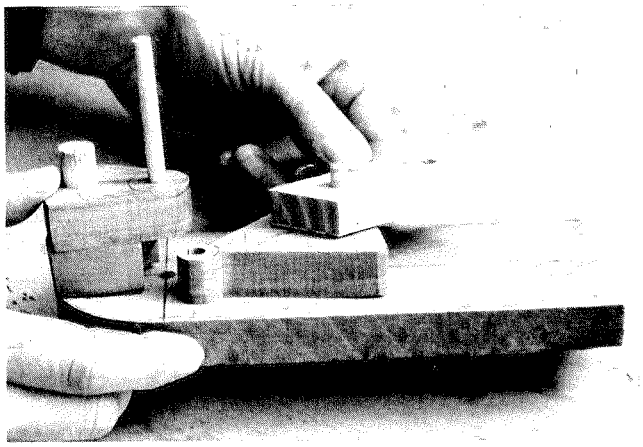


FIGURE 2-10
Have a trial fitting of both the sector weight and the partially worked connecting rod. Adjust the various thicknesses so the movement is smooth and easy.

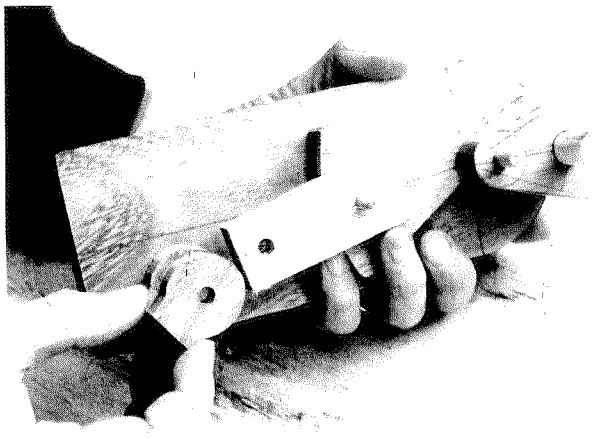


FIGURE 2-11
To minimize friction, adjust the thickness of the wood at the end of the rod and inside the ears of the joint. Use a twist of sandpaper to ensure that the end-of-rod hole is a loose fit on the ¼"-diameter dowel.

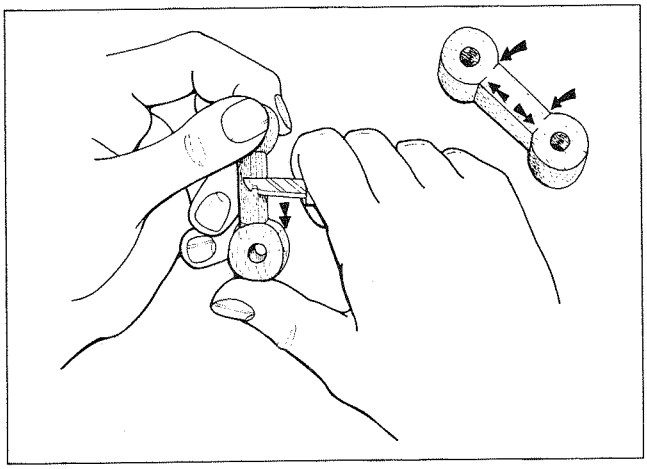


FIGURE 2-12
Use a tight, thumb-braced paring cut to whittle the rod to a round section. Work from the center through to the stop-cut.

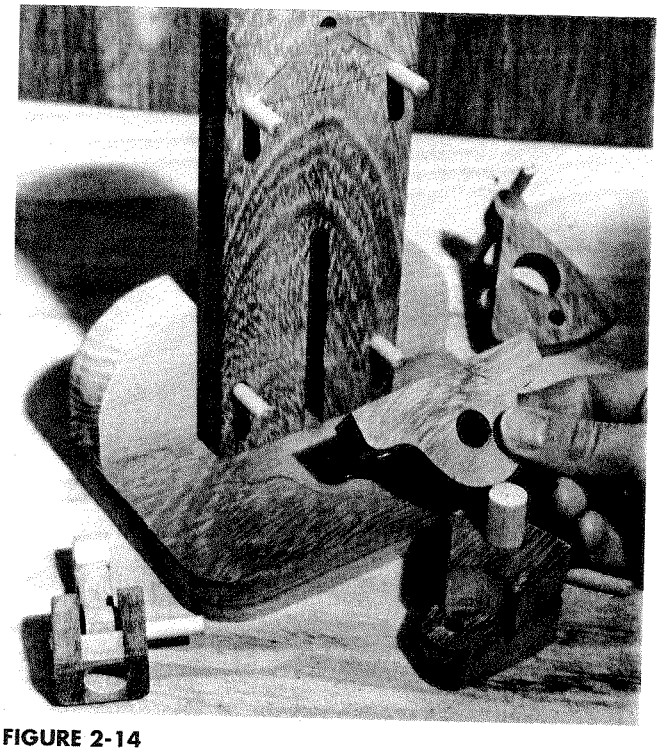


FIGURE 2-14
The bracket dowels need to run through all three components: the bracket and the two backboards. Note that—as an afterthought—we drilled a ½"-diameter blind hole in the base for the punch rod.

FIGURE 2-15
Set the connecting rod and joint unit in place on the punch rod, and locate the dowel in the guide slot.

right angles. It's important that everything is square.

3 Set the backboard in place on the base, establish the position of the bracket, and fix the whole works together with a couple of ¼"-diameter dowel pegs (Fig 2-14). Have the pegs running through all three layers of wood. While the ¼"-diameter dowel is at hand, fit the two pegs that limit the swing of the sector weight.

4 Slide the end of the connecting rod into the crosshead joint, push the dowel pivot in place, and check for a smooth, easy fit (Fig 2-15). If need be, reduce the wood—on the rod end, in the rod hole or in the joint—so the movement is smooth running.

5 Push the punch dowel into place in the bottom of the joint, and drill and fit with a round toothpick that runs through the whole width of the unit (Fig 2-16).

6 Take the sector and lower the wood at the back by about 1/16" so the circle of wood around the pivot stands out in relief—like an integral washer. Fit the sector on its pivot, and spend time easing and sanding until it swings with the minimum of friction (Fig 2-17).

7 Use a dowel to link the top end of the connecting rod to the sector (Fig 2-18) so the dowel is a tight fit in the sector hole and a loose, easy fit in the rod end.

8 Push the spacer and plate in place over the sector pivot, and test for fit and function (Fig 2-19). If all is well, you should be able to tickle the sector from side to side in such a way that the punch rod joggles up and down in its bracket.

9 When you are pleased with the fit, finish and function, glue the whole works in place, rub down all the surfaces with a sheet of fine-grade sandpaper, wipe the dust, and give the project a wipe with the teak oil.

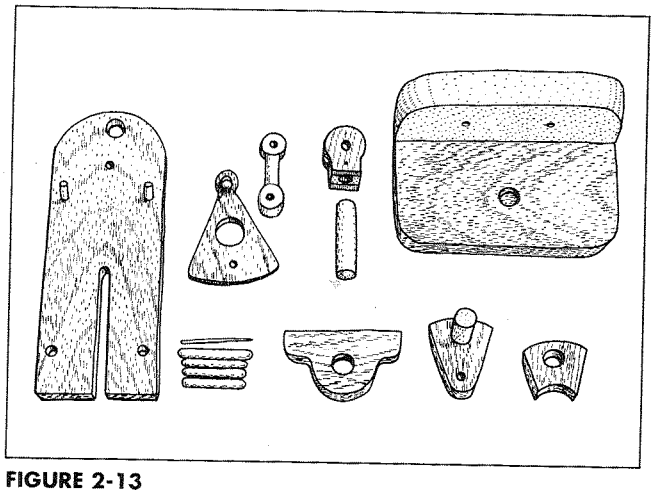


FIGURE 2-13
Check the parts over for flaws and blemishes. Turn a damaged face away so the flaw is hidden from view.

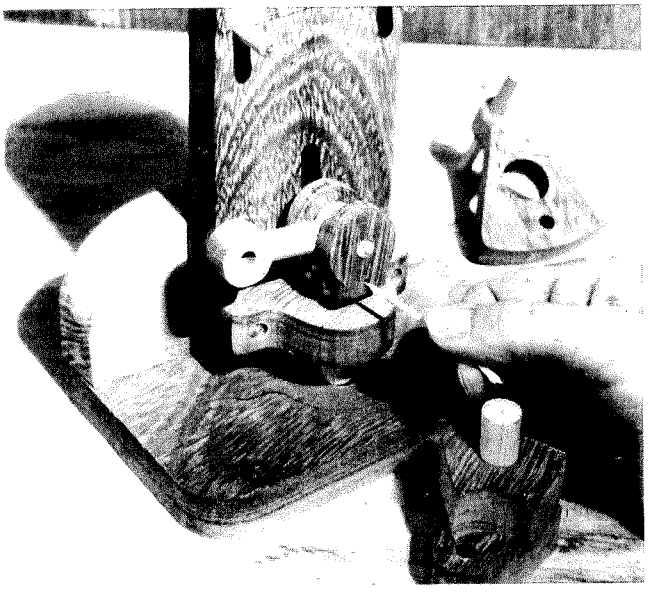


FIGURE 2-16
Set the joint in place on top of the punch rod, and hold the two together with a round toothpick dowel.

FIGURE 2-18
Link the connecting rod and the sector weight with a short length of dowel so the dowel is a tight push fit in the sector and a loose, easy fit in the rod.

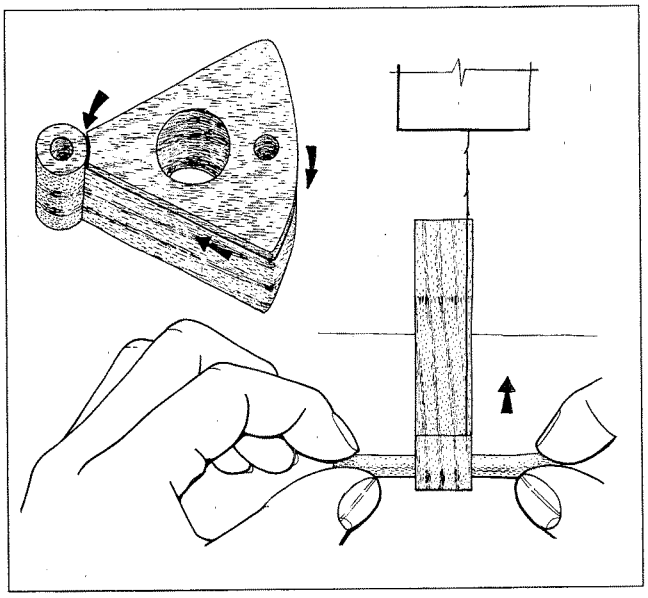


FIGURE 2-17
(top left) Reduce the total thickness of the back face by about 1/16". Run a guideline around the edge, and run a saw cut down into the face—between the pivot circle and the sector face so the pivot area will be left to act as a washer or distance piece.
(right) If you decide to clear the 1/16" slice of waste on the band saw, then run a dowel through the pivot hole so you have a safe handhold. Having run a 1/16" hole through the sector and the dowel pivot and followed through with a round toothpick, set the dowel pivot in place in the backboard hole.

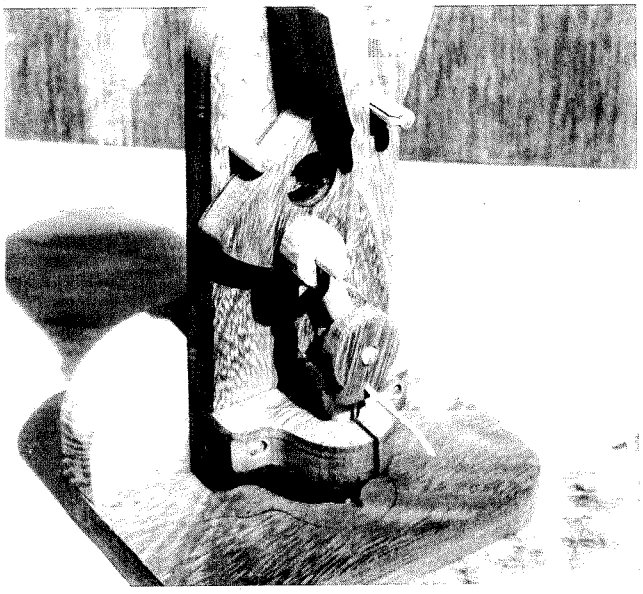


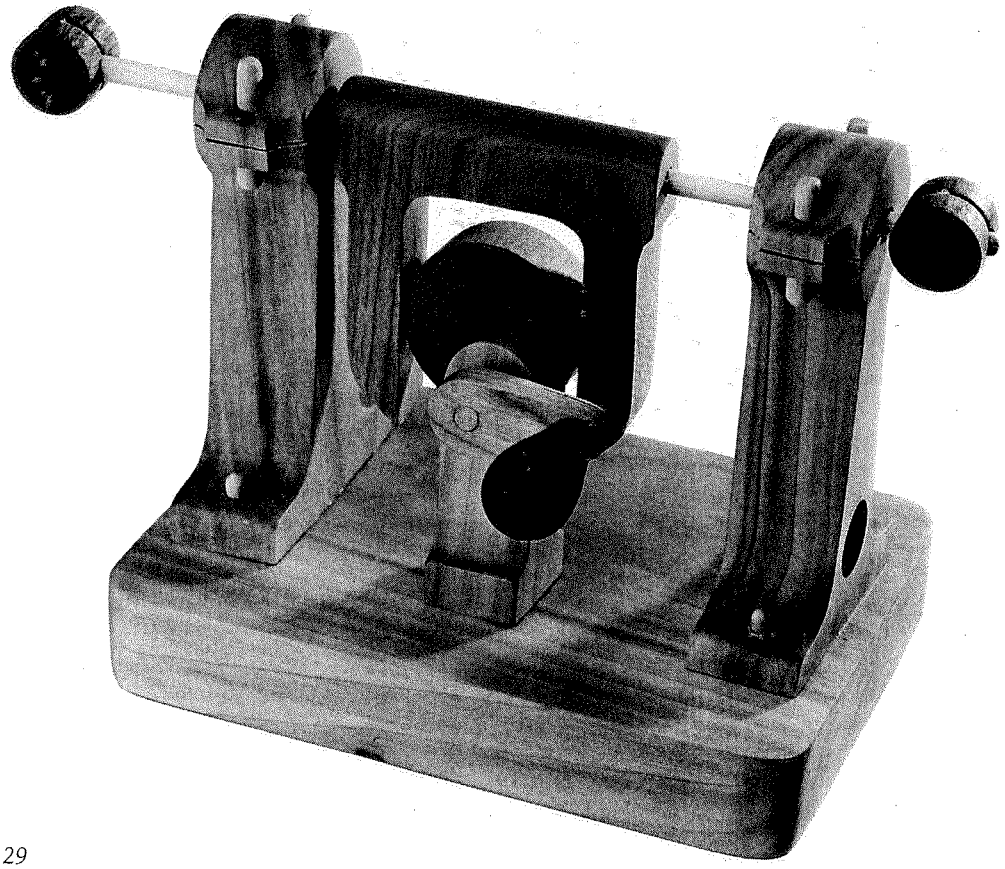
FIGURE 2-19
Set the plate and spacer in place on the sector weight pivot, and adjust for an easy movement.

PROBLEM SOLVING

- If you like the idea of this project but want to change the design, it's important you realize that the relationship between the swing of the sector weight and the length of the connecting rod is critical.
- If you decide to modify the design and are at all unsure about the feasibility of the design, it's best to make a working model.

PROJECT THREE

Cam and Fork Machine



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PROJECT BACKGROUND

This machine is a joy to make and a joy to watch.

Our dictionary describes a cam as being "a rotating cylinder with an irregular profile attached to a revolving shaft to give a reciprocating motion to a part connected to it." With our machine, the off-center, or eccentrically mounted, disk is the cam, while the fork is the in-contact connection that gives reciprocating motion.

When the crank handle is turned—clockwise or counterclockwise—the cam revolves eccentrically on its fixed bearing, with the effect that the fork and control rod oscillate on the pillar bearings. The fork is fixed on the rod, while the rod is free to slide from side to side through the bearings.

PROJECT OVERVIEW

Have a look at the project picture (above), the working drawing (Fig 3-1a) and the template design (Fig 3-1b), and note that the disk cam is pin fixed to a shaft in such a way that its movement is off-center. Consider carefully how, when the contained off-center disk cam turns, the fork has no option but to track and follow the cam profile.

Although the design is pretty flexible—inasmuch as there is no reason you can't chop and change various wood thicknesses and dowel sizes to suit your needs—the size of the disk cam, the distance between the fork prongs, and the distance between the side of the fork and the support stanchions are all critical. That said, if you have a notion to change wood sizes, it's best to sort out potential problems by making a cardboard-and-pins prototype.

Prior to cutting the various profiles from your chosen wood, be sure to study the working drawing (Fig 3-1a) and template design (Fig 3-1b), and take note of the direction of the grain.

PROJECT THREE: WORKING DRAWING

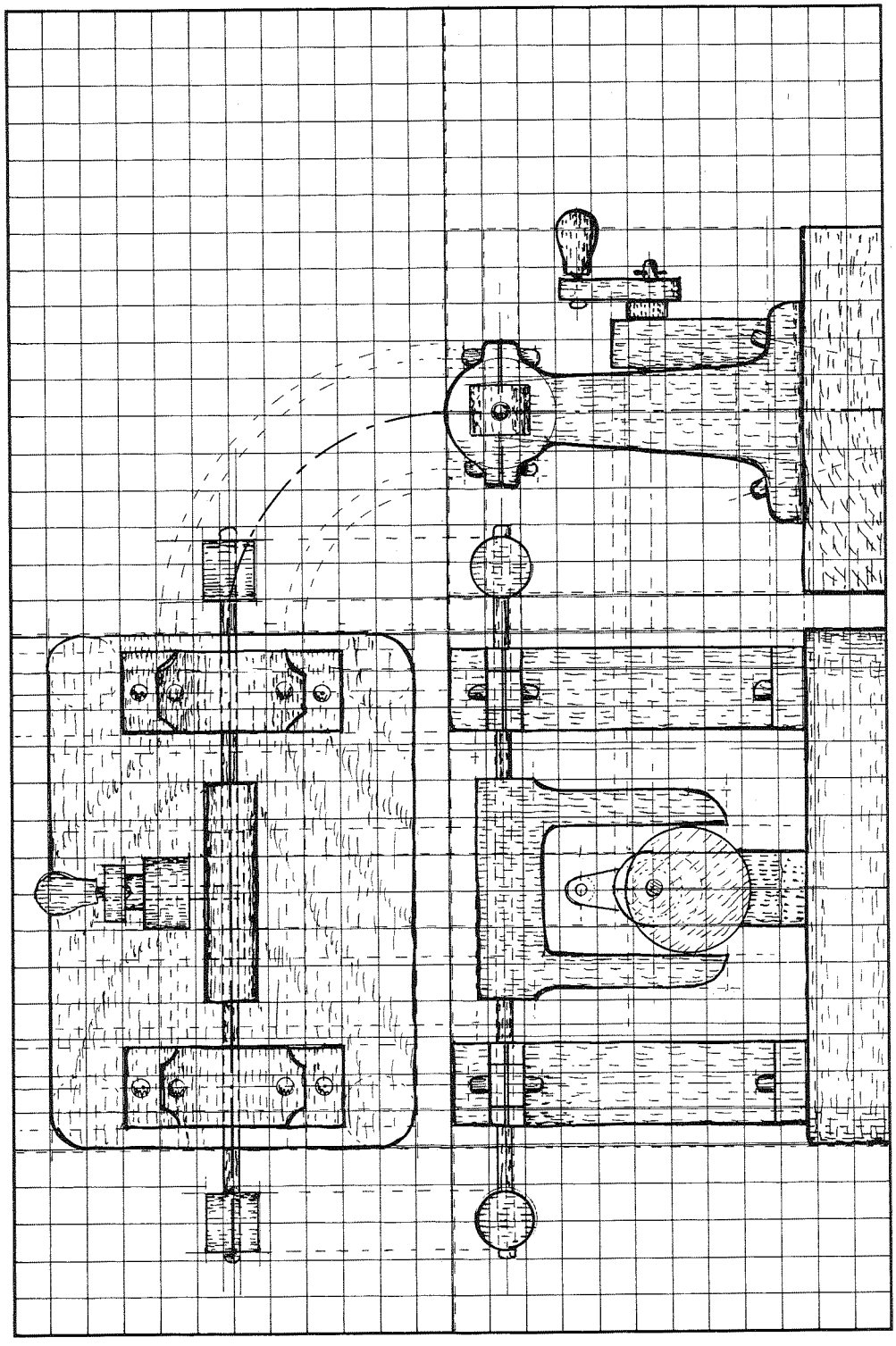


FIGURE 3-1A
At a grid scale of two squares to 1", the machine stands about 6" high and a little over 10" wide across the span of the end-of-rod pill stops.

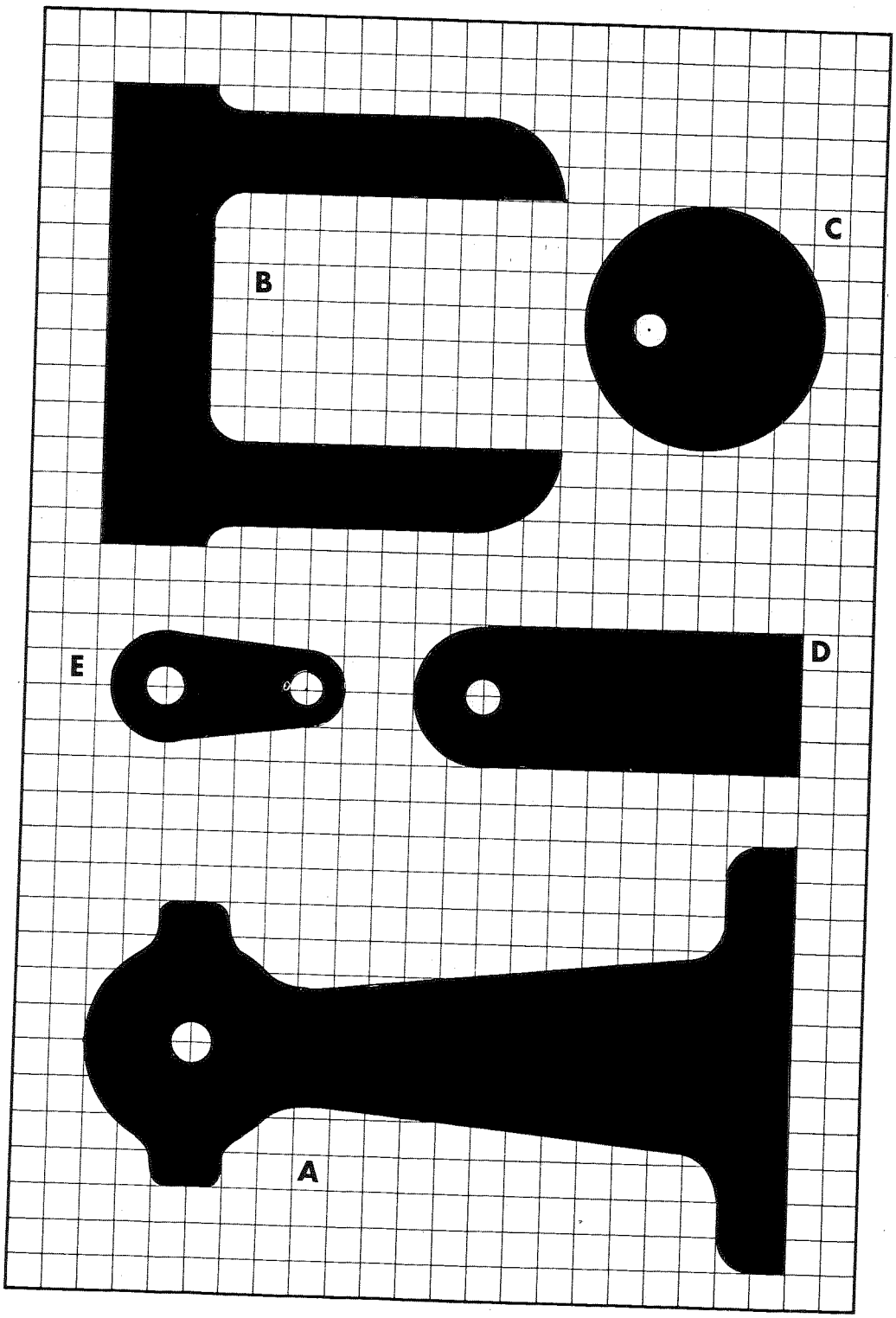


FIGURE 3-1B
The scale is four grid squares to 1".
A *Stanchions or pillars.*
B *Fork.*
C *Disk cam.*
D *Cam post.*
E *Crank.*

CUTTING LIST—PROJECT THREE

A	Stanchions or pillars	1 × 3 × 12 tulip
B	Fork	¾ × 3¼ × 4 cherry
C	Disk cam	⅝ × 2 × 2 cherry
D	Cam post	¾ × 1 × 3
E	Crank	¼ × 1 × 1¾ cherry
	Base	1 × 5½ × 7½ tulip
	Crank handle and end-of-rod pills	1 × 1 × 6 walnut
	Rods	24"—⅜" dowel

CHOOSING YOUR WOOD

This is one of those projects where you might—if you are pressed—reduce wood thickness to suit your stock or your wallet. For example, the base and the stanchions could be a bit thinner—say ¾" instead of 1"—while the fittings could be worked from offcuts.

We chose to use North American cherry for the cam, fork and crank; North American tulip for the base, stanchions, and one or two bits and pieces; and American walnut for the crank handle and rod-end pills.

MAKING THE BASE

1 Take the piece of 1"-thick tulip wood—the piece for the base—and with the grain running along the length, use the pencil, ruler and square to mark it at 7" × 5".

2 Set the compasses/dividers to ½" radius, and scribe out the 1"-diameter circles that make up the design of the corner curves (Fig 3-1a). Use the tools of your choice to cut the wood to shape and size.

3 When you have cut the base to size, use the graded sandpapers to rub down all faces and edges to a smooth finish. Pay particular attention to the top face and edges, and then pencil mark the underside.

MAKING THE STANCHION PILLARS

1 Draw the shape of the stanchions to size on the work-out paper, and then—being mindful that the grain must run from top to toe—use the pencil, ruler and compasses to mark the image on your chosen wood. Repeat the procedure so you have two identical images.

2 Having double-checked from pillar to pillar that the circle center-points, meaning the points that mark the center of the rod hole, are the same distance up from the baseline, use the scroll saw to cut out the two identical forms (Fig 3-2).

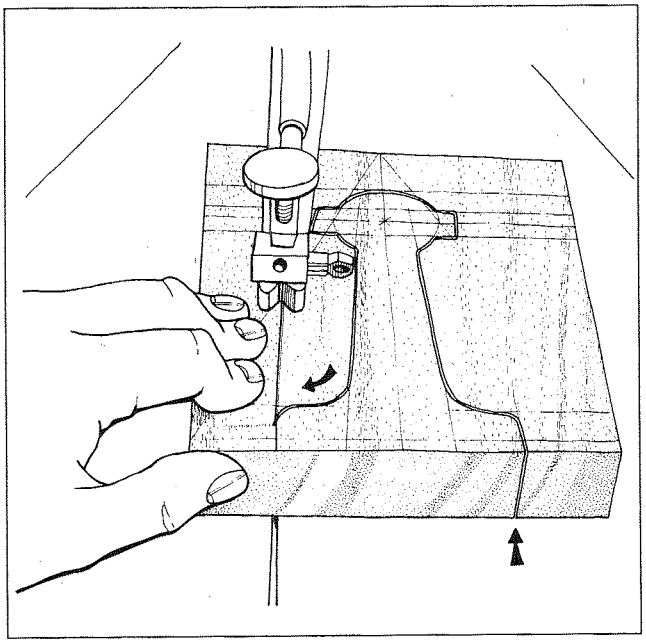


FIGURE 3-2
When using the scroll saw, control the rate of feed so the blade is always presented with the line of next cut. If the cut is ragged, the blade is too slack or the wood is too moist. If the wood is scorched, the blade needs changing or you are working at the wrong pace.

3 With the cutout securely clamped flat on the work surface, take the ¼" U-section carving gouge and lower the top-of-stanchion "lugs," or ear-like protrusions, by about ¼". Do this with both lugs on both faces, so when seen in edge-on view, the wood curves down from the face to a thickness of about ½" (Figs 3-3 and 3-1a).

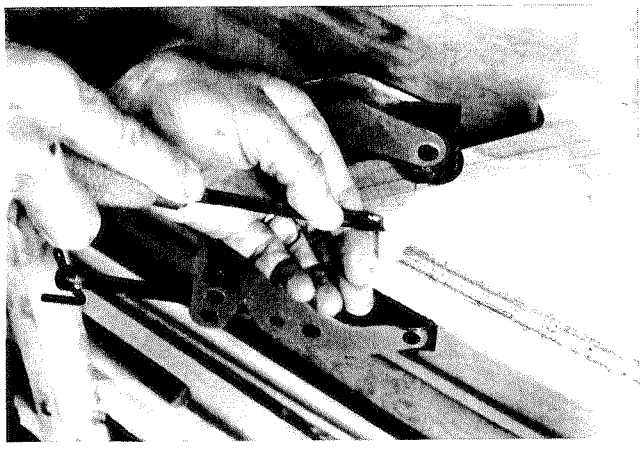


FIGURE 3-3
With the workpiece secured flat on the work surface—with a clamp or up against a bench stop—use the U-section gouge to carve the scooped shape of the side lugs.

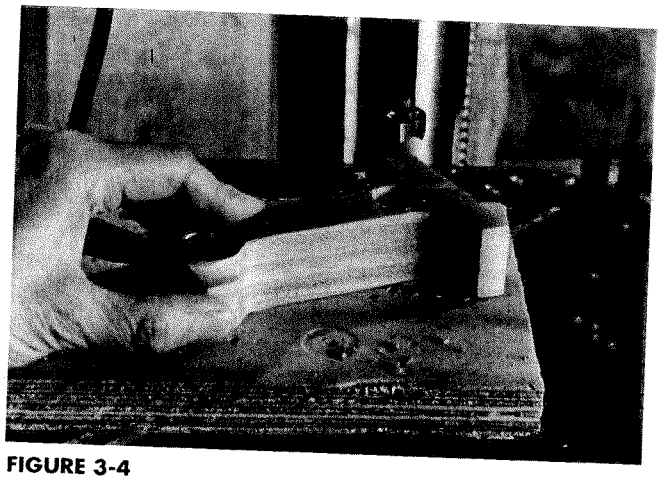


FIGURE 3-4

With the workpiece supported on a waster to prevent exit damage, bore out the ¼" bearing hole and the ¾" blind hole. Note: We have removed the clamp for the photograph.

4 When you have carved the lugs to shape so the circle at the top of the stanchion looks to be standing slightly forward, use the pillar drill and the Forstner bits to bore out a ¼"-diameter rod-bearing hole and the decorative ¾"-diameter blind hole. Aim for a blind hole at about ¼"-deep (Fig 3-4).

5 Take your fine-grade sandpaper—and bring all the edges to good order. Aim for edges that are slightly rounded.

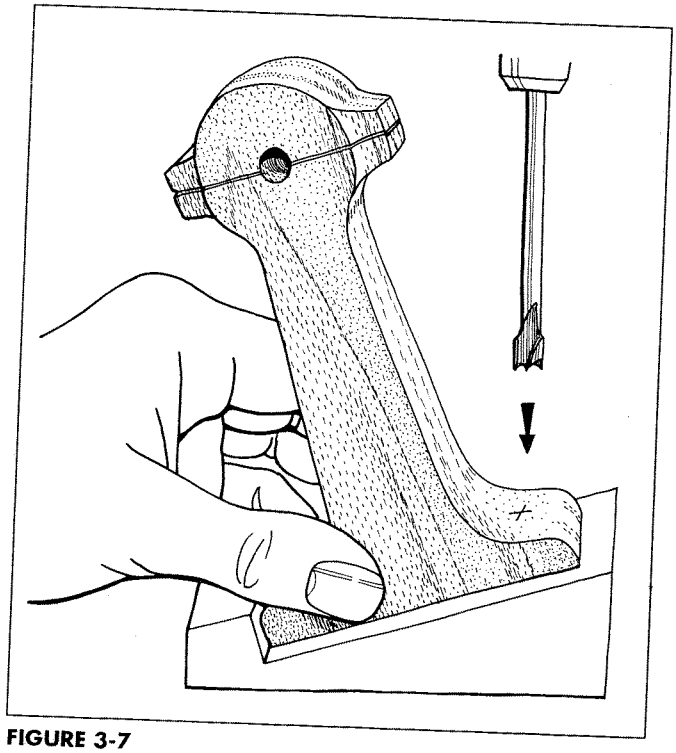


FIGURE 3-7

Make a simple wedge-and-stop jig to help you hold and support the workpiece while the hole is being drilled.

6 When the time comes to sink the decorative cut that runs around the top of the stanchion, firmly brace the workpiece against the bench hook, and use the fine-toothed saw to sink the cuts to a depth of about ⅛" (Fig 3-5).

7 Having drilled the two face holes, then comes the tricky task of drilling the lug and foot holes. I say tricky because with both the lug and the foot, the holes need to be run into a curved face. When you come to drill the lug hole—and bearing in mind that the drill bit will try to push the curved surface to one side—first set the workpiece square between a couple of heavy blocks, and then hold it in place with a good clamp. This done, run the ¼"-diameter hole through the thickness of the lug (Fig 3-6).

8 To drill the ¼"-diameter foot hole, set the workpiece on a stack of scrap so the hole is angled in toward center. Use a long, shanked bit so as to avoid contact between the chuck and the top of the pillar (Fig 3-7).

MAKING THE CAM POST

1 Have a look at the working drawing (Fig 3-1a) and template design (Fig 3-1b), and see that the controls, meaning the parts you turn, are made up of a fixed post, crank, crank handle, crank handle pin, or

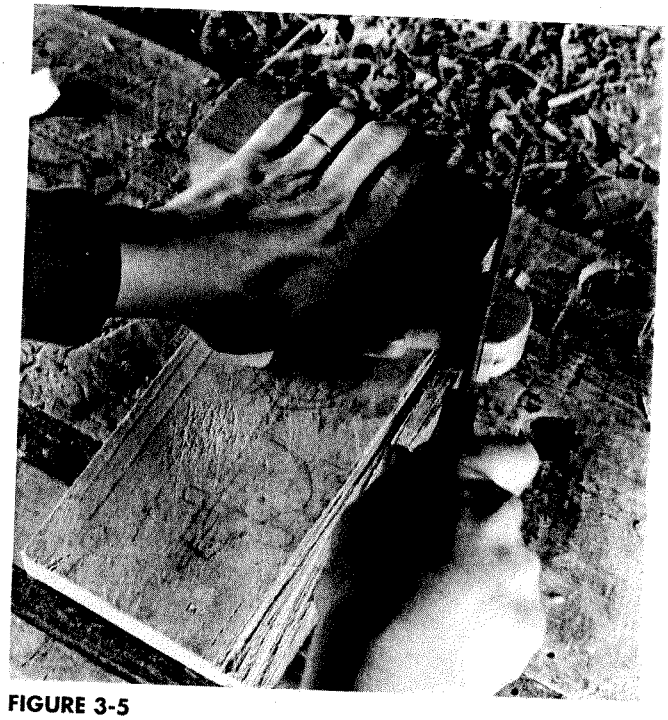


FIGURE 3-5

Firmly butt the workpiece against the bench hook, adjust the angle of cut so the saw runs against the side of the hook, and then sink the cut to a depth of about ⅛".

pivot, washer to distance the crank from the post, disk cam and pivot rod.

2 Mark the size and shape of the post on your chosen wood—we use tulip wood—double-check the dimensions, and then cut out the curved-top front view on the scroll saw.

3 Mark the position of the pivot rod hole, and run it through with the ¼"-diameter drill bit. It's important that the hole and the bottom of the hole are both square and true with the base, so aim to get it right the first time around.

4 Draw in the "feet"—as seen in side view—and then cut them out on the scroll saw (Fig 3-8).

TURNING THE HANDLE, PIVOT PIN AND ROD PILLS

1 Take the length of square section walnut, establish the end center points by drawing crossed diagonals, and set it securely on the lathe.

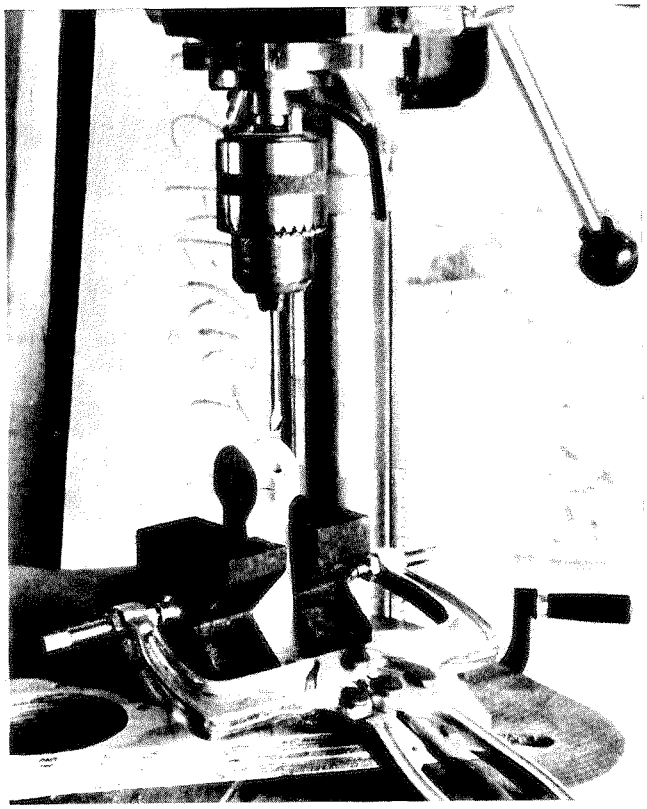


FIGURE 3-6

Clamp the workpiece between a couple of steel blocks so it is square with the surface and the drill bit, and run the lugs through with the ¼"-diameter bit. Note: If you like woodwork, you can't do better than set yourself up with a good selection of clamps. We have pincer action clamps for small work, toggle clamps for machine hold-downs and so on.

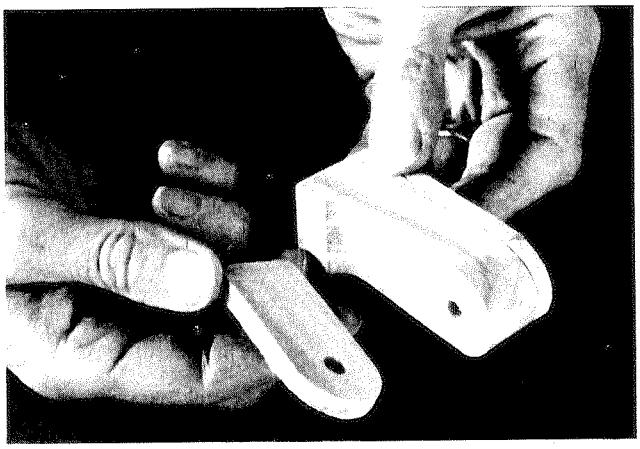


FIGURE 3-8

When you have cut out the little post in front view and drilled the rod hole, draw out the curved-foot, side-view design, and complete the cut on the scroll.

2 Having made sure you and the lathe are in good, safe order, swiftly turn down the piece of walnut to the largest possible diameter.

3 Use the dividers to mark all the step-offs that make up the design. Working from left to right along the turning, allow a small amount for headstock waste—either for the chuck or for parting off—about ¼" for the handle pivot head, ¾" for the pivot, 2" for the handle, 1" for one pill, ¼" for waste, 1" for the other pill, and a small amount for tailstock waste (Fig 3-9a).

4 Having first removed the bulk of the waste, use the round-nosed gouge and the skew chisel to turn down the wood to shape and size. Make repeated checks with the calipers (Fig 3-9b).

5 Turn and sand the string of turnings to a good finish, and carefully part off from the lathe.

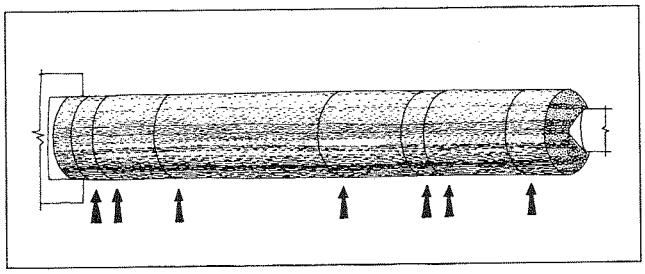


FIGURE 3-9A

Use the dividers to mark the cylinder with all the step-offs that make up the design. Working from left to right along the workpiece, allow ¼" for chuck, ¼" for the mushroom head, ¾" for the pivot shank, 2" for the handle, 1" for the first pill, ¼" for waste, 1" for the second pill, and a final small amount for waste.

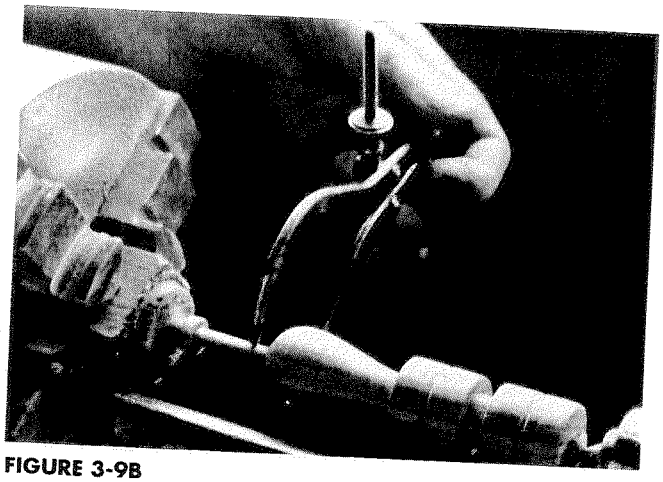


FIGURE 3-9B

Use the calipers to check the diameters against the working drawings. Note: If you are working with a limited number of drill bit sizes, be sure to adjust the width of the pivot shank to suit your chosen bit diameter.

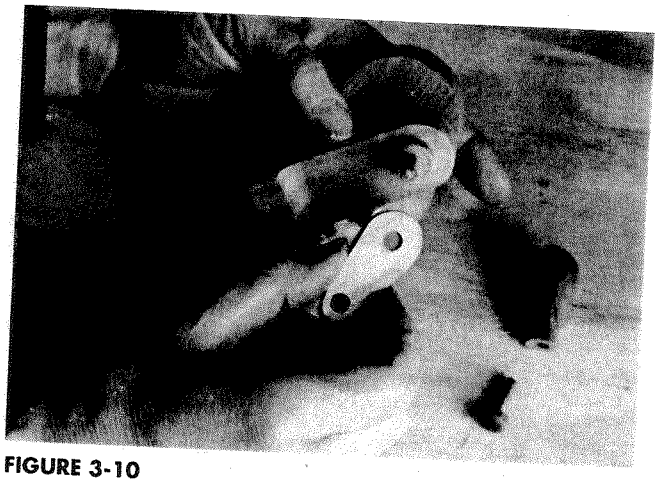


FIGURE 3-10

Have a trial fitting to make sure all the control column parts come together for a smooth-working fit.

MAKING THE CRANK, HANDLE AND CAM

1 Take a ¼"-thick piece of cherry offcut and use a pencil, ruler and pair of compasses to draw the shape of the crank and the little washer spacer. Plan on the crank being about 1" between centers (Fig 3-1b).

2 With all the lines of the design clearly established, first run ¼"-diameter holes through the crank and the spacer, and then use the scroll saw to cut out the shapes. While the drill is convenient, run a hole into the turned handle to a depth and size to suit your turned mushroom-headed peg.

3 When you make the disk cam, you can either cut it out with a scroll saw or turn it on the lathe, as long as it's 1¾" in diameter, about ¾" thick, and as near as possible to a perfect circle.

4 When you have what you consider is a good disk—nicely sanded to a smooth finish—run it through with a ¼"-diameter shaft hole, and then have a trial fitting (Fig 3-10).

5 If you have followed our directions to the letter, you will need to adjust selected holes or parts of the dowel shaft to achieve a suitable fit. For example, the handle peg needs to be a tight fit in the handle and a loose fit through the crank. Then again, the dowel shaft needs to be a tight fit in the crank and disk cam, while being a loose, easy fit through the little stanchion (Fig 3-11). Play around with the fit until you get it right.

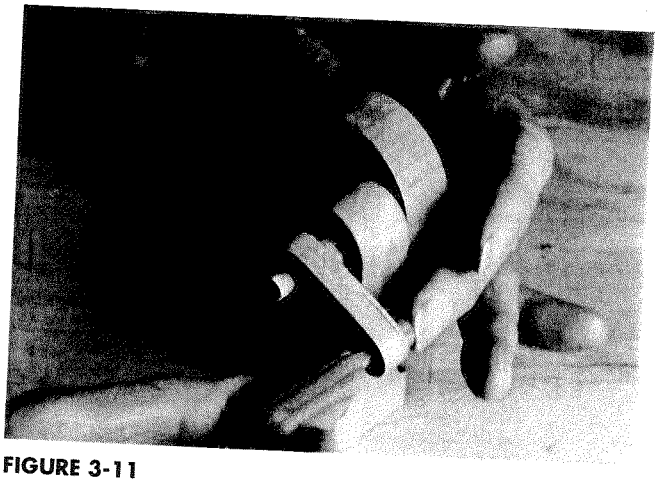


FIGURE 3-11

If need be, sand the holes or dowels to achieve an appropriate fit. The little pivot needs to be a loose fit through the shank and a tight push fit in the handle.

MAKING THE FORKED FOLLOWER

1 If you have a look at the working drawing (Fig 3-1a) and template design (Fig 3-1b), you will see that the forked follower, or frame, is cut from ¾"-thick wood, with the grain running from top to bottom and the inside fork width being the same as the diameter of the disk cam.

2 Having drawn the frame on your piece of prepared wood, give it a good checking over just to make sure you haven't made any mess-ups, and then carefully fret out the frame on the scroll saw.

3 If you take it at an easy pace, all the while being ready to pull back if the blade snatches, the cut face will be so smooth it will only require the minimum of sanding.

4 Take the cutout and carefully draw diagonals to establish the position of the through-top rod, or shaft, hole.

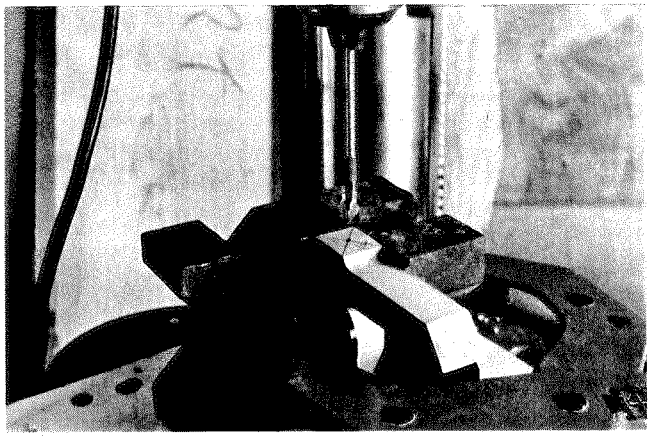


FIGURE 3-12
Drilling the rod hole through the top of the forked frame is slightly tricky inasmuch as while the hole needs to run square and true, most drill bits are too short. A good method is to establish the center points for the holes, clamp the workpiece to a square iron block, and then run the holes through from both sides.

5 Hold the workpiece secure with blocks and a clamp so the hole is going to be well placed and true, and run it through with a long, shanked ¼" bit (Fig 3-12). If your bit isn't long enough, turn the whole works around, and drill it through from the other side.

PUTTING TOGETHER AND FINISHING

1 When you have completed all the component parts that make up the design, then comes the exciting but finger-twisting task of putting everything together. You should have ten primary parts in all: the base, two bearing posts, disk cam post, disk cam, washer, crank, handle, handle pin, two end-of-rod pills, or stops, and a whole heap of dowels cut to size (Fig 3-13).

2 Before you do much else, take the finest-grade sandpaper and rub down all faces, edges and corners to a smooth finish. Give all the surfaces—barring the mating faces that are to be glued—a swift rubdown with a small amount of teak oil.

3 Having cut all the rods and dowels to length, spend time rubbing them down with a scrap of sandpaper so they are an appropriate fit and all the on-view ends are nicely rounded. Have all the ends standing slightly forward by about ¼"-⅜".

4 When you have generally brought everything to good order, start the fitting by pegging and adjusting the three posts.

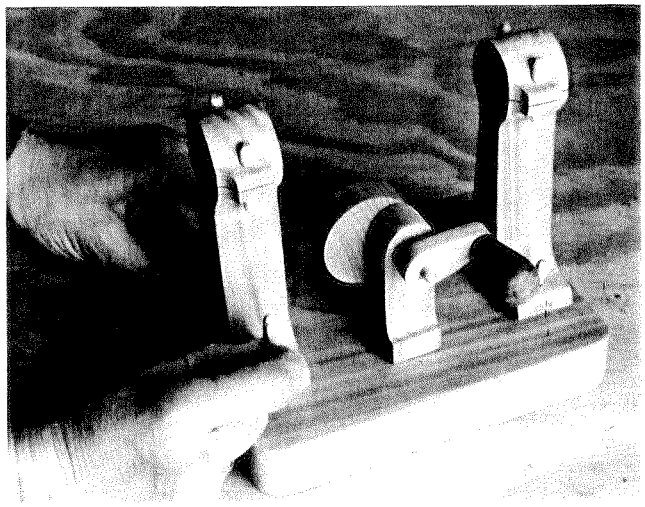


FIGURE 3-14
Align the three posts so they are true, and fix with the pegs.

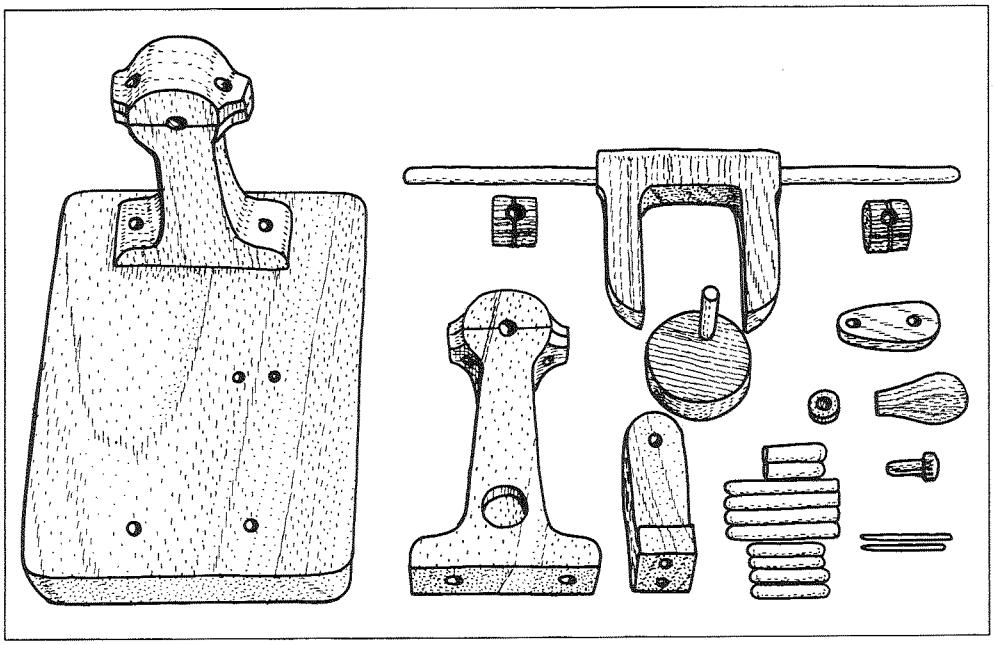


FIGURE 3-13
When you have completed all the component parts that make up the project, check all the measurements against the working drawing and template design, and then sand all the surfaces down to a good, smooth finish.

5 Glue, peg and fit the disk cam, crank and handle, and carefully adjust one with another so they are square and perfectly aligned (Fig 3-14).

6 Slide the forked follower on its rod, and peg or glue. Slip the ends of the rods through the bearings so the fork straddles the disk cam (Fig 3-15).

7 With all the parts variously glued or pegged in place, test for squareness, make sure the machine works, and then put it to one side until the glue is set (Fig 3-16). Finally, give the whole works another rubdown with the teak oil, and then the fun can begin!

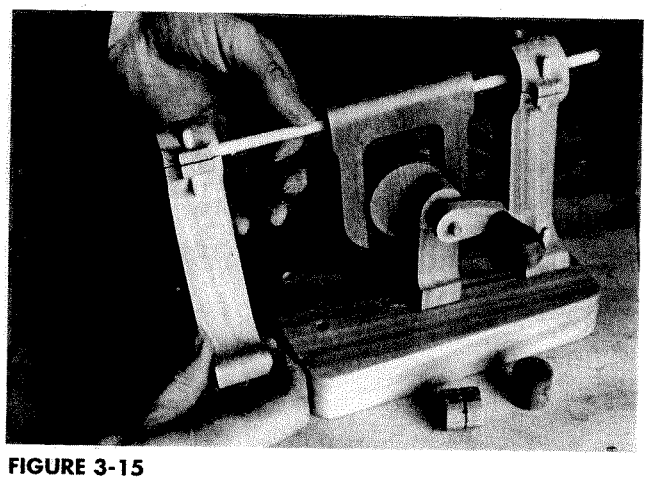


FIGURE 3-15
Slide the forked frame over the cam, and fit the other post. Note how the top of the frame has been rounded.

PROBLEM SOLVING

■ If you like the idea of this project but want to change the design, no problem, as long as you make sure the cam and fork are compatible.

■ Having made the project, Gill thinks the base and the stanchions would look even better if they were cut from slightly thinner wood. That said, I like the thickness of the wood, but I am not so keen about its color and texture.

■ If you want to make the project but can't get use of a lathe, settle for making the crank handle from a shop-bought dowel.

■ As the distance between the side ends of the forked follower and the inside faces of the stands is critical—the machine won't work unless it's right—make sure everything is smooth running before you glue up.

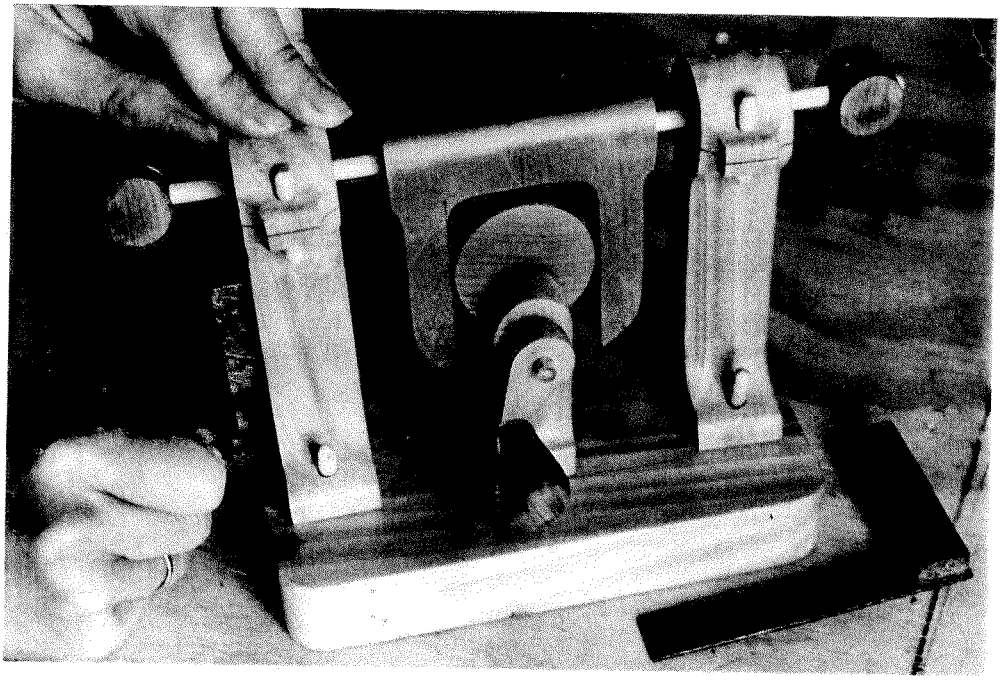
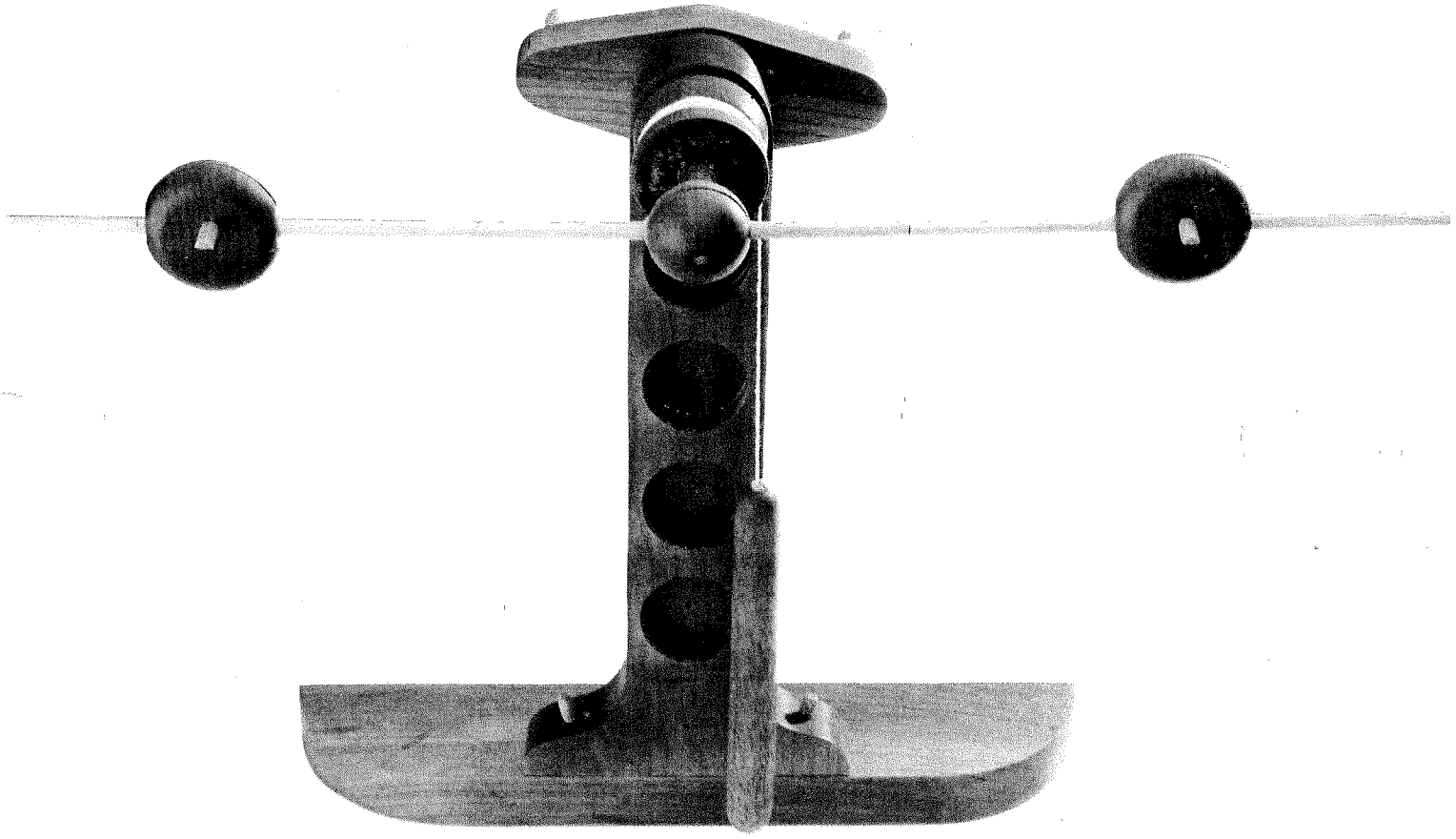


FIGURE 3-16
When you've finally put the whole machine together, spend time making sure all components are square and true to each other.

PROJECT ONE

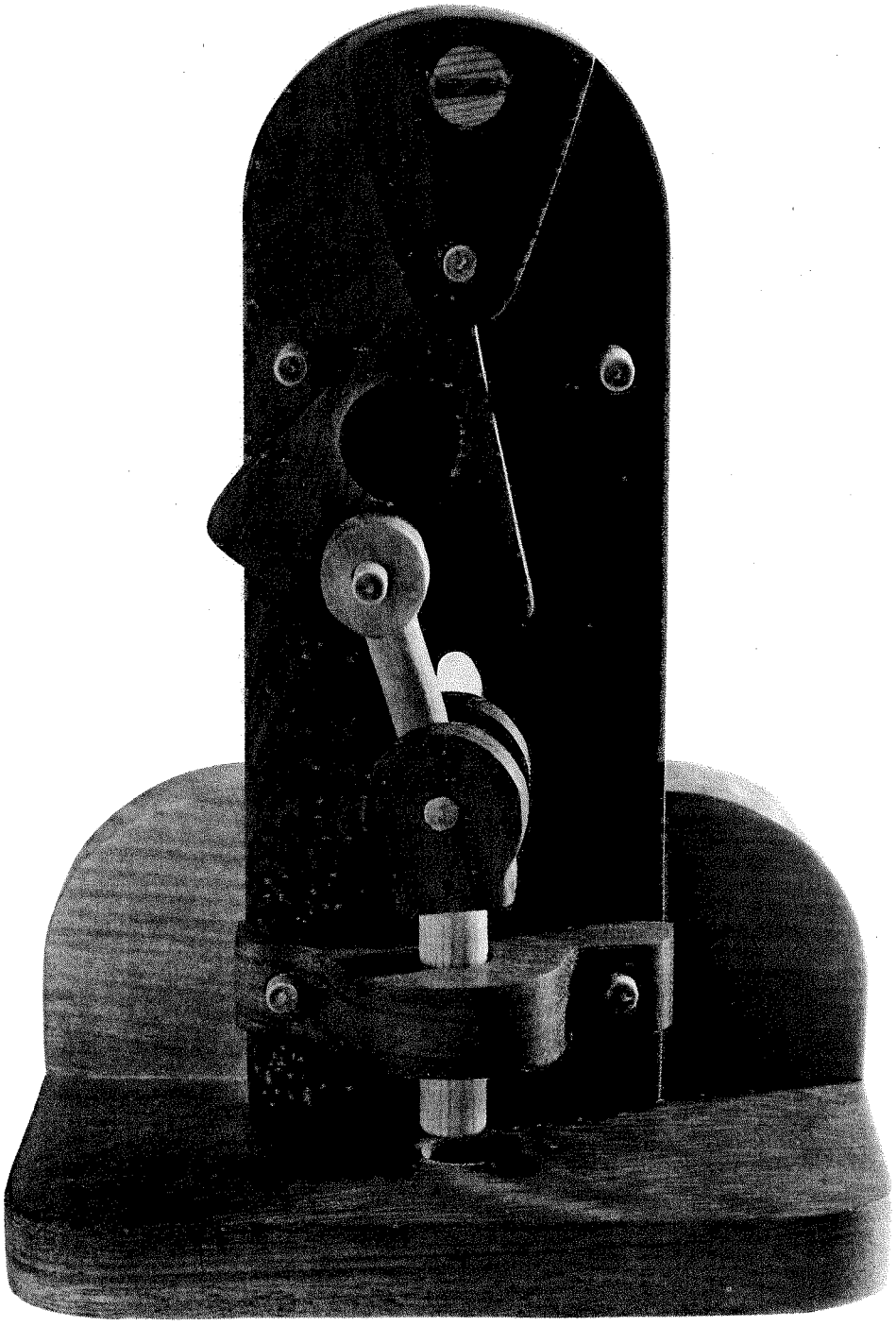
Circular Movement Machine



Instructions for building this project begin on page 1

PROJECT TWO

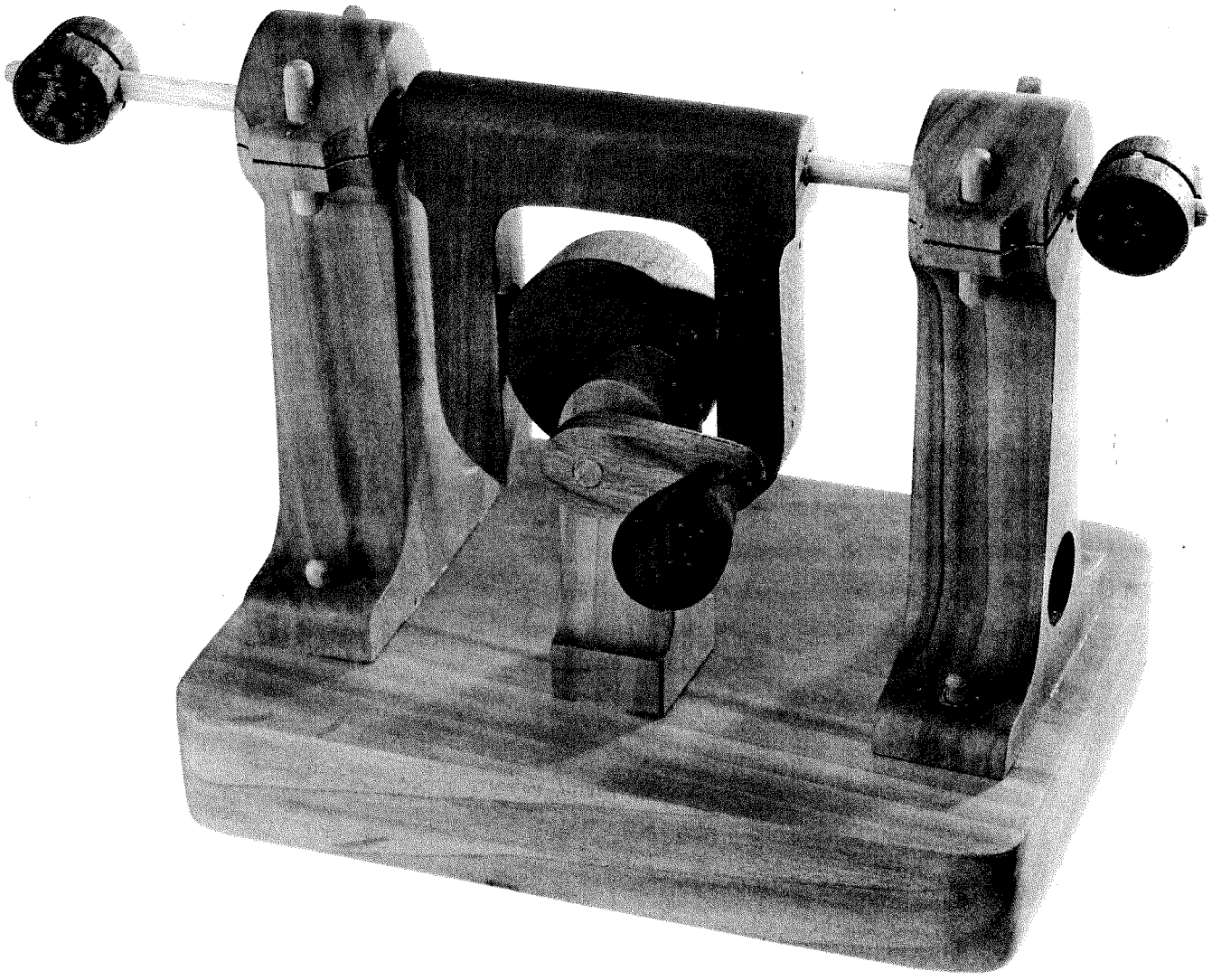
Harmonic Oscillation Punch Machine



Instructions for building this project begin on page 9

PROJECT THREE

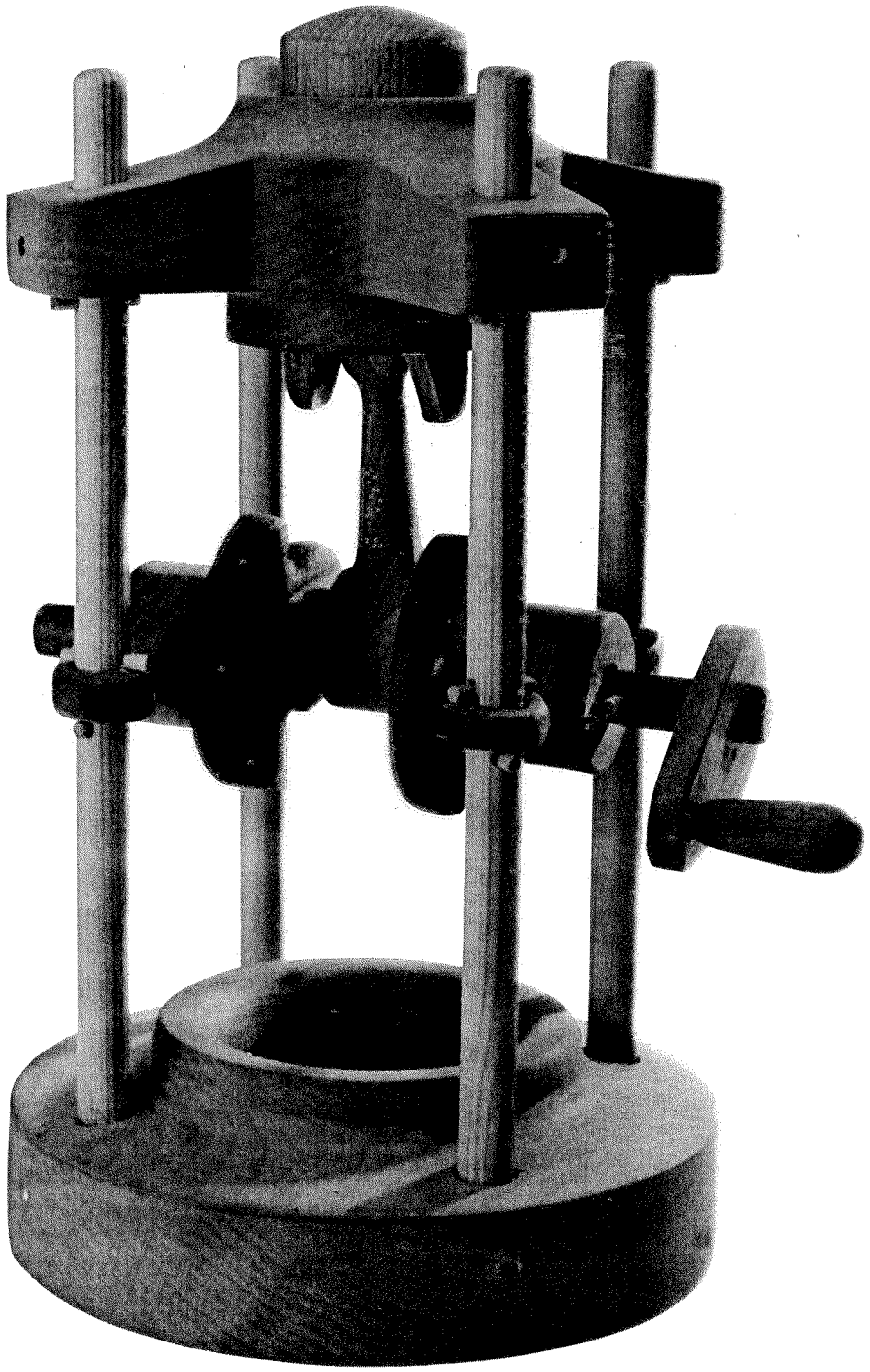
Cam and Fork Machine



Instructions for building this project begin on page 18

PROJECT FOUR

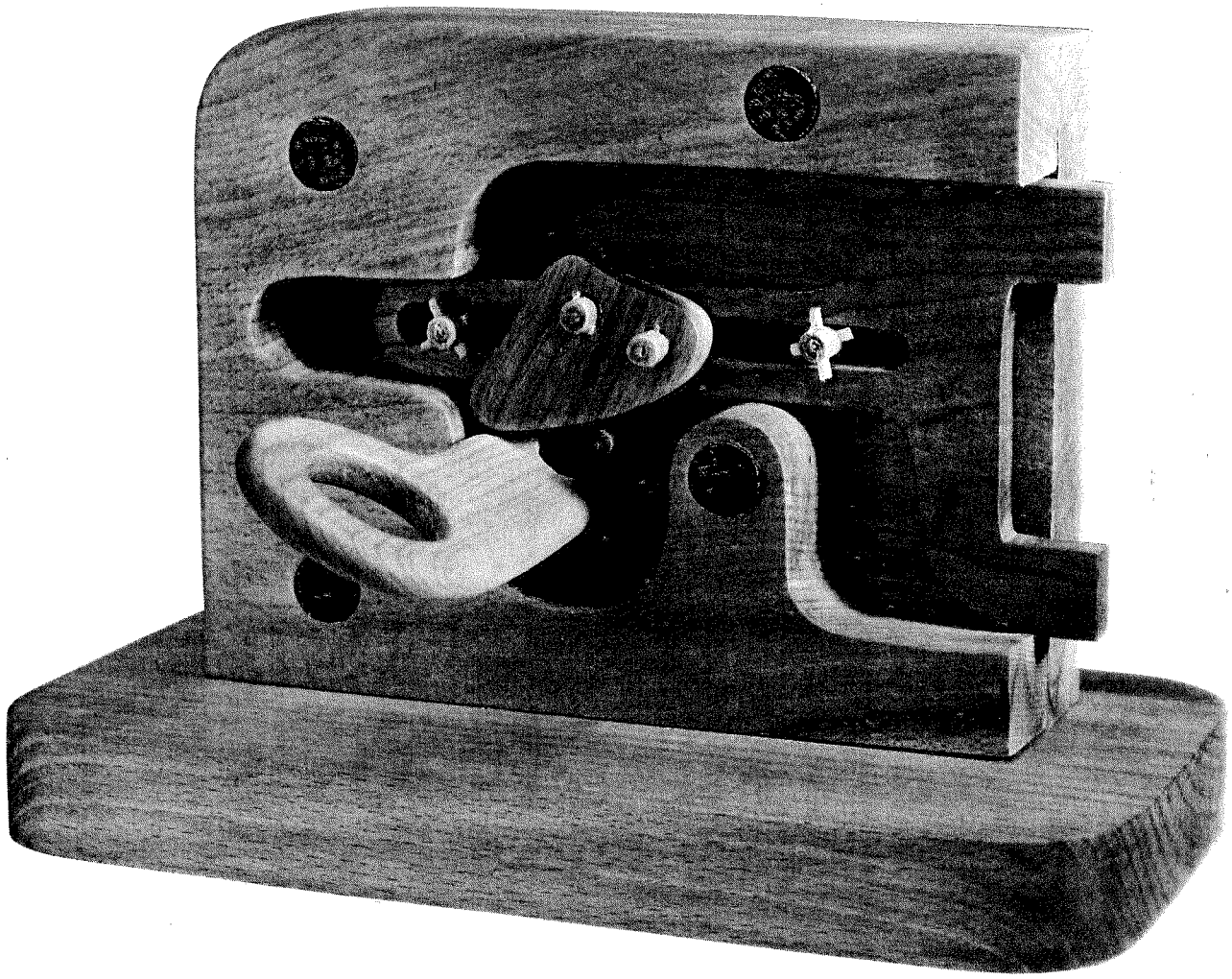
In-the-Round Combustion Engine



Instructions for building this project begin on page 42

PROJECT FIVE

Ward Lock and Key



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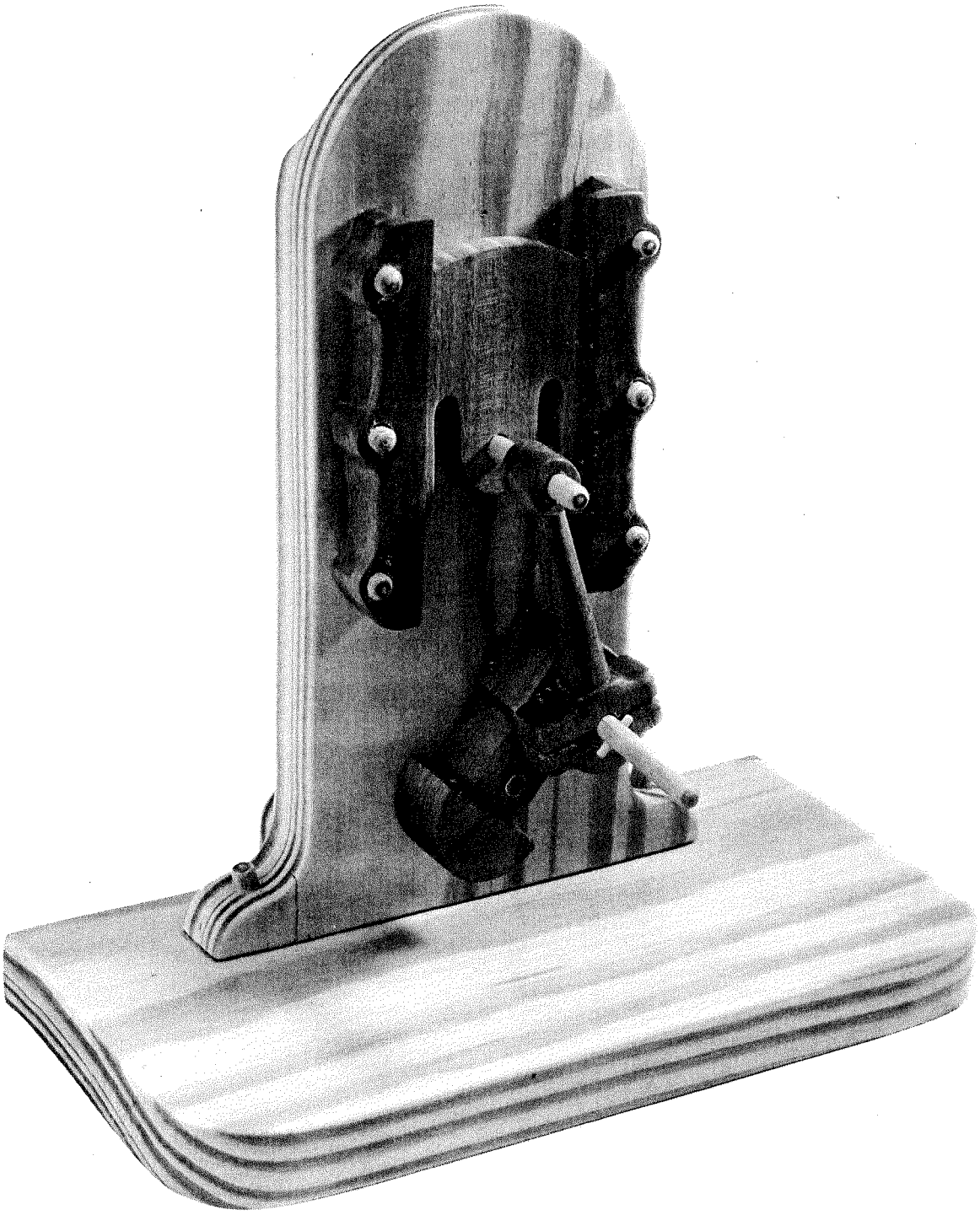
PROJECT SIX

Reciprocating Engine



Instructions for building this project begin on page 59

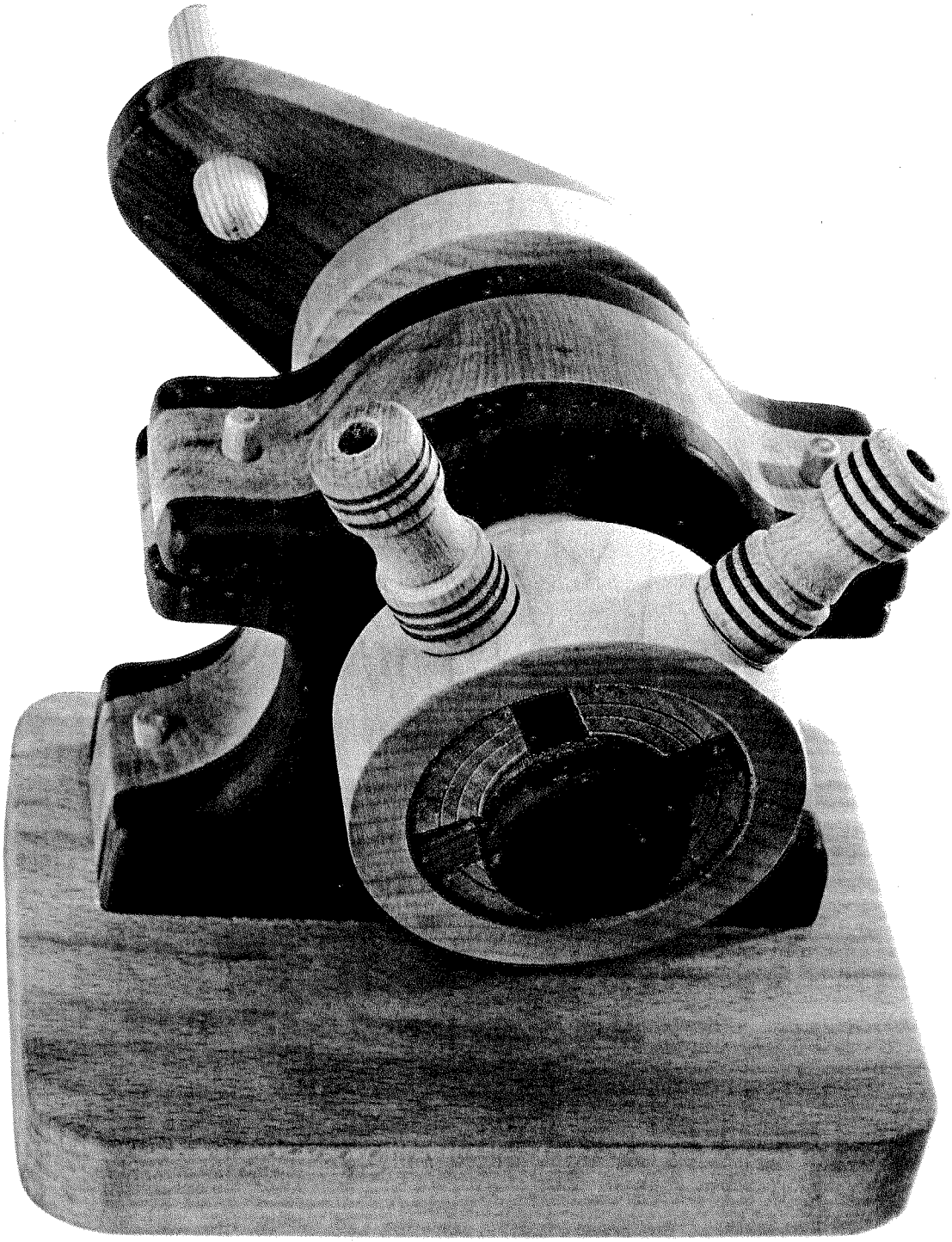
PROJECT SEVEN

Oil Pumping Rig

Instructions for building this project begin on page 66

PROJECT EIGHT

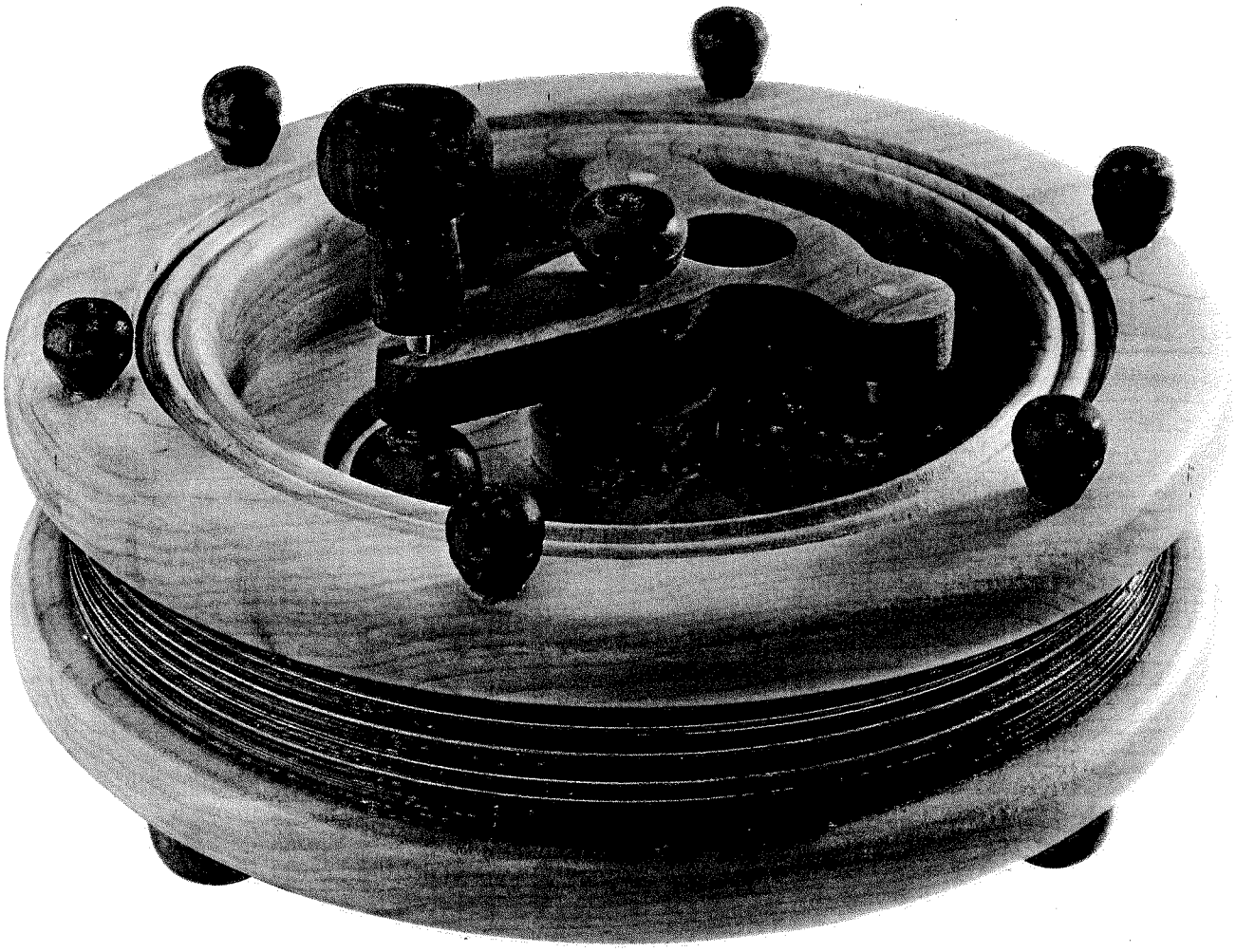
Centrifugal Impeller Pump



Instructions for building this project begin on page 73

PROJECT NINE

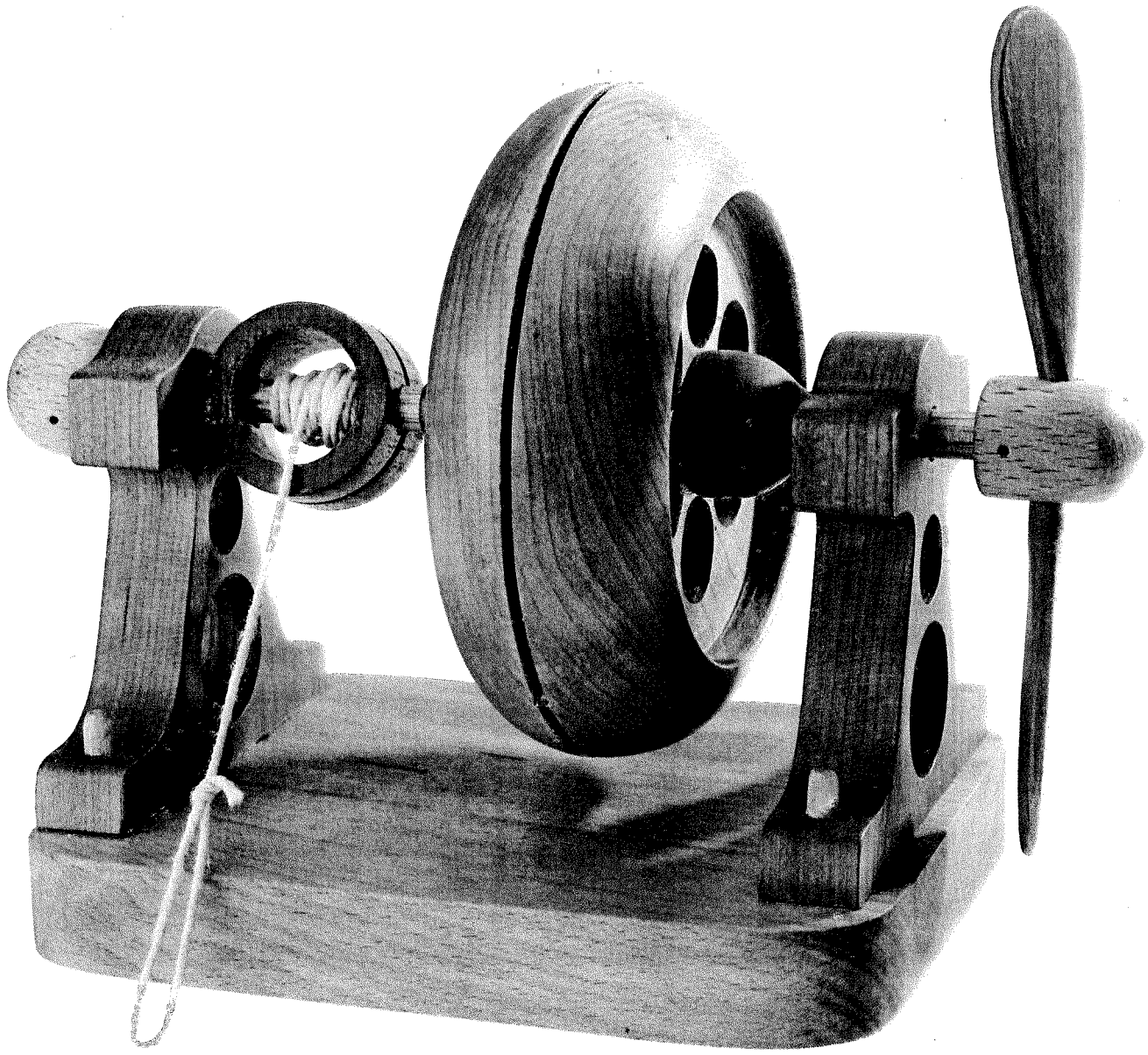
Sector Wheel Bearing Machine



Instructions for building this project begin on page 81

PROJECT TEN

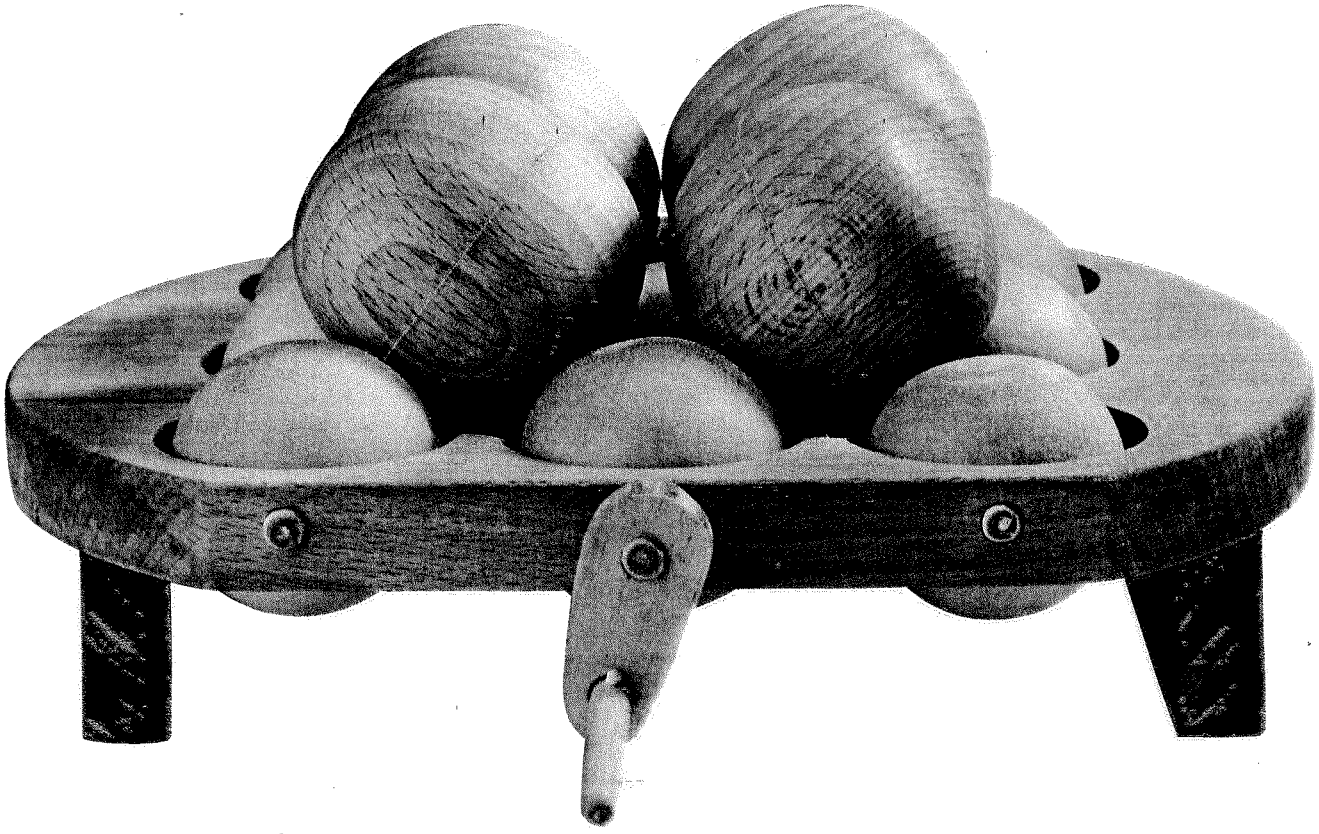
Flywheel Propeller Machine



Instructions for building this project begin on page 89

PROJECT ELEVEN

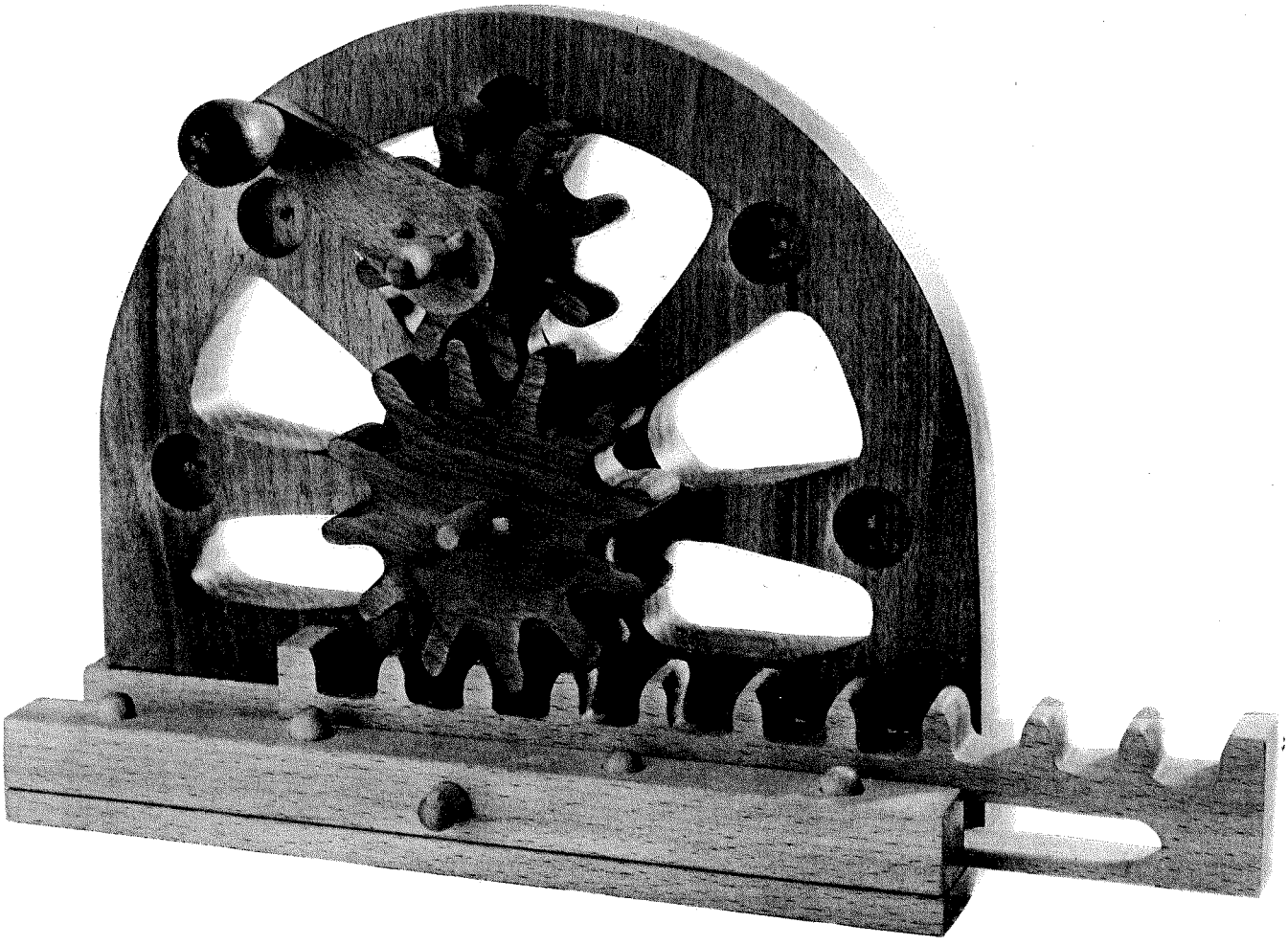
Pyramid Roller-Ball Machine



Instructions for building this project begin on page 98

PROJECT TWELVE

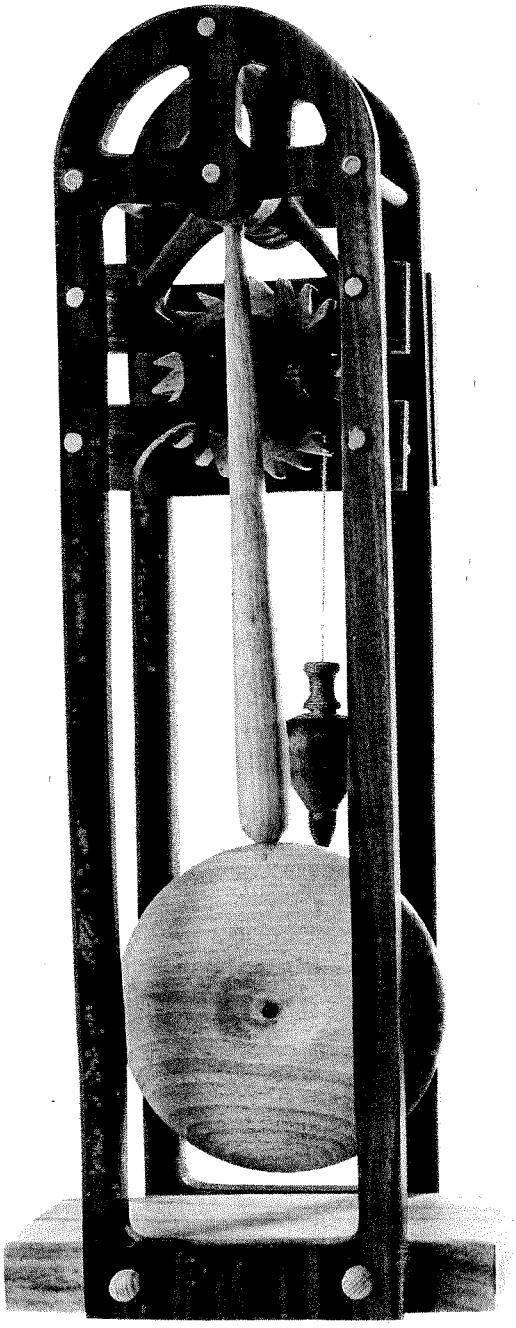
Rack and Pinion Machine



Instructions for building this project begin on page 106

PROJECT THIRTEEN

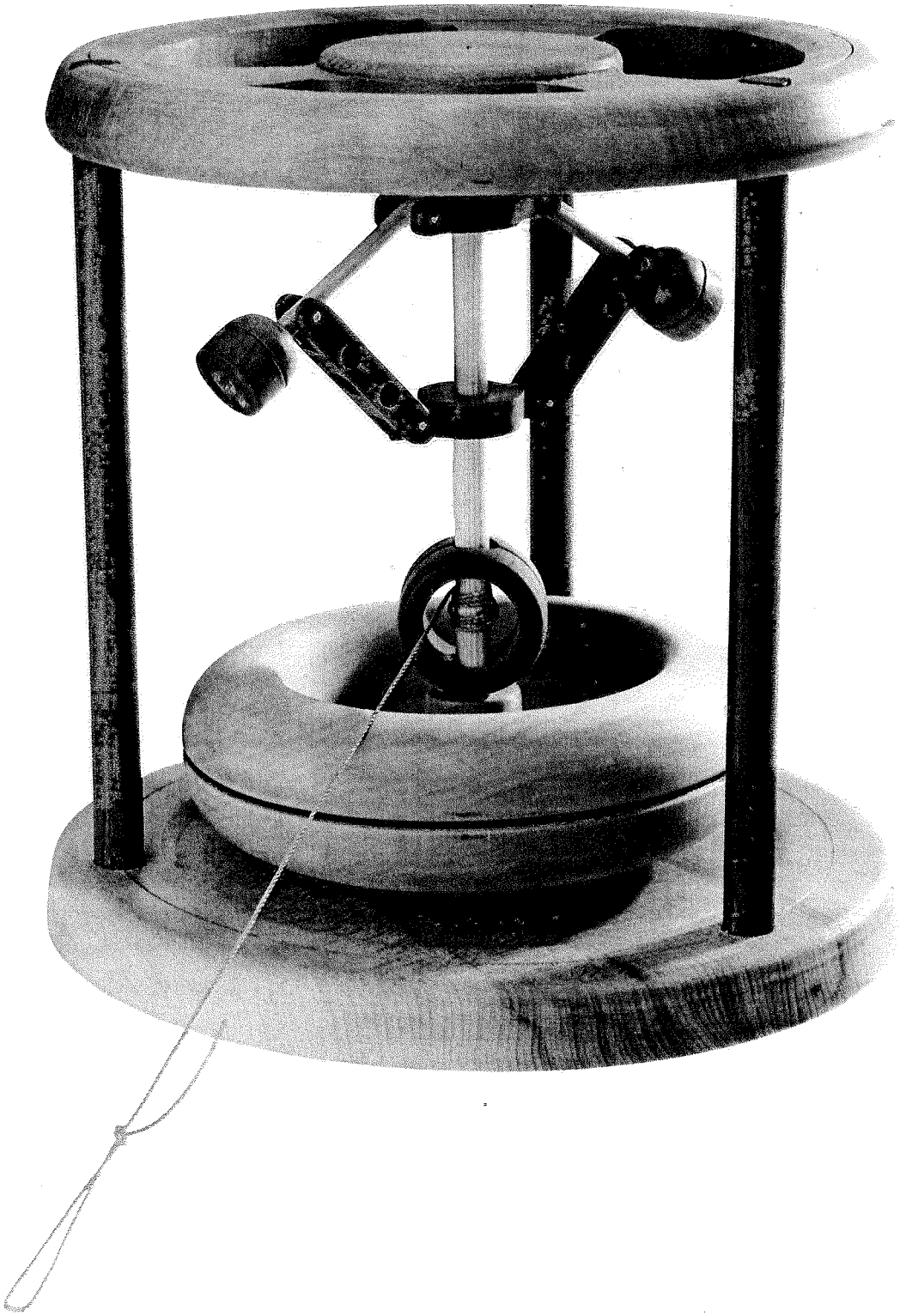
Pendulum Recoil Escapement Machine



Instructions for building this project begin on page 112

PROJECT FOURTEEN

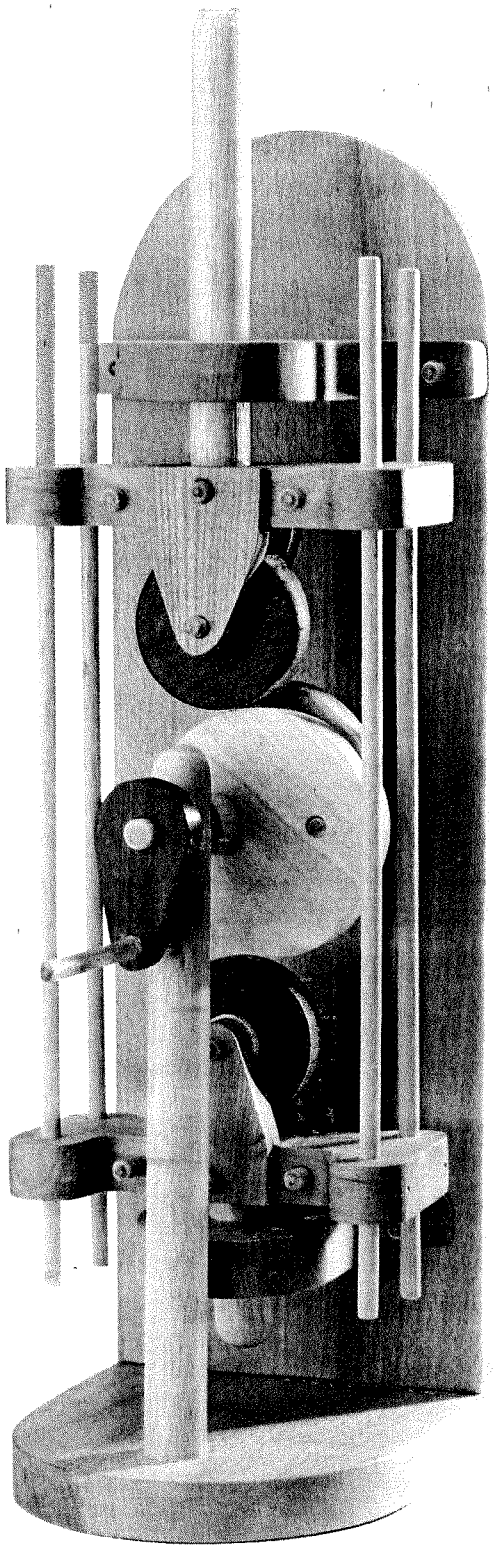
Flywheel and Governor Machine



Instructions for building this project begin on page 121

PROJECT FIFTEEN

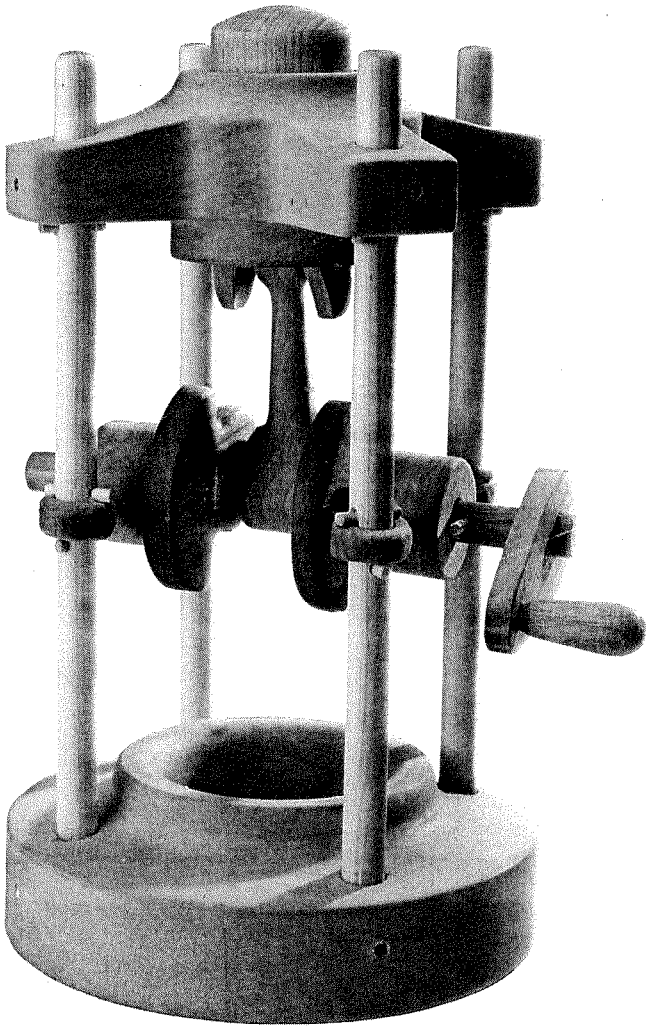
Cam Machine



Instructions for building this project begin on page 130

PROJECT FOUR

In-the-Round Combustion Engine



Color photo page 30

PROJECT BACKGROUND

Although the in-the-round combustion machine is in essence much like the reciprocating machine, as shown in project six, it is in many ways all the more exciting in that it can—like a piece of sculpture—be seen and enjoyed from all angles. The turn-handle movement attractively illustrates how the up-and-down operation of a piston is converted, by way of a crank, into rotary motion (above).

PROJECT OVERVIEW

Have a look at the working drawing (Fig 4-1) and the template design (Fig 4-2), and see that at a grid scale of two squares to 1", the machine stands almost 12" high and over 6" wide across the span of the drive shaft. Consider that the greater part of the machine is made up of three beautifully complex turnings: the base, which is drilled and hollow turned; the quatrefoil top, which is both drilled and fretted halfway through the turning stage; and the cylinder, which is turned, drilled and then sawn.

Though the project is challenging, a lot of the tricky procedures relate not so much to your skill level, but to your equipment. Modify the stages to fit your tool kit. OK, so it might take a lot longer, but then, the pleasure is in the doing!

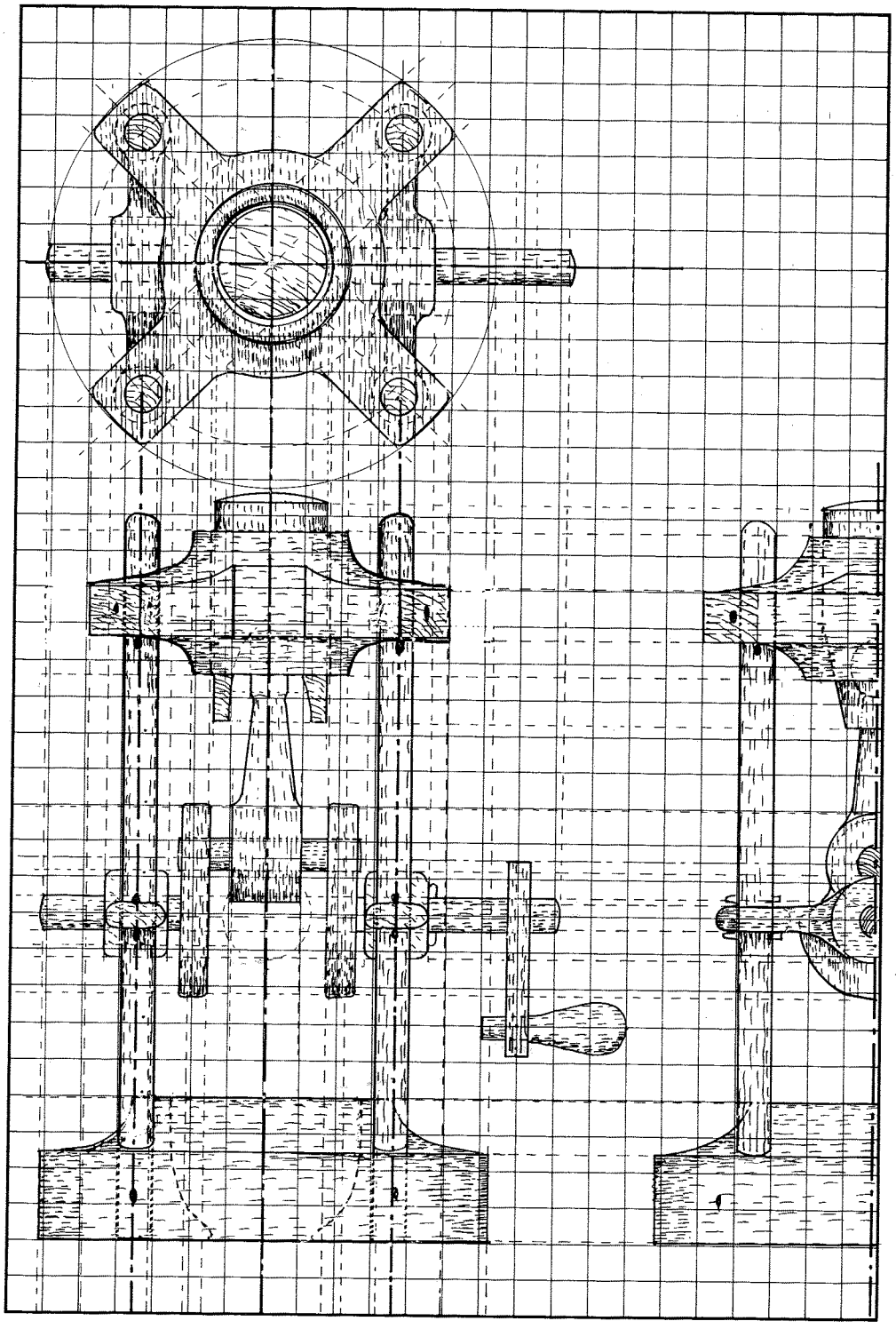


FIGURE 4-1
At a grid scale of two squares to 1", the machine stands almost 12" high and about 6" wide across the diameter of the base.

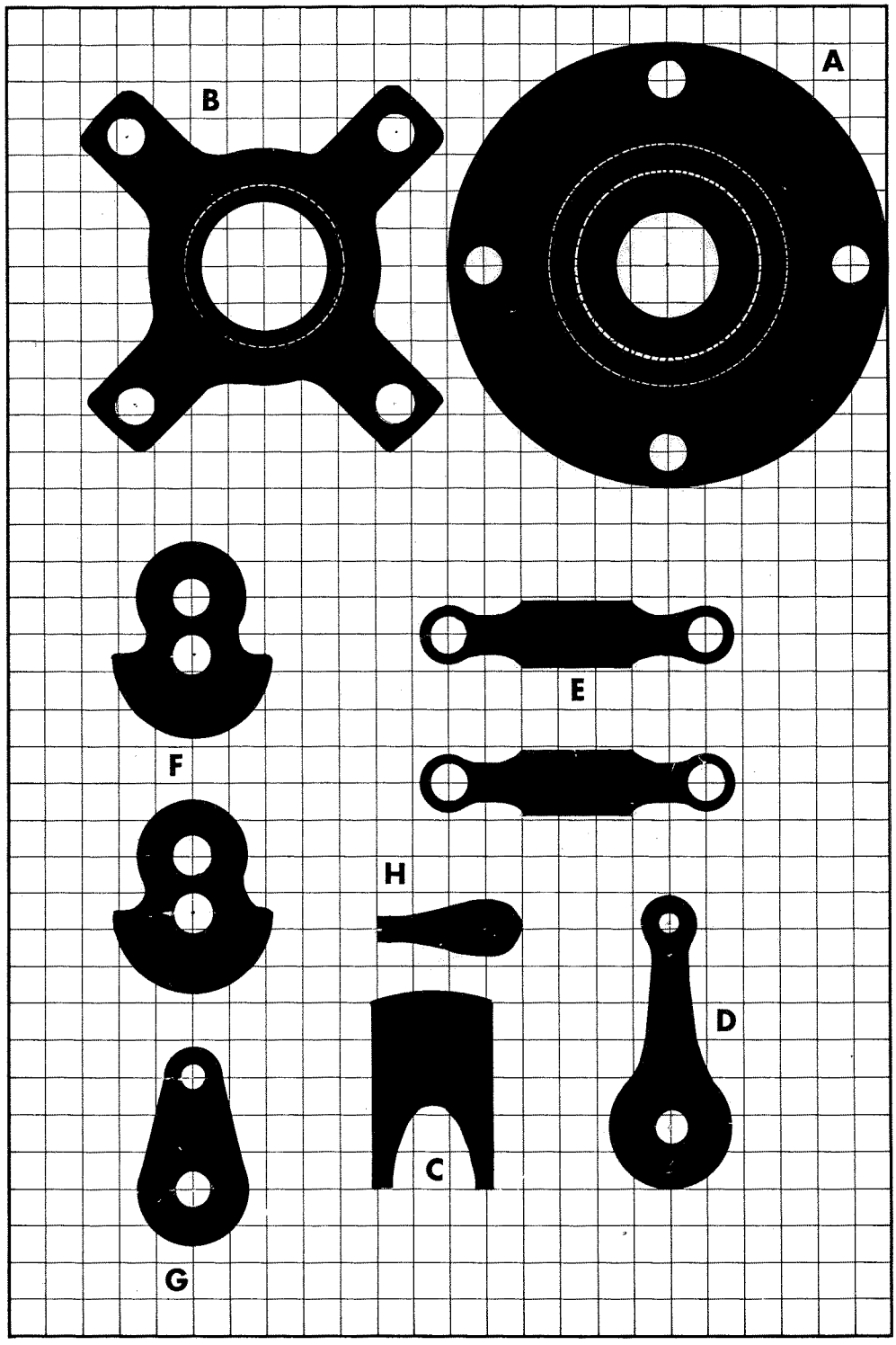


FIGURE 4-2
The scale is two grid squares to 1". Note that we have only shown what we consider are the most difficult-to-visualize views.
A *Base.*
B *Top.*
C *Piston.*
D *Piston rod.*
E *Crankshaft bearings (2).*
F *Crank plates.*
G *Handle crank.*
H *Knob.*

CUTTING LIST—PROJECT FOUR

A	Base	2 × 7 × 7 easy-to-turn lime
B	Top	2 × 7 × 7 easy-to-turn lime
C	Piston	2½ × 2½ × 6 beech
D	Piston rod	1¼ × 1½ × 5 beech
E	Crankshaft bearings (2)	1 × 3½ × 6 cherry
F	Crank plates	⅜ × 3 × 7 cherry
G	Handle crank	⅜ × 1½ × 2¾
H	Knob	2"—¾" dowel
	Stand rods and shaft	60"—½" dowel

CHOOSING YOUR WOOD

This is one of those projects where the choice of wood is all important; it's got to be just right. We have chosen European beech for the piston, because it's easy to turn and yet strong across the short grain, and lime for the base and top, because it's both easy to turn and easy to work on the scroll saw.

MAKING THE ENGINE CASE AND BASE

1 Have a good, long look at the working drawing (Fig 4-1) and template design (Fig 4-2), and see that the quatrefoil component at the top of the engine—we call it the engine or piston case—is both turned on the lathe and worked with the saw and drill. Note also the shape of the base.

2 Take one of the 2"-thick slabs of lime and fix the center point by drawing crossed diagonals.

3 Mark the slab with a 6½"-diameter circle. Cut away the waste on the scroll saw or band saw. Screw the resultant disk on the 6" faceplate using short, fat screws.

4 With the tool rest set over the bed of the lathe, turn down the wood to a smooth 6"-diameter disk and true up the face.

5 Use the dividers to mark the disk with a 2½"-diameter circle, and then turn down the waste so the 2½" circle stands up as a ½"-high plateau (Fig 4-3).

6 Mount the drill chuck on the tailstock, fit the 1⅝" Forstner bit, and run a hole through the center of the plateau (Fig 4-4).

7 Mark the lowered area with a couple of guideline circles, one at about ½" from the edge, for the postholes, and one about ⅜" outside the plateau, for the profile line.

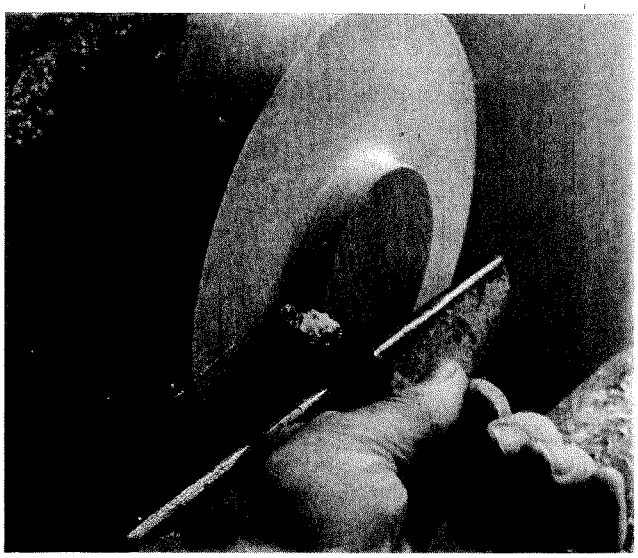


FIGURE 4-3
Mount the blank on the lathe, and turn down the edge and profile. See how I use a round-nosed scraper for the inside curve.

8 Having first rubbed down the turning to a smooth finish, take it off the lathe—off the faceplate—and set to work on the turned face of the wood, drawing in all the lines that make up the quatrefoil design. Pencil label the turned face "bottom," fix the position of the four postholes on the guideline circle—at 90° intervals—and establish the shape of the crossarms. Make the arms about 1¼" wide and all the corners and angles nicely rounded (Figs 4-1 and 4-2 top).

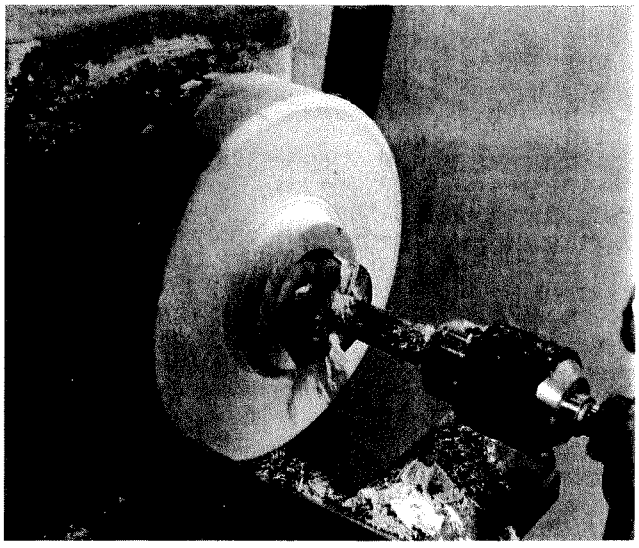


FIGURE 4-4
Bore out the piston hole with a Forstner bit. Advance and retreat with the tailstock so as not to burn or clog the bit.

9 Run the holes through with the ½"-diameter drill bit, and cut the quatrefoil profile out on the scroll saw (Fig 4-4a).

10 When you have completed the cross—all drilled and cut—mount it on the expanding jaws option of the chuck, and set to work turning down what will be the "top" face (Fig 4-5). I used the small, round-nosed gouge and the round-nosed scraper.

11 Rub down the whole works with the fine-grade sandpaper. Do one face of the turning, then turn it over on the chuck and do the other face. If you rub down one face as it points toward the bed of the lathe plus the difficult-to-reach face between the whole piece and the chuck, you will find that the change of direction ensures that all the edges are well rounded.

12 Having achieved a well-turned and finished component, redo the same procedures and turn the base. That is to say, turn down the wood to a 6½" disk and run a 1⅝" borehole through the disk.

13 Turn down the top-of-base profile so the underside rim of the cross is a neat fit in the hole (Fig 4-6).

14 Take the whole works off the lathe—the turning on the faceplate—set the cross component in place so the cross plateau is in the hole, and then use the four holes on the cross to drill four matching holes through the base (Fig 4-7).

15 Finally, remount the base on the lathe and drill, and turn the profile in much the same way as already described. Check your turning against the working drawing (Fig 4-1 bottom).

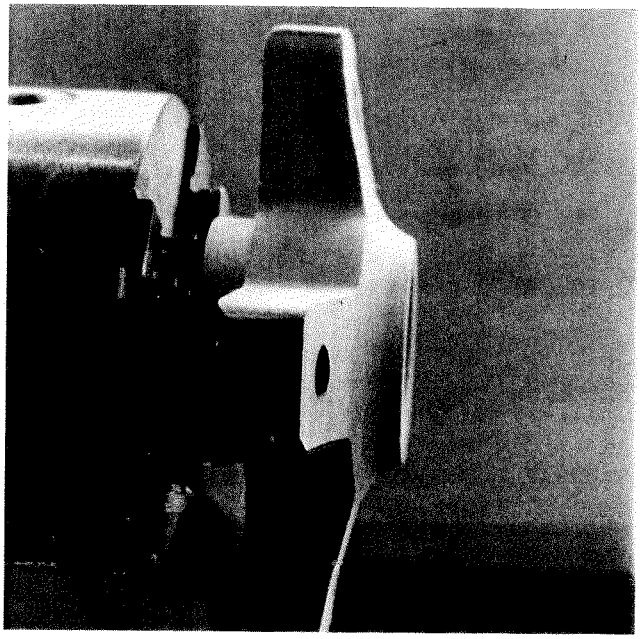


FIGURE 4-5

With the workpiece held securely on the expanding jaws of the chuck, use a round-nosed tool to turn down what will be the underside of the casing. Go at it nice and easy, all the while being mindful that this is a stage that needs to be worked with extreme care and caution.

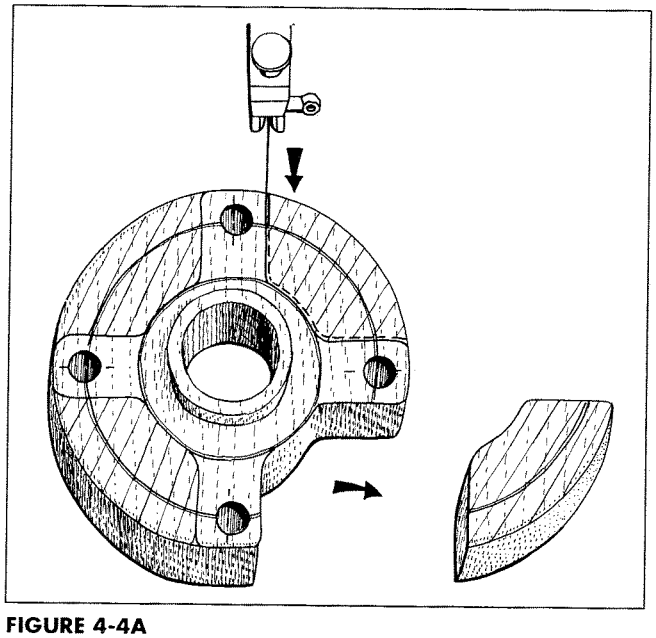


FIGURE 4-4A

Having drawn the quatrefoil profile, use the scroll saw to clear the waste. Have the workpiece flat on the cutting table so the cut faces are at right angles to the working face.

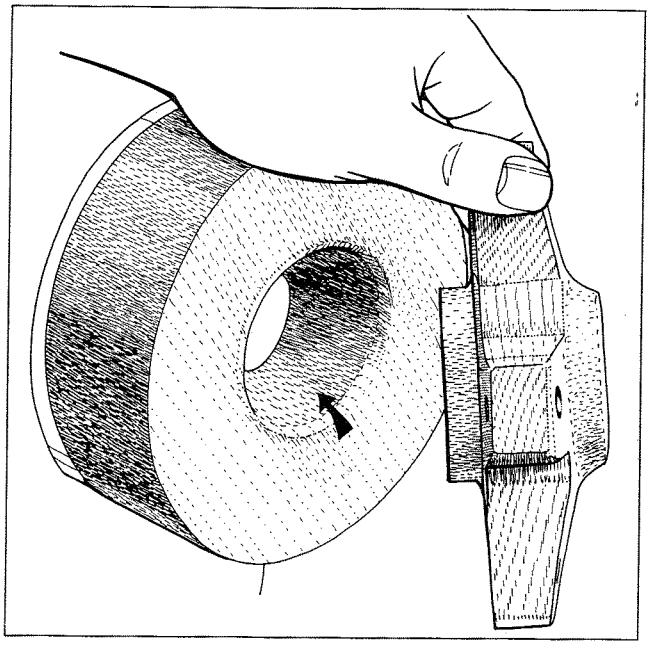


FIGURE 4-6

Turn out the base hole until the neck of the top casing is a nice slide fit.

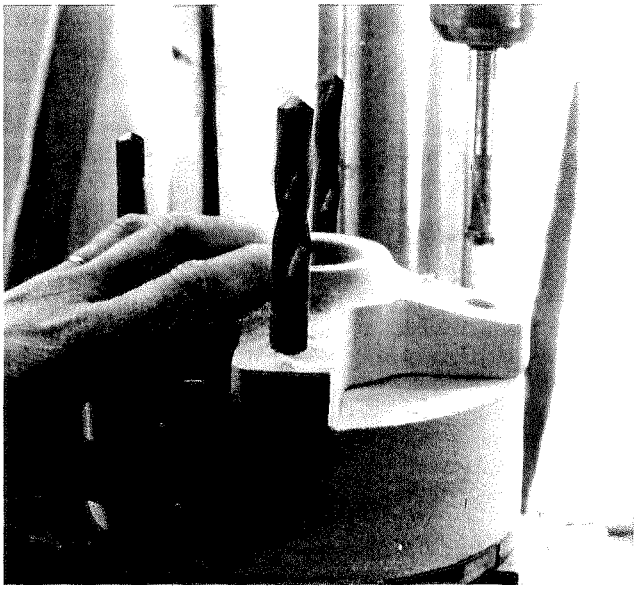


FIGURE 4-7
With the base still screwed to the faceplate, and using the quatrefoil casing as a pilot guide, bore out the four postholes.

MAKING THE CRANKSHAFT BEARINGS

1 When you have studied the working drawing (Fig 4-1) so you know what you are doing, take the 1″-thick piece of cherry and use the pencil, ruler, square and compasses to mark the design as seen in side view.

2 With all the lines in place, and having first established the exact position of the various holes—both the bearing holes and the postholes—bore the holes out with the ½″-diameter bit. Be careful when you run the postholes down through the 1″ thickness of the wood; be sure they are well aligned and true.

3 Take the wood, all marked and drilled, and set to work fretting out the two side-view profiles (Fig 4-8).

4 Mark the plan-view imagery out on the newly revealed cut faces, and then begin shaping and sculpting with the scroll saw, knife and tube rasp (Fig 4-9).

5 Continue whittling, rasping and sanding until you have what you consider are two well-matched forms (Fig 4-10).

MAKING THE CRANK AND CONNECTING ROD

1 Have a look at the working drawing (Fig 4-1), template design (Fig 4-2) and the various photographs, and see that the crank is achieved by having two identical plates and offset dowels.

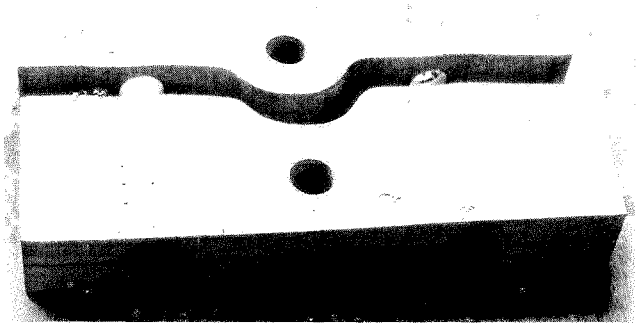


FIGURE 4-8
See how the postholes run through the thickness of the wood.

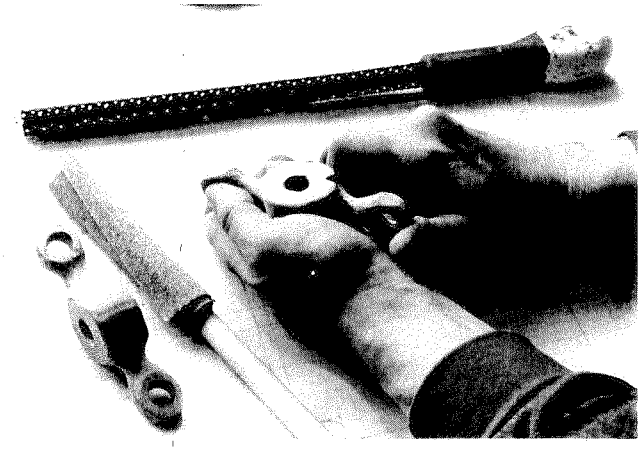


FIGURE 4-9
Use the knife, rasp and sandpaper to whittle the crankshaft bearings to shape. Be careful not to force the blade at the relatively fragile short-grained areas.

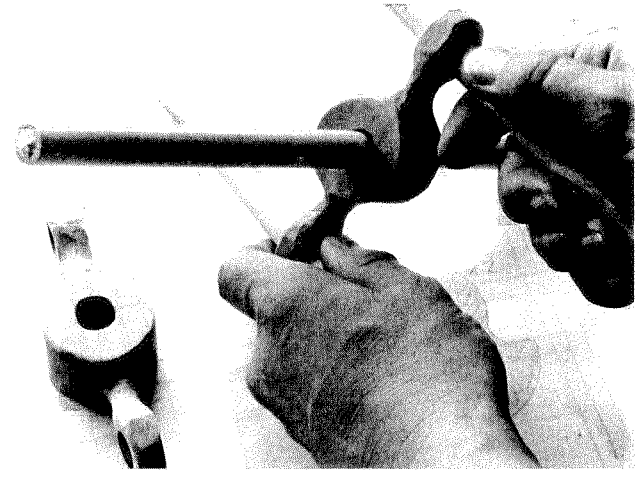


FIGURE 4-10
Have repeated fittings until the components come together for a good fit.

2 Cut the ⅜″-thick cherry into two crank-sized pieces, draw the imagery out on one of the pieces, and then fix them together with a single pin at one corner. Keep the pin out of the design area.

3 Bore and dowel plug the two ½"-diameter shaft holes right through both pieces of wood, first one hole and then the other. Use lengths of scrap dowel.

4 With the holes in place, begin fretting out the crank shape on the scroll saw. Work at a steady, even pace, all the while feeding the wood into the blade so the line of cut is a little to the waste side of the drawn line (Fig 4-11).

5 Having first drawn the shape of the connecting rod on the 1"-thick cherry and variously fixed the position of the rod holes, fret out the connecting rod profile as drawn (Fig 4-12).

6 Draw the side-view imagery of the rod on the sawn face, mark in the waste, and then slice it off on the saw (Fig 4-13).

7 Use the knife and rasp to shape the connecting rod. Take your small, sharp knife and whittle the straight part of the rod to a roundish section. The best technique is to set the circle lines of the ends in with a stop-cut on both sides of the wood and at both ends and then to carefully slice the blade into the stop-cut so the waste falls away.

8 When you have shaped and lowered the round section so the flat faces of the end circles stand somewhat in relief, take a scrap of sandpaper and generally rub down the whole workpiece to a smooth, slightly round-edged finish.

9 When you have finished fretting and shaping the connecting rod, and drilled out the two holes, go back to the crank plates and wedge the ½" shaft dowels in place (Fig 4-14). The dowels have to run true, so spend time making sure everything is aligned.

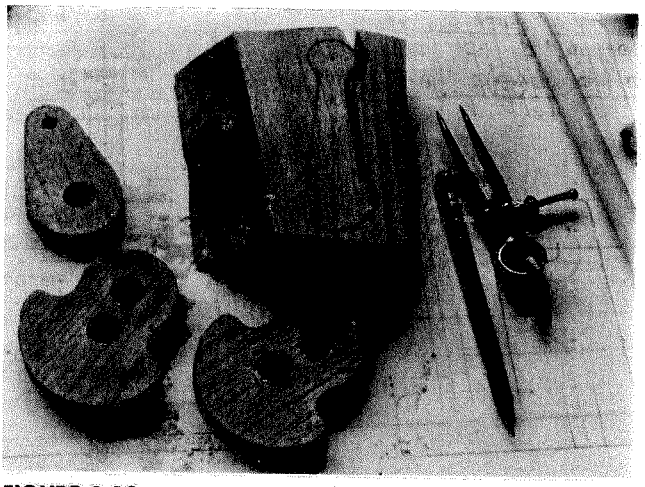


FIGURE 4-12
While you are busy at the scroll saw, you might as well fret out the connecting rod and crank handle.

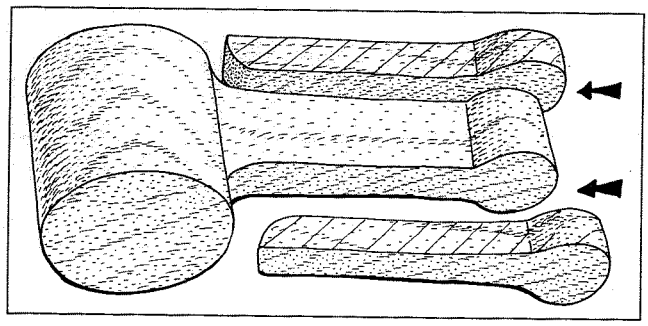


FIGURE 4-13
Slice away the connecting rod waste—as seen in top view.

MAKING THE PISTON

1 Set your chosen square section length of wood on the lathe, and use the large gouge to swiftly turn down the wood to a diameter of 1¾". If all is correct and as described, 1¾" will be slightly larger than the hole that runs through the cross-shaped unit at the top of the engine.

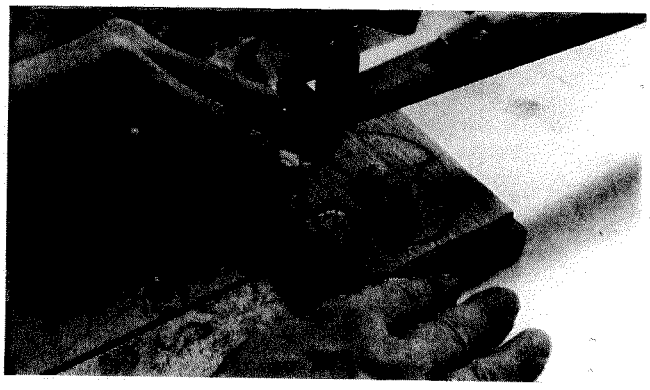


FIGURE 4-11
Fitting the single pin and two dowels at the presaw stage ensures that the two crank plates are identical mirror-image cutouts.

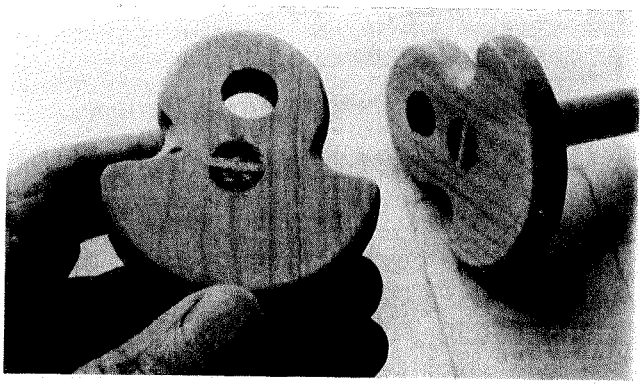


FIGURE 4-14
Slot and wedge the drive shaft stubs into the crank plate. Don't glue at this stage.

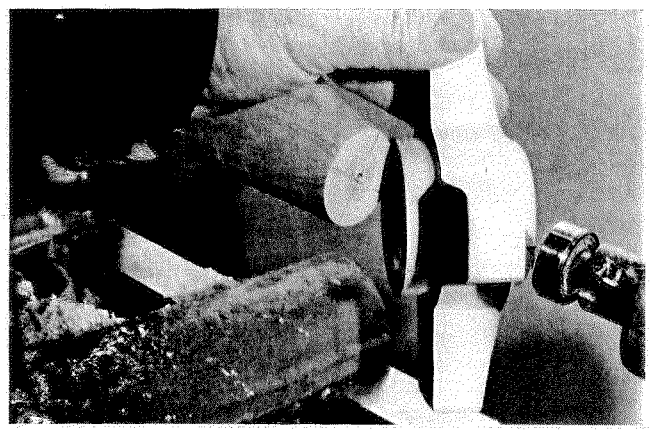


FIGURE 4-15
When you think the piston turning is to size, wind back the tailstock and have a trial fitting.

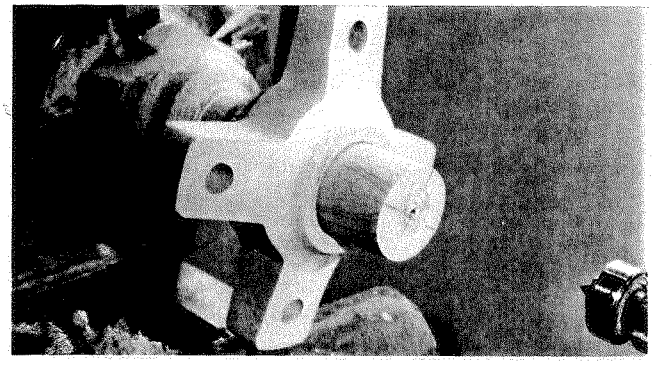


FIGURE 4-16
Aim for a nice, smooth-sliding fit.

2 This done—and having first set the calipers to the exact diameter of the crosspiece hole—take the skew chisel and turn down the piston so it is an easy-slide fit in the case hole. The best procedure is to carefully draw the tailstock out of the way and then to try the cross casing on for size (Figs 4-15 and 4-16).

3 Fit the tailstock drill chuck on the lathe, and use the 1⅛"-diameter bit to run a hole down into the cylinder (Fig 4-17).

4 Push the piston through the scroll saw—or you might prefer to use a handsaw—and take an angled slice from each side (Figs 4-18 and 4-2).

5 Run a pencil guideline up, down and around the piston, and drill out the ¼"-diameter pinhole—through one side and out the other. It might be a good idea to plug the center of the piston with a length of waste to minimize exit damage.

6 Have a trial fitting of the small end of the connecting rod in the piston (Fig 4-19).

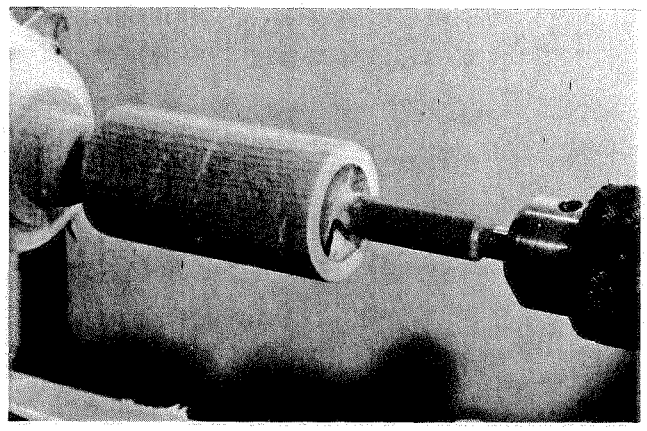


FIGURE 4-17
Use the tailstock drill chuck to bore out the piston waste. Advance cautiously so as not to knock the workpiece off-center.

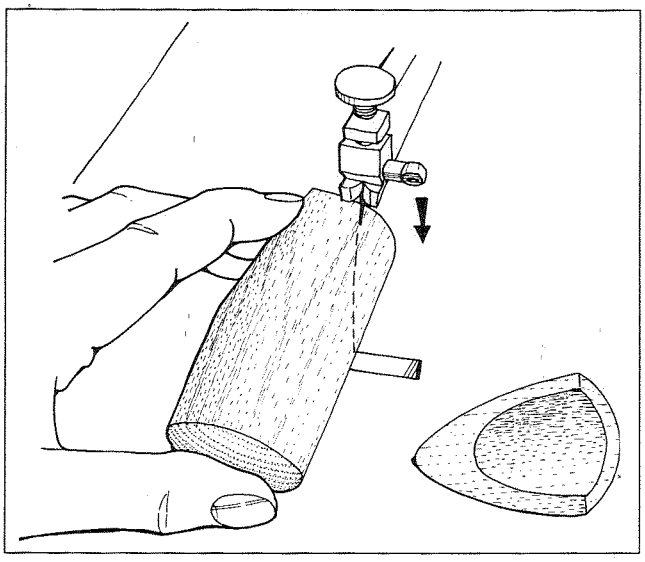


FIGURE 4-18
Slice the sides away from the bottom of the piston pot, and sand them to a smooth finish.

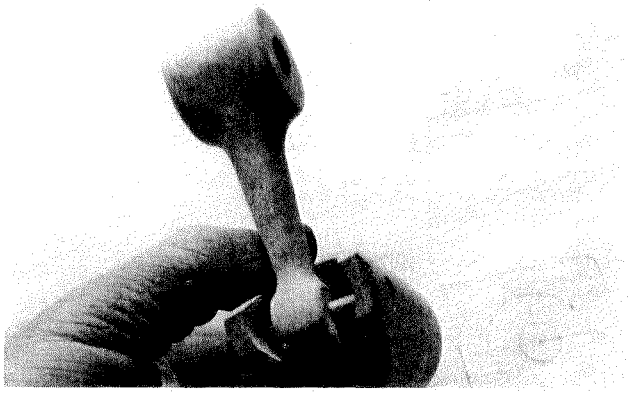


FIGURE 4-19
Have a trial fitting of the connecting rod small end in the piston. The pin needs to be a tight fit in the piston and a loose fit through the small end.

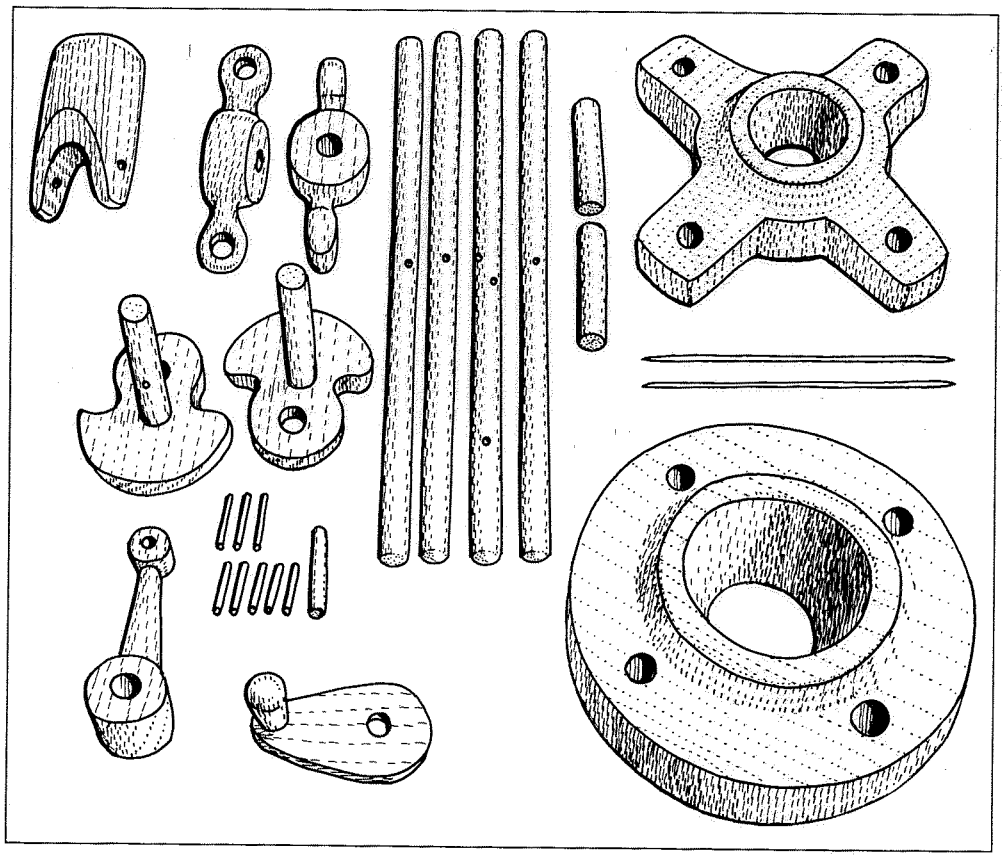


FIGURE 4-20
Set out all the component parts, and check them over to make sure you haven't made any slipups.

PUTTING TOGETHER AND FINISHING

1 When you have before you all the component parts that make up the project (Fig 4-20), then comes the difficult task of putting the machine together.

2 Start by fitting the small end of the connecting rod in the piston. Aim for a tight fit of the pin through the sides of the piston and a loose fit of the pin through the small end. If need be, rub out selected holes or parts of the pin until everything fits just right (Figs 4-21 and 4-22).

3 When you are happy with the fit of the small end in the piston, take the two crank plates—complete with their lengths of drive shaft dowel—and link them with a short length of dowel that runs through the big end bearing at the end of the connecting rod. Make the rod about 2″ long (Fig 4-23). Don't glue at this stage.

4 One piece at a time, fit the piston in the cross-shaped casing, set the crankshaft bearings in place on the dowel ends (Fig 4-24), and set the pair of bearings on the four support dowels (Fig 4-25). Fit little pegs to hold the various components at the correct height.

5 Continue fitting and sanding and generally easing until the whole machine comes together.

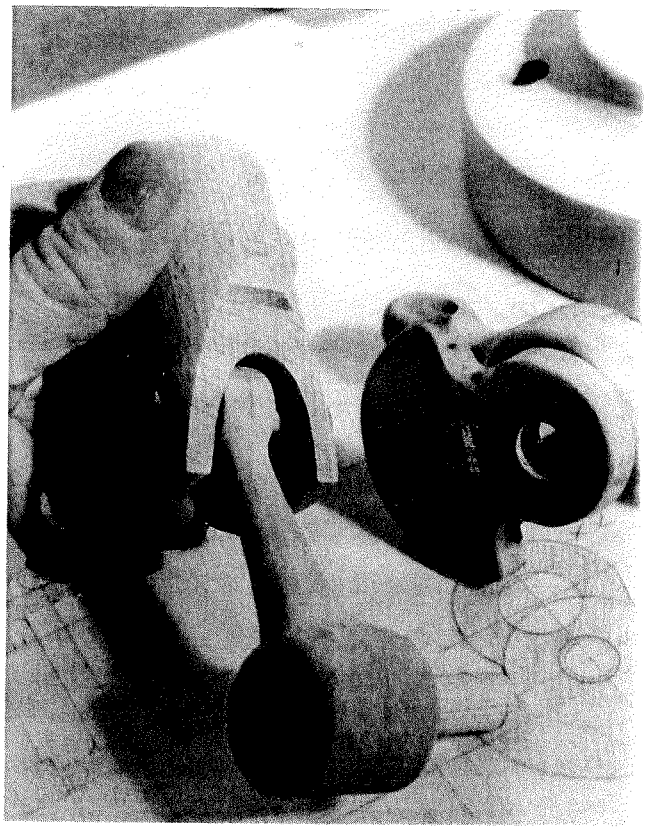


FIGURE 4-21
Pass the short length of crank dowel through the big end, and check for an easy, well-aligned fit.

6 Finally, wipe all nonglued surfaces with the teak oil, glue, clamp, burnish the machine to a dull sheen finish, and . . . hurrah—everything is finished and ready for showing!

PROBLEM SOLVING

■ If you like the idea of this project but want to change the design, be mindful that it's not so easy to redesign a single element in isolation. This being so, we would always advise that you make a prototype.

■ Any time you are ordering wood, it's always a good idea to ask for wood that is well seasoned and dry, but it's all the more important when you are ordering wood for turning.

■ Warning: Fitting the crank plates to the drive shaft stubs is difficult—the sort of task that requires a lot of time, a lot of patience, and not too much glue!

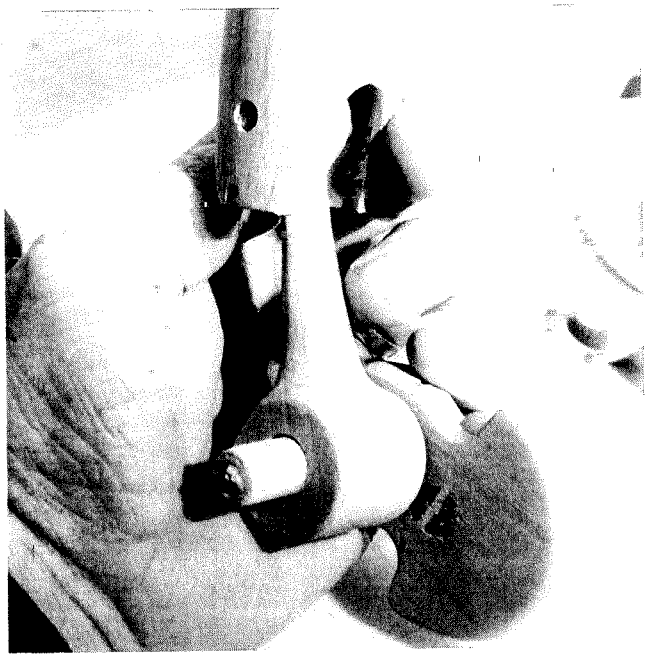


FIGURE 4-22
Fit the crank plates so there is a small space between the plate and the flat face of the big end.

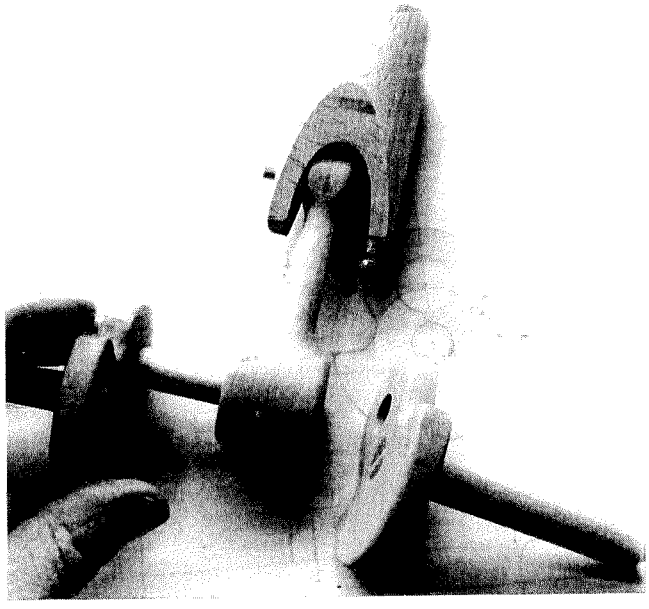


FIGURE 4-23
The crank plates need to have perfect mirror-image alignment.

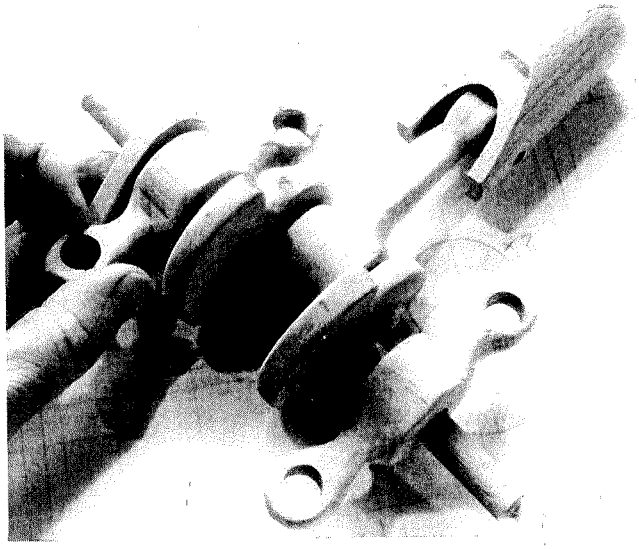


FIGURE 4-24
Fit, check and ease the crankshaft bearings.

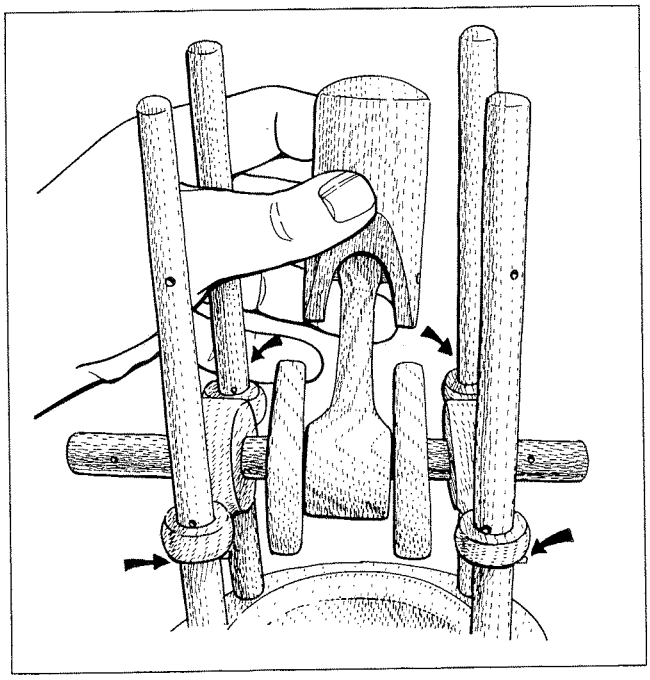
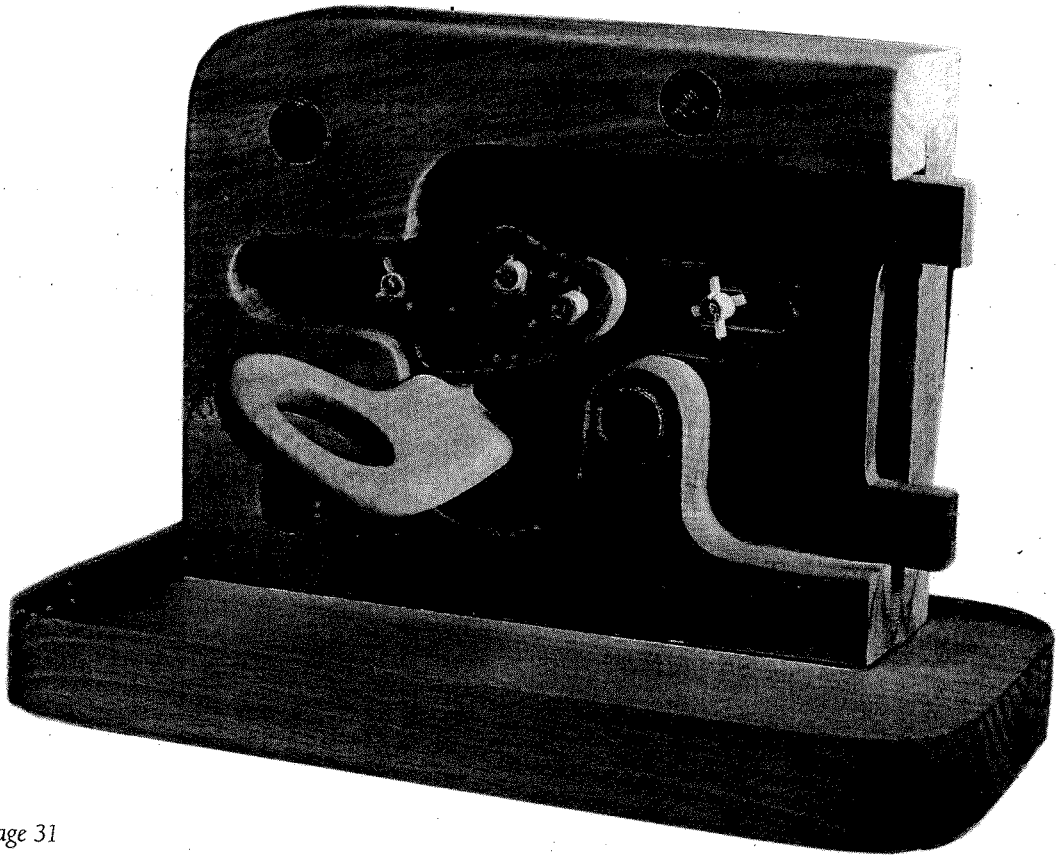


FIGURE 4-25
Set the component parts in place on the posts, and hold them in position with small pegs.

PROJECT FIVE

Ward Lock and Key



Color photo page 31

PROJECT BACKGROUND

When I was a kid—I must have been about seven years old—I was absolutely fascinated by locks and keys. As I remember, I spent a good deal of my time collecting keys, mending locks, and generally showing friends and family just how easy it was to escape from a locked room.

Most of us are literally surrounded by locks; we can hardly move without first finding our keys. Yet, few of us know how locks work. The good news is our simple ward-and-tumbler locking machine illustrates all the essentials of the archetypal locking mechanism. There is a key, a ward to block the passage of the wrong key, a sliding latch plate, and a tumbler that holds the latch in place. In action, the shaped key is pivoted past the blocking ward knob, with the effect that in its turning, it lifts the tumbler out of the way and pushes the latch forward (above). So there you go. If you want to know a little more about one of our most common mechanisms, now's your chance.

PROJECT OVERVIEW

Have a look at the working drawing (Fig 5-1) and the template design (Fig 5-2), and see that the locking machine stands about 6″ high with a base slab at 8″ long and 4½″ wide. Note that we have reduced the workings, meaning the number of moving parts, to a minimum in an attempt, as it were, to show the "bones." Of course, most ward locks have a number of springs that bear down on a series of tumblers, but in the context of our machine, we feel that a single heavy tumbler falling down under its own weight is enough to demonstrate the basic principle.

Consider how the cavity has been constructed by setting a fretted front plate against a solid back plate. As for the overall design, we have consciously gone for a solid, easy-to-make, good-to-hold structure. All in all, we have kept the fixings to a minimum so everything is in view.

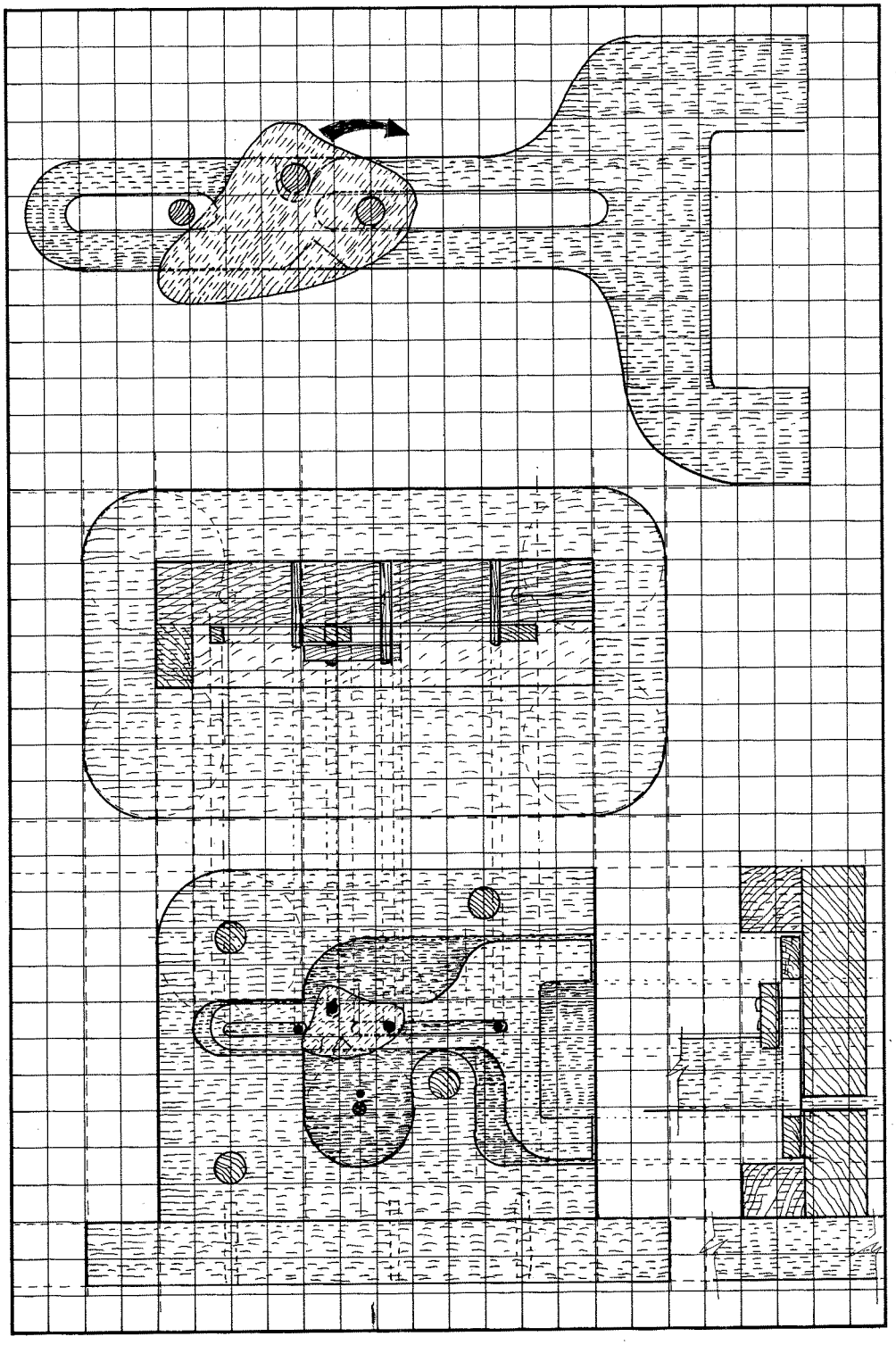


FIGURE 5-1
The finished machine stands about 6" high and about 8" long.
(top) Latch plate and tumbler at a scale of four grid squares to 1".
(bottom) Views and section at a scale of two squares to 1".

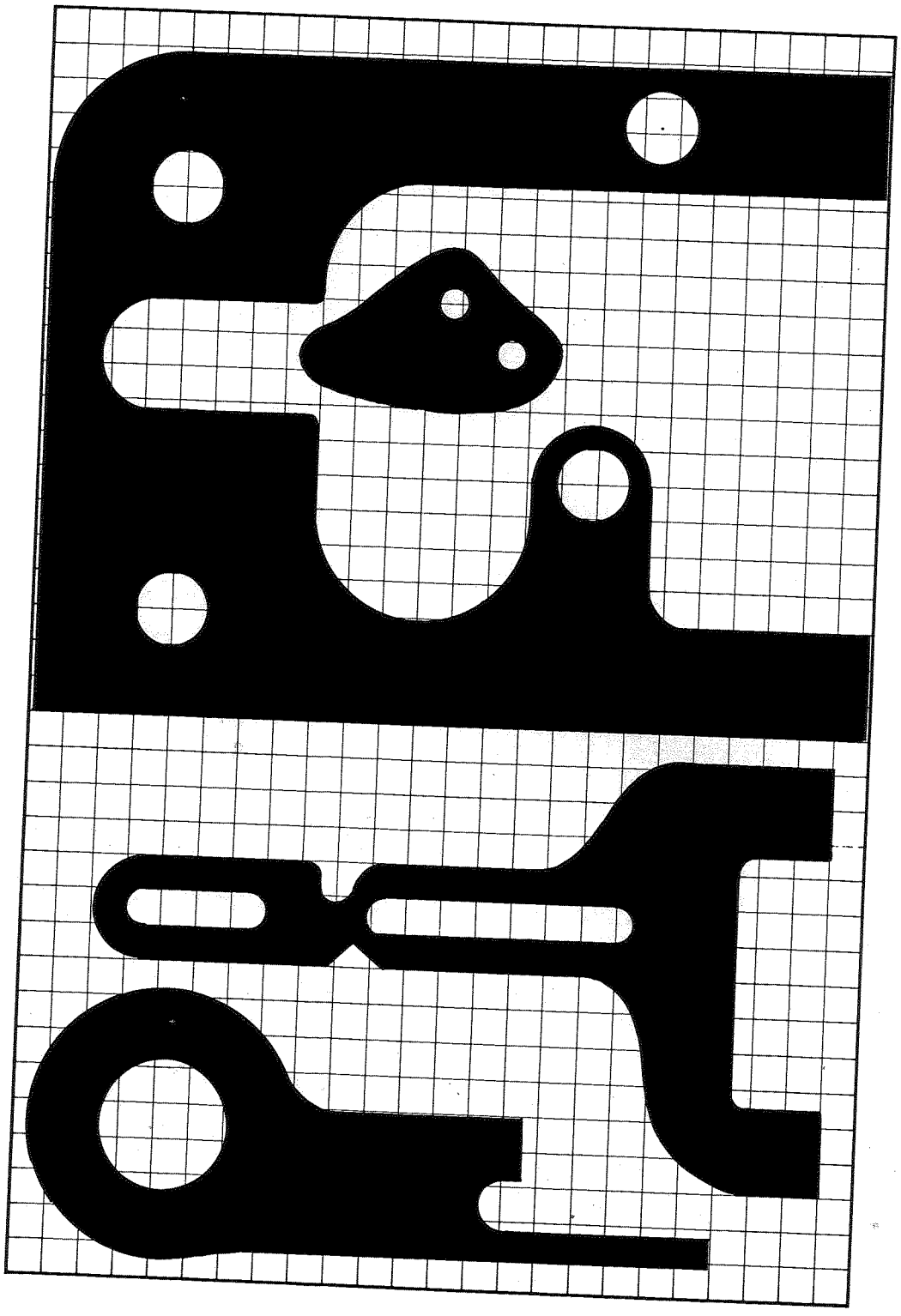


FIGURE 5-2
The scale is four grid squares to 1". With a project of this character—where success might hinge on the width of a saw cut or the placing of a dowel hole—you must take it that these profiles are only broad guides.

CUTTING LIST—PROJECT FIVE

A	Box front	7/8 × 5 × 6 beech
	Box back	7/8 × 5 × 6 beech
B	Tumbler	1/4 × 1 1/4 × 2 maple
C	Latch plate	1/4 × 3 1/4 × 5 1/4 maple
D	Key	1/4 × 2 1/4 × 5 1/4 maple
	Base	7/8 × 4 1/2 × 8 beech
	Pivots	1/4" dowel
	Decorative pins	12"—1/2" dark wood dowel
	Fixing pins	round toothpicks

CHOOSING YOUR WOOD

As this is a project that is best made from a hard, straight-grained wood, we have gone for beech for the box and base and maple for the moving parts: the key, sliding latch and tumbler.

MAKING THE BOX AND BASE

1 Have a good, long look at the working drawing (Fig 5-1) and template design (Fig 5-2), and see that the main structure is made up of three pieces of wood: a single slab for the base and two glued and pinned slabs for the box.

2 With your workshop in good order, and when you are clear in your own mind as to the procedures, take the three slabs of wood—for the base and the box—and use a pencil, ruler and pair of compasses to mark the design. Mark the base with the corner radius curves and the front box slab with the single corner curve and interior shape that needs to be cut away.

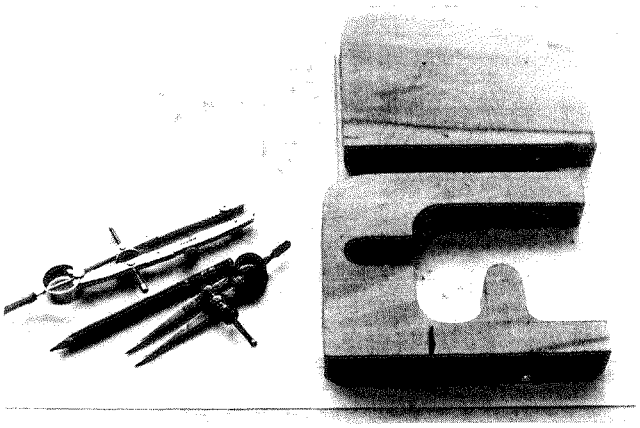


FIGURE 5-3
Having cut the two slabs of wood to the same shape, fret out the front slab to make the latch box cavity.

3 Having first pinned the two box slabs together so you have them as if they were a single slab nearly 2" thick, move to the scroll saw and carefully cut out the single radius curve. While you are working on the machine, cut the four curves that make up the base.

4 Take the two-layer box slab, ease the layers apart, partially withdraw the pins so the points are out of harm's way, and then cut away the central area of waste so you are left with the profile that makes up the front of the box (Fig 5-3).

5 Align and repin the two box slabs, and run the various holes through with drill bits of a size to fit your dowel (Fig 5-4).

6 Finally, take the two slabs that make up the box, set them on the base slab, and mark in the position of the three fixing dowels, meaning the three dowels that fix the box to the base.

MAKING AND FITTING THE LATCH PLATE

1 Take the front-of-box cutout, set it on the 1/4"-thick maple—like a template—and use a pencil to transfer the imagery.

2 Having drawn the shape of the sliding latch plate to size and made a good tracing, use the tracing to press transfer the drawn image through to the box shape you've marked on the maple (Fig 5-5).

3 If you have a close-up look at the photograph—in this and many other projects—you will perhaps wonder at there being a great number of differences between our initial prototype drawings, as seen on the tracing paper, and the actual workpiece. The project

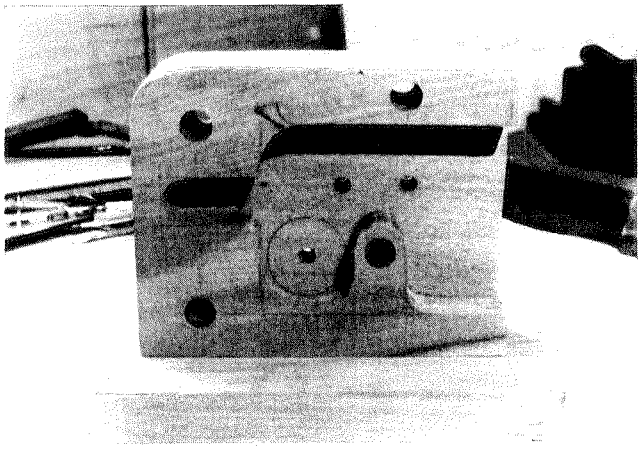


FIGURE 5-4
Drill out all the primary holes, and have a trial fitting of the box to the base slab.

changes a bit as we work on it. If you have a notion that such and such a shape or way of working is the best way, then that is the best way for you.

4 With the shape of the latch plate clearly marked within the shape of the box, and having made adjustments to allow for easy movement, fix the position of the various holes and pilot piercing within the plate, and run them through with the ¼" drill bit (Fig 5-5).

5 When you feel all is correct, fret out the latch plate on the scroll saw. Don't bother at this stage to cut the fine details; just go for the main profile.

6 With the plate partially cut out, wipe the edges with a fine-grade sandpaper to remove any rough edges that might get in the way, and have a trial fitting in the lock box (Fig 5-6). The latch plate should slide neatly backward and forward without sticking or racking.

MAKING THE KEY AND TUMBLER MECHANISM

1 When you have completed the basic sliding latch profile and have succeeded in getting it to slide smoothly in the box, then comes the not-so-easy business of fitting the key and tumbler. Start by looking at the working drawing (Fig 5-1) and template design (Fig 5-2), and seeing that the key needs to be cut and worked so the end-of-key profile, or ward, is able to pass over a ward stud that is set in the body of the box.

2 Having first cut out the basic shape of the key blank (Fig 5-7), whittle the stem to a round section so it fits in the keyhole, and shape the leading edge of the key (Fig 5-8) so when it is turned, it catches the notched underside of the latch plate, with the effect that the latch slides forward.

3 The trick to fitting the key is to trim back little by little, stop and have a fitting, trim back some more and so on (Fig 5-9) until the movement is just right.

4 When you have cut the key to a good fit, then comes the frustrating task of fitting the tumbler. If you look at the mechanism (Fig 5-10), you will see that the little, shaped profile of the tumbler has two dowels: the one on the far right, which is the pivot, and the one at top center, which is a peg or knob. In action, the turning key catches and lifts the curved underside of the tumbler, with the effect that it swings up on its pivot. And, of course, as the tumbler rises, the peg is lifted out of the notch on the top edge of the latch, and the turning key goes on to move the latch.

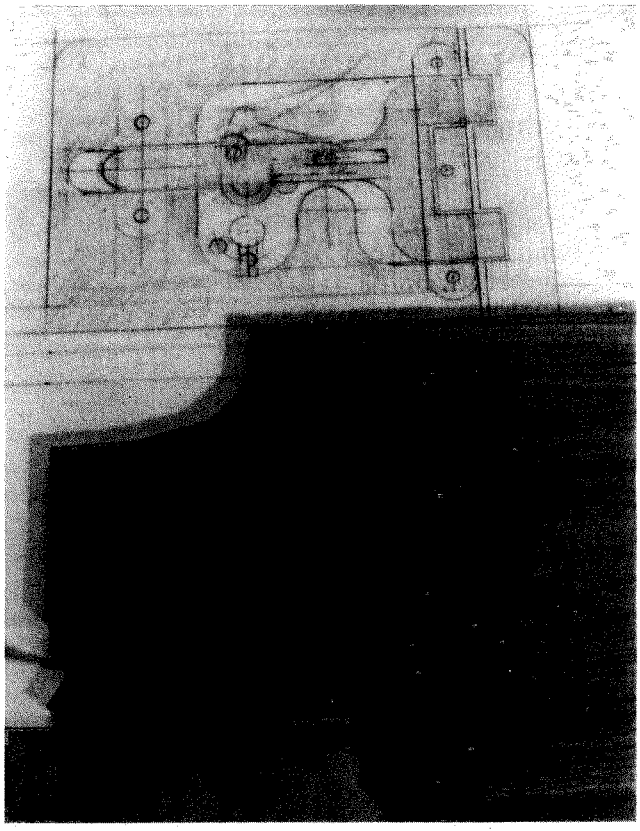


FIGURE 5-5
Having transferred the shape of the box cavity through to the ¼"-thick wood, set to work transferring and modifying the latch profile to ensure a smooth-sliding fit.

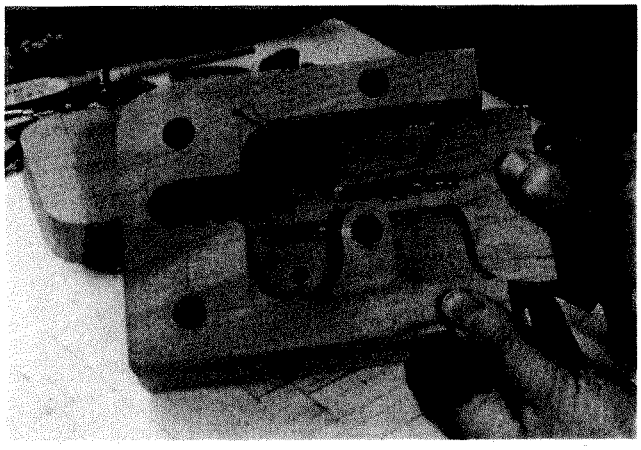


FIGURE 5-6
Fret out the latch plate, and try it out for size. If it's too tight, it won't move, and if it's too loose, it twists and gets stuck—so go at it slowly.

5 Once again, you might well have to cut two or three tumbler plates and play around with the position of the pivot hole and the shape of the underside curve before you get it just right.

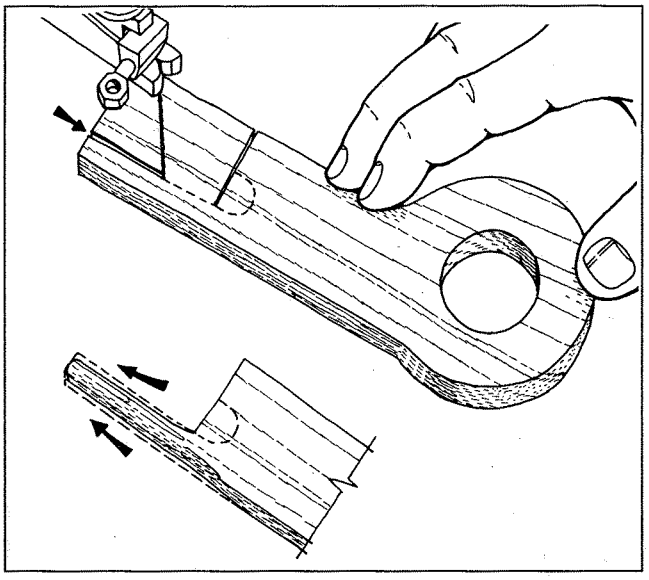


FIGURE 5-7
Cut out the key shape on the drill and scroll saw, and whittle the stalk so it's an easy-to-turn fit in the ¼"-diameter box hole.

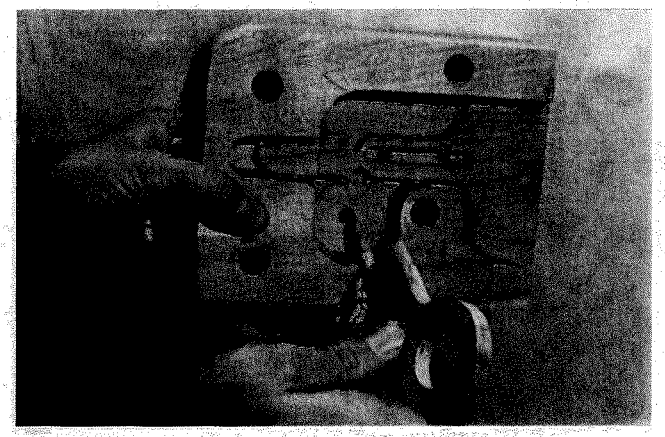


FIGURE 5-8
Whittle away the leading edge of the key so it fits in the notch on the underside of the latch.

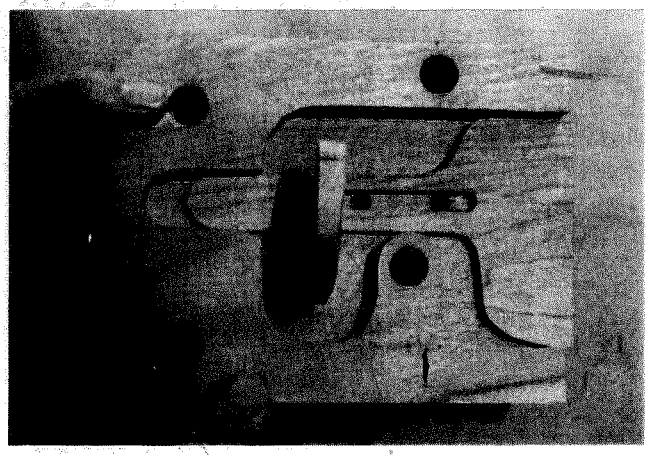


FIGURE 5-9
Continue whittling the leading edge of the key to shape so when it turns, it catches and moves the sliding latch plate.

PUTTING TOGETHER AND FINISHING

1 When you have achieved a smooth movement of the key, tumbler and latch, take the latch plate back to the drill and the scroll saw and finish cutting the other location slot and the two-pronged bolt profile on the leading edge of the latch (Fig 5-11).

2 Having fretted out all the component parts that make up the project, spread them out (Fig 5-12) and check them over for potential problems.

3 When the whole movement is smooth running, fit the ward knob in the back of the box, and whittle a little bridge ward on the bottom edge of the key so it just clears the knob. The idea is, of course, that only your key will fit into the lock (Fig 5-13).

4 Finally, when you are happy with all the moving parts, fit and glue the dowels and pins that hold the sliding latch in place, glue and peg the two layers that

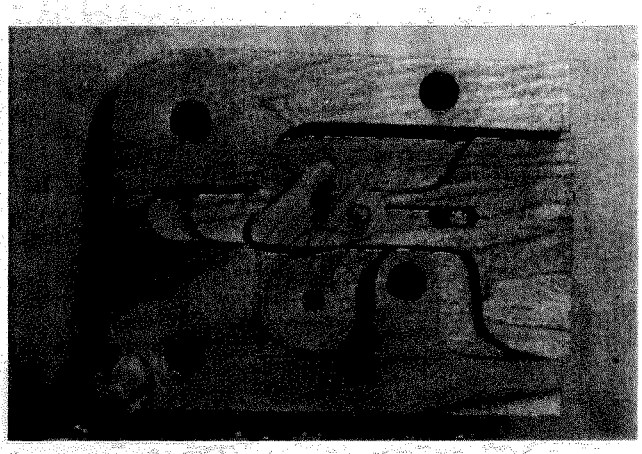


FIGURE 5-10
Shape and fit the tumbler. Eventually, the pivot peg needs to be glued into the tumbler plate and held in place with a round toothpick with the heel end of the pivot running back through the box. The other dowel is no more than a stub that sticks out at the back of the tumbler plate—to rest in the latch notch.

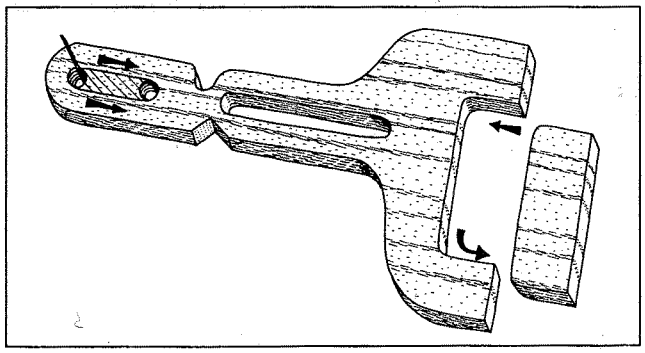


FIGURE 5-11
Having established the position of the slot at the back end of the latch, go back to the scroll saw and finish cutting the profile.