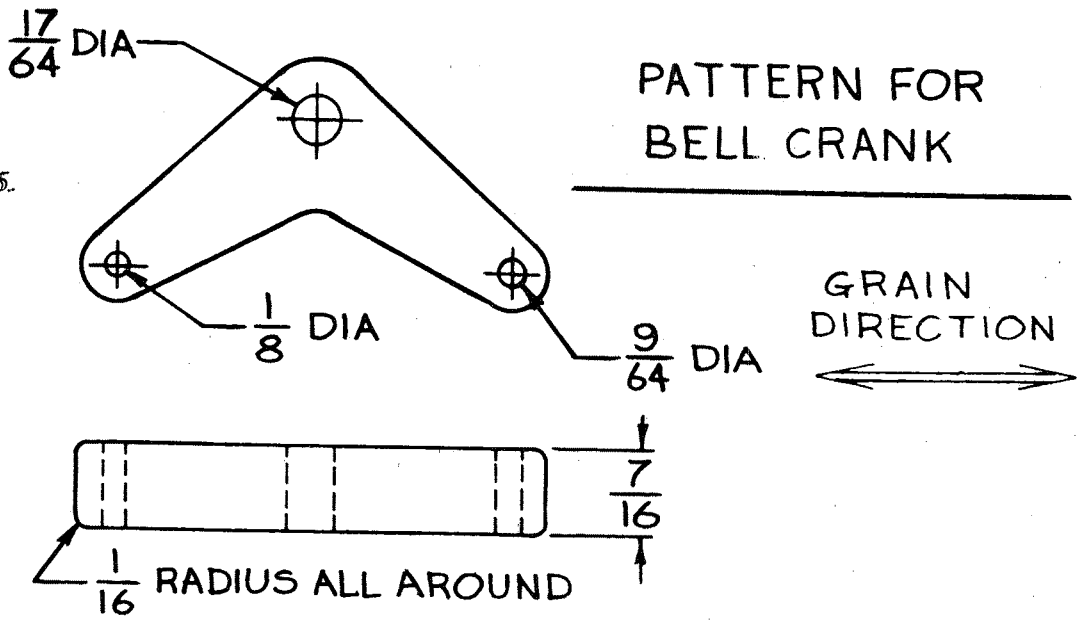
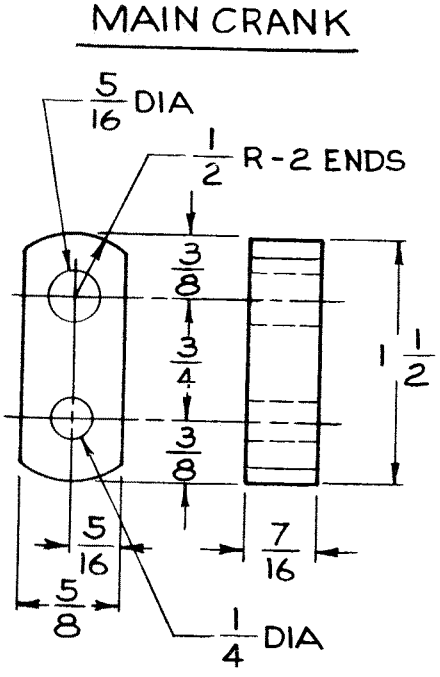
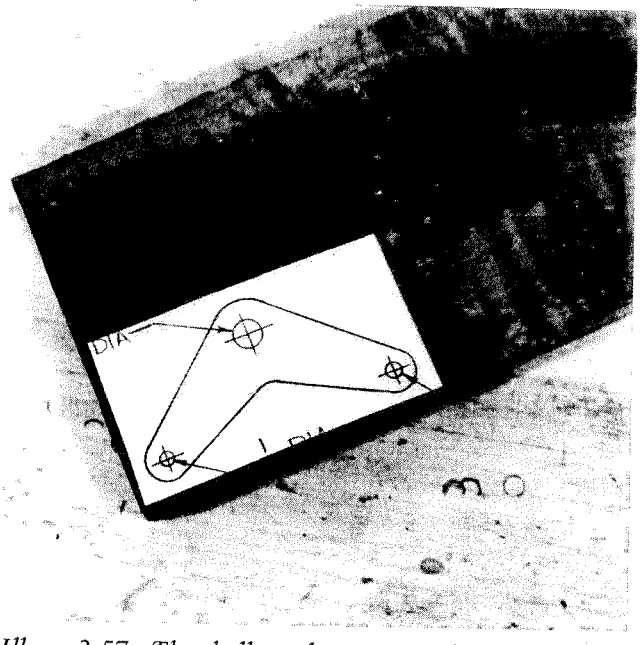
Illus. 3-55.



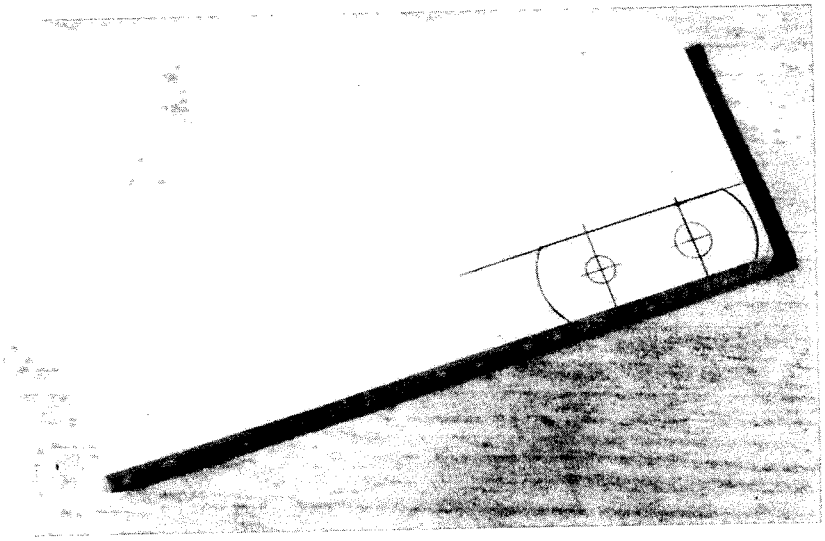


Illus. 3-56.

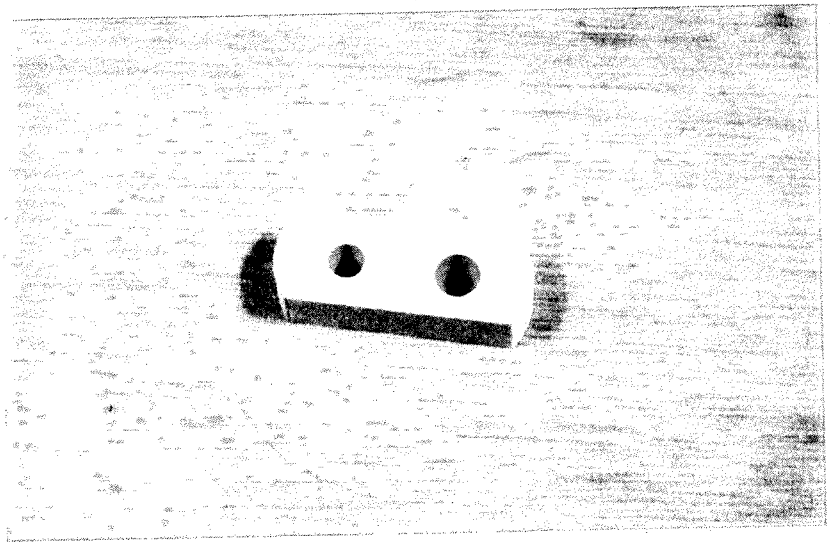


Illus. 3-57. The bellcrank pattern glued onto the wood.

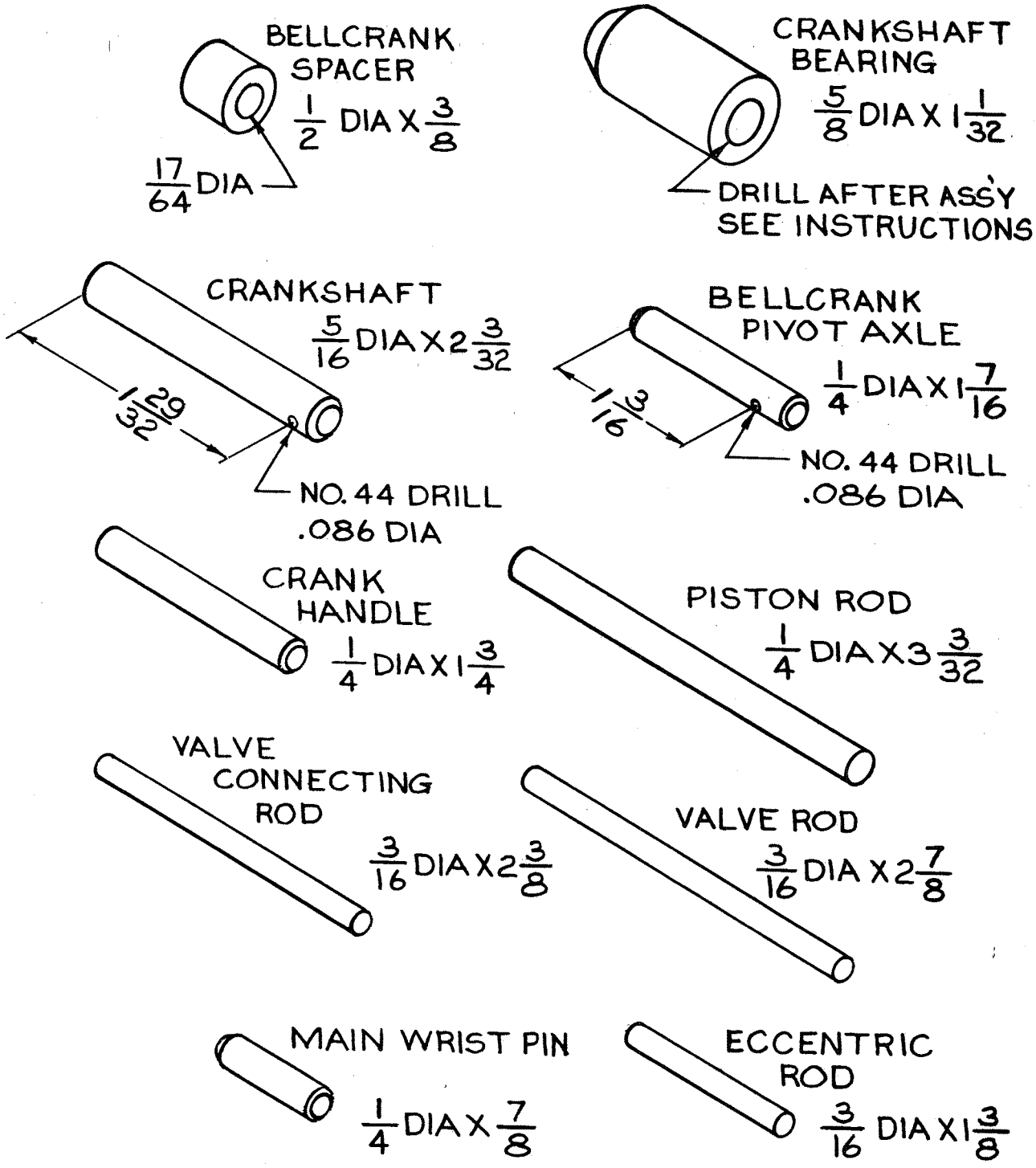
Illus. 3-58. The completed bellcrank.



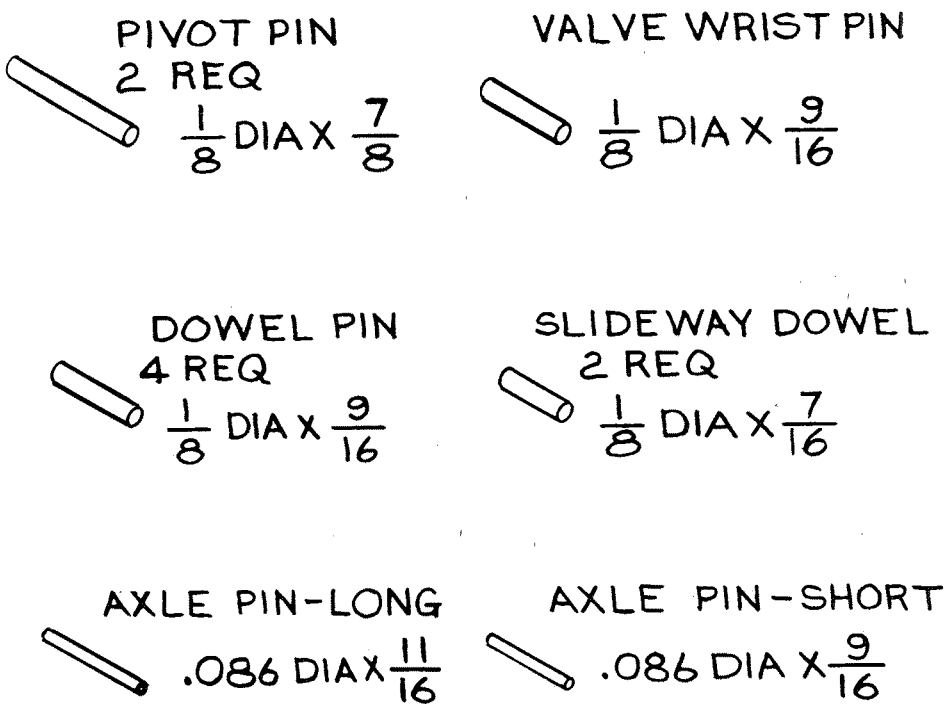
Illus. 3-59. The main crank layout.



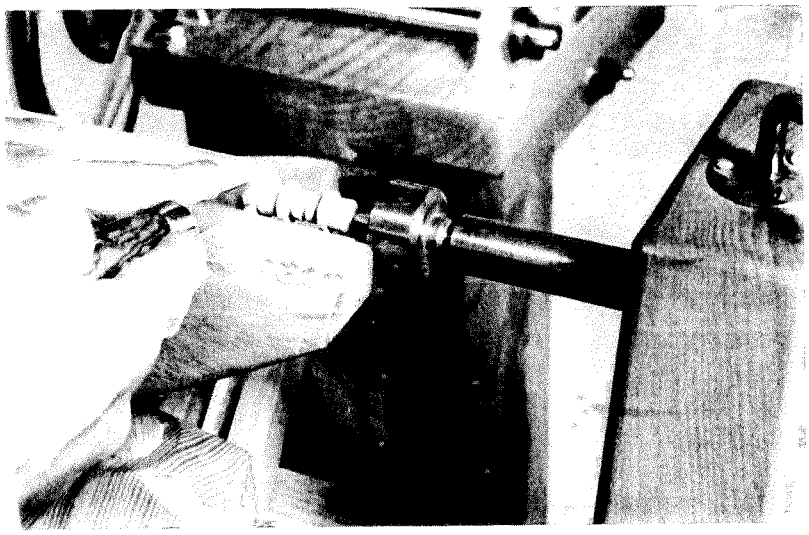
Illus. 3-60. The completed main crank.


BELLCRANK SPACER
1/2 DIA X 3/8
17/64 DIA
CRANKSHAFT BEARING
5/8 DIA X 1 1/32
DRILL AFTER ASSY SEE INSTRUCTIONS
CRANKSHAFT
5/16 DIA X 2 3/32
1 29/32
NO. 44 DRILL .086 DIA
BELLCRANK PIVOT AXLE
1/4 DIA X 1 7/16
1 3/16
NO. 44 DRILL .086 DIA
CRANK HANDLE
1/4 DIA X 1 3/4
PISTON ROD
1/4 DIA X 3 3/32
VALVE CONNECTING ROD
3/16 DIA X 2 3/8
VALVE ROD
3/16 DIA X 2 7/8
MAIN WRIST PIN
1/4 DIA X 7/8
ECCENTRIC ROD
3/16 DIA X 1 3/8

Illus. 3-61.



Illus. 3-62. Remaining parts continued.

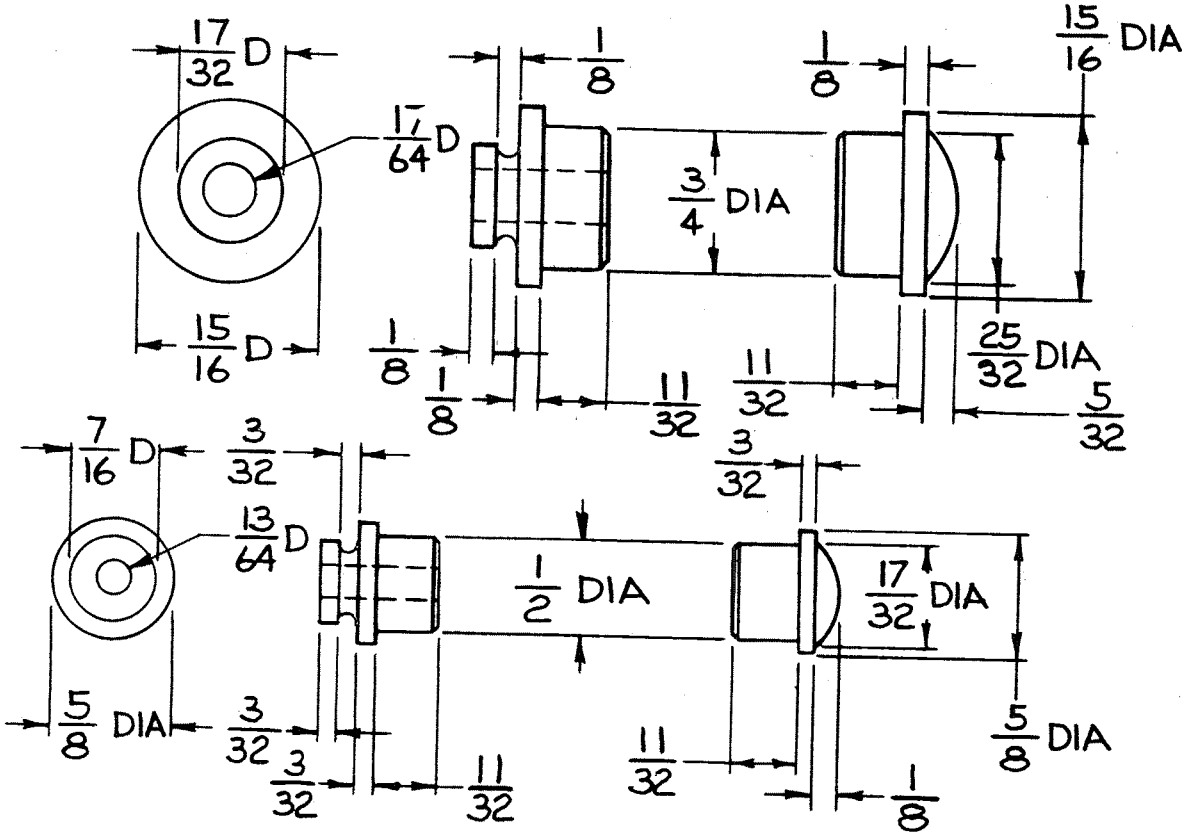


Illus. 3-63. Turning the cylinder heads.

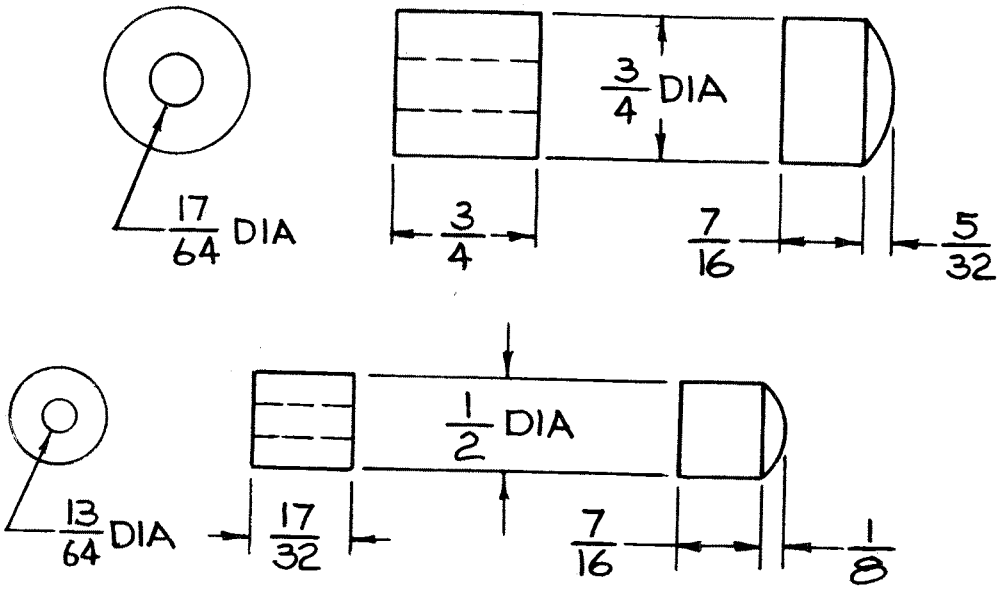
Review the material in Chapter Two, if necessary, for details on making these parts.

Illus. 3-64 contains drawings for two different sets of cylinder heads and stuffing boxes. (Also see Illus. 3-63.) The simpler version is for those who don't own lathes. The end radii can be formed by twirling a dowel against a belt or disk sander. The stuffing boxes should have accurately-centered holes, so make these parts on the ends of lengths of dowel, and cut off any rejects, until you have things right. Fine-sand the parts, and glue the valve-rod stuffing box into place first. Let the glue set, and, using the hole in the stuffing box as a guide, drill a 13/64-inch hole all the way through the valve chest. Now, clean out all chips and sawdust and glue in the remaining parts. This completes the assembly of the cylinder block. (See Illus. 3-65.)

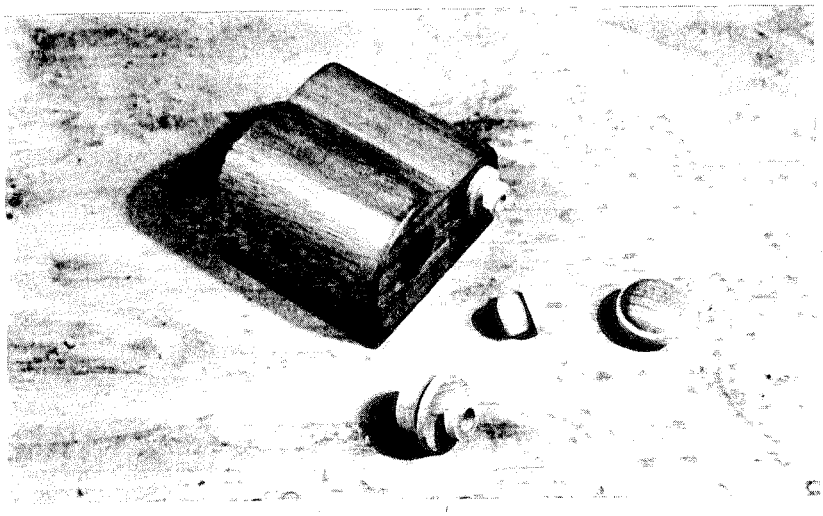
CYLINDER HEADS AND STUFFING BOXES



ALTERNATIVE DESIGN



Illus. 3-64.



Illus. 3-65. Assembling the cylinder heads and stuffing boxes to the cylinder block.

ASSEMBLING THE MECHANISM

Crank

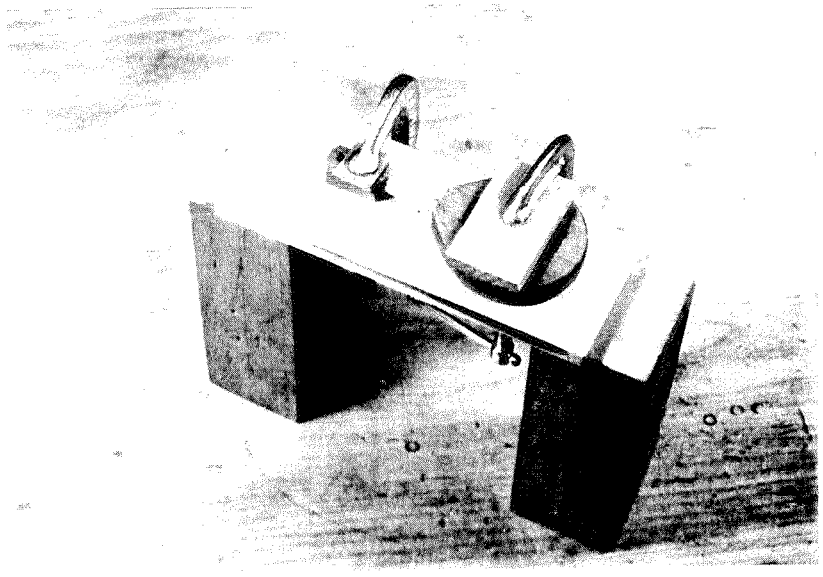
The parts shown in Illus. 3-2 are assembled for an engine with a clockwise rotation, but as this one doesn't run, it's not that important. Push the eccentric onto the crankshaft without glue; this is not a good assembly for gluing. Insert the crankshaft into its bearing on the backplate, and adjust the eccentric so that the small shaft-pin hole stands 1/64 inch clear of the back of the bearing.

Now, assemble the main crank, gluing it to the crankshaft and also to the eccentric. This will hold everything together. Remove any excess glue, and when the glue has dried sand the end of the shaft flush with the face of the crank. Glue the crank handle into its hole, checking it for squareness all around.

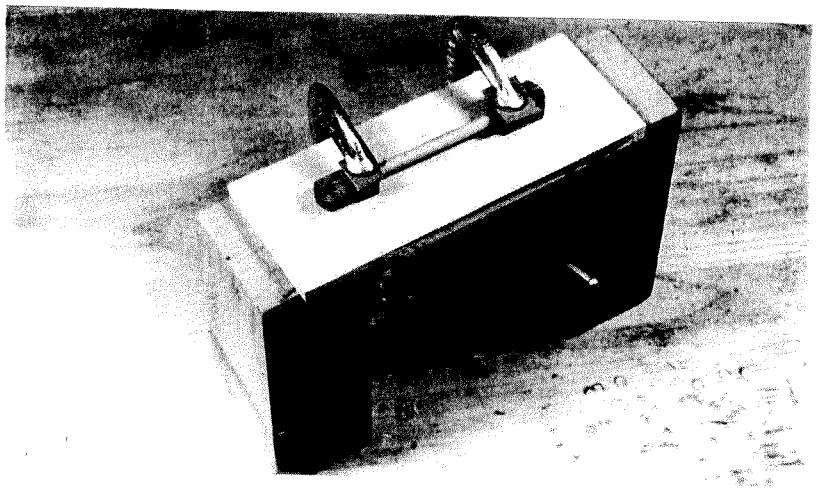
Rod Ends and Eccentric Strap

On those rods that have parts at both ends, it is important to assemble everything in the same plane. Illus. 3-66 and 3-67 show a simple way to do this. Clamp the parts to a flat block, thus ensuring that their faces are aligned. Then check that all the edges are parallel in

Illus. 3-66. Gluing the eccentric strap subassembly.



Illus. 3-67. Gluing the valve/ connecting rod subassembly.



the vertical plane, using a straightedge. Needless to say, these parts must be gently clamped.

Piston Rod and Crosshead

The piston rod must be parallel to all faces of the crosshead, or binding may result when the engine is operating. Hold each face in turn against a flat surface; any angular error of the rod will be readily visible. Check this several times, until the glue is firmly set.

Pivot Pins

With the appropriate drawing in front of you, push the 1/8-inch pivot pins into their respective holes. No glue is necessary, unless the fits are too loose. Be careful; it's easy to put the pins in backwards at this stage.

Wipe a film of glue into the bellcrank pivot hole in the backplate. Put the pivot axle through the bellcrank and the spacer, and insert it into its hole. Tap it into the backplate until the little pin hole is about 1/64 inch from the face of the bellcrank. Remove all loose parts, and check the axle for squareness to the backplate.

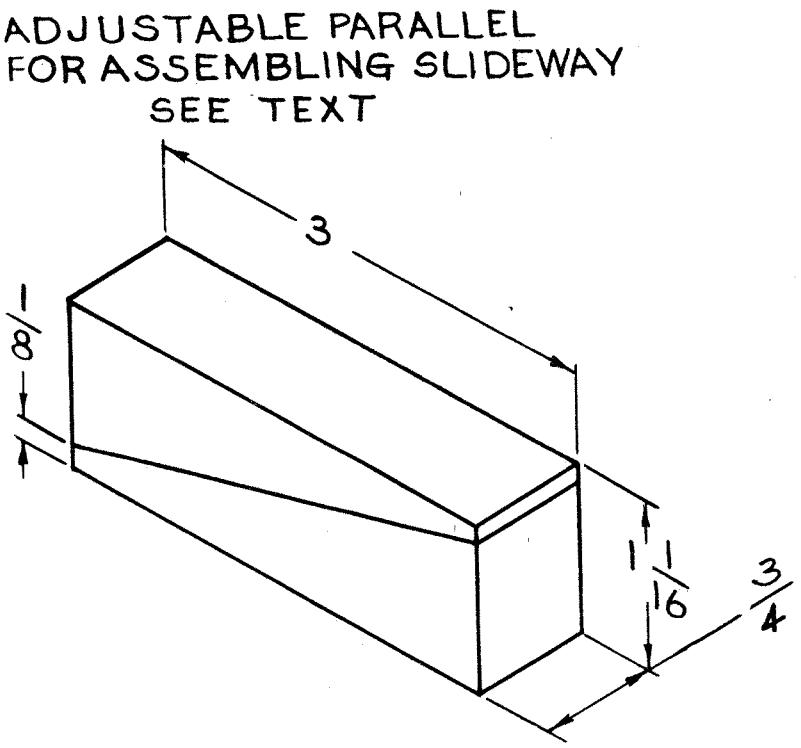
The main and valve wrist pins and the two small axle pins are not glued in place, thereby permitting disassembly of the model when necessary. You should be able to push these pins in easily with your thumb.

Cylinder Block and Crosshead Slideway

Unless you intend to use a very thin wipe-on finish, finish the components separately. Push two dowel pins into the backplate and set the cylinder block on them. Lightly clamp it with a padded clamp, and check that it fits flat all around. Take a sharp scriber or an awl and score a line all around the cylinder block, outlining its position.

It is essential that the crosshead slide is assembled correctly. One way to ensure this is to make and use the assembly tool shown in Illus. 3-68. Just saw a little block to the dimensions shown and you will have an adjustable parallel block that's ready for use. (You won't need the graduated scale shown on mine.)

Put the two short dowel pins in place and position the slideway on them. Set your adjustable parallel on the baseplate and adjust it so that the slideway looks about right. Now, insert the piston rod into its stuffing box and adjust the slideway up or down until the crosshead will slide freely with uniform clearance on top and bottom. Make certain that the slideway is sitting flat on the adjustable parallel, and then make a pencil mark across both parts of the parallel, for future alignment. Remove the crosshead and clamp the slideway in place. Scribe around it as for the cylinder block.



Illus. 3-68.

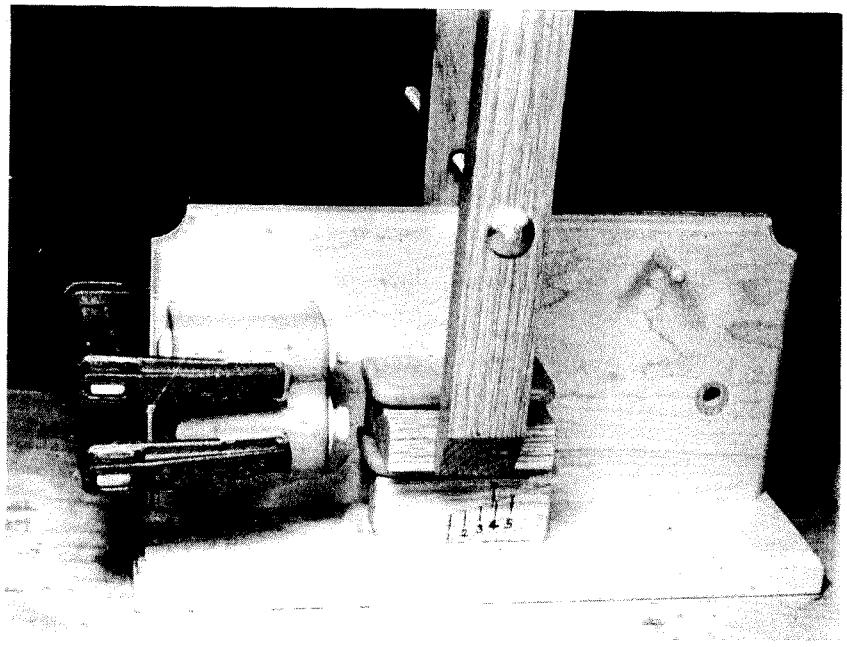
Cut masking tape to fit inside the two gluing areas, keeping it about 1/16 inch from the scribed lines. Press the tape down quite firmly with a small wood block. (See Illus. 3-69.) Now, apply whatever finish you desire, sanding or rubbing with steel wool between coats. Don't saturate the tape with heavy, wet coats of finish, or you may dissolve the adhesive. Finish the cylinder assembly and the crosshead slideway, keeping the gluing areas as clean as possible.

When you are satisfied with the finish on the subassemblies, scrape their gluing surfaces. Remove the tape from the backplate, and scrape the areas where the two parts will be glued. I make small scrapers for this work, using old utility-knife blades set in handles and ground to shape. Scrape the surfaces almost, but not quite, to the scribed lines. Take your time with this operation, or you might have to repair your finishing job.

Put two dowel pins in the cylinder location,

Illus. 3-69. The taped backplate, ready for a finish.

Illus. 3-70. Gluing the cylinder and slideway to the backplate.



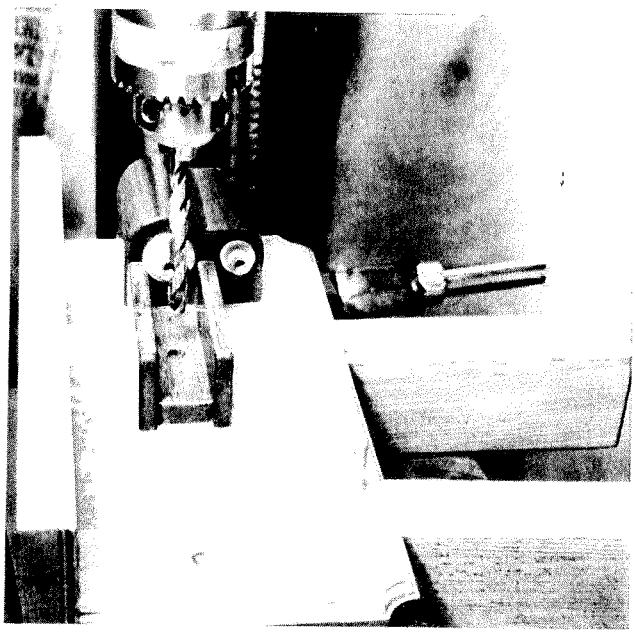
set the cylinder in place, clamp it lightly, and check that it sits flat all around. If it looks all right, apply a thin film of glue to the cylinder block, keeping it at least ⅛ inch from all edges, and clamp it in position.

Repeat the above operation for the slideway, locating it with the adjustable parallel block as before. Clamp the assembly and remove any squeezed-out glue with a wet cloth, as water won't soak into your finished wood. Put the assembly aside to dry. (See Illus. 3-70.)

When you have removed the clamps, there is one more operation that you must perform. Drill through the hole in the slideway spacer and into the backplate 7/16 inch deep, as shown in Illus. 3-23. (See also Illus. 3-71.) This is absolutely necessary so that the wrist pin has somewhere to go whenever you want to take the model apart.

Apply a finish to all the remaining parts. Use light coats of a thin finish, as these small parts can't tolerate a heavy buildup. Rub the parts to a uniform surface with steel wool. When the finish is dry, run drills through any bearing or pin holes that may have become partially filled. Remember that the two little axle pins should be no tighter than a moderate push fit, and all bearings must move freely.

Wax all the moving parts; you can wax the whole assembly, if you wish. All the subassemblies are now complete. (See Illus. 3-2.)



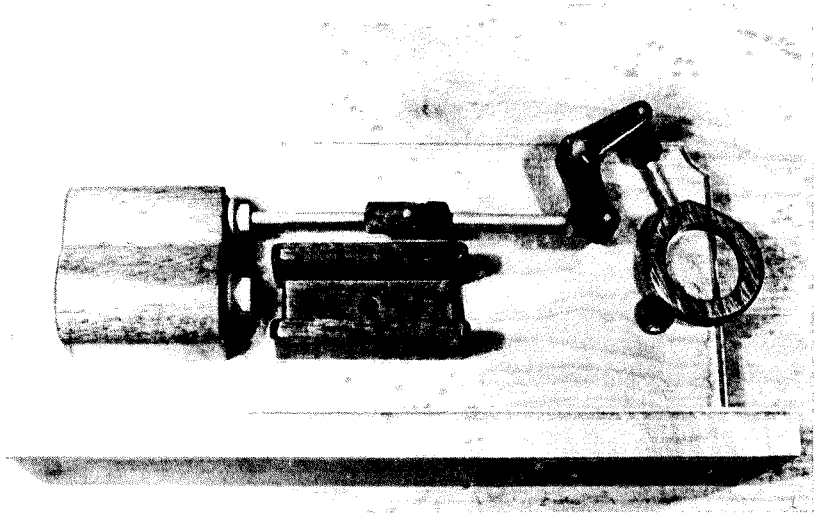
Illus. 3-71. Drilling the wrist-pin clearance hole.

FINAL ASSEMBLY

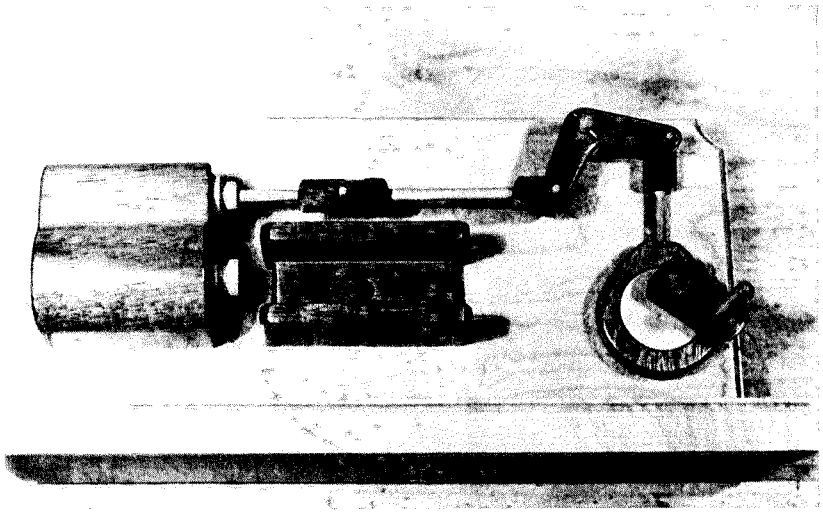
If you observe the following procedures, you will be able to assemble almost everything on the workbench, instead of on the model itself.

Assemble the valve train consisting of the valve rod, the valve connecting rod, the wrist pin, the bellcrank, and the eccentric strap. Place the bellcrank and its spacer onto the pivot axle on the backplate, and push in the short axle pin to retain the assembly. Work the linkage so that you can insert the valve rod into its hole in the valve chest. (See Illus. 3-72.) Operate this much of the assembly for a few strokes to ensure that all the parts move freely. Then swing the eccentric strap down over the crankshaft bearing hole, insert the crankshaft into its bearing, and slide the eccentric into its strap. (See Illus. 3-73.) Turn the crank a few times and, if all works correctly, push in the long axle pin on the back side of the crankshaft.

Slide the piston rod into the cylinder. The crosshead will probably fit better one way than the other, so make certain that it moves freely in its guides. Push the crosshead as far left as it will go, turn the crank handle all the way to the right, and place the large end of



Illus. 3-72. Final assembly: Step one.

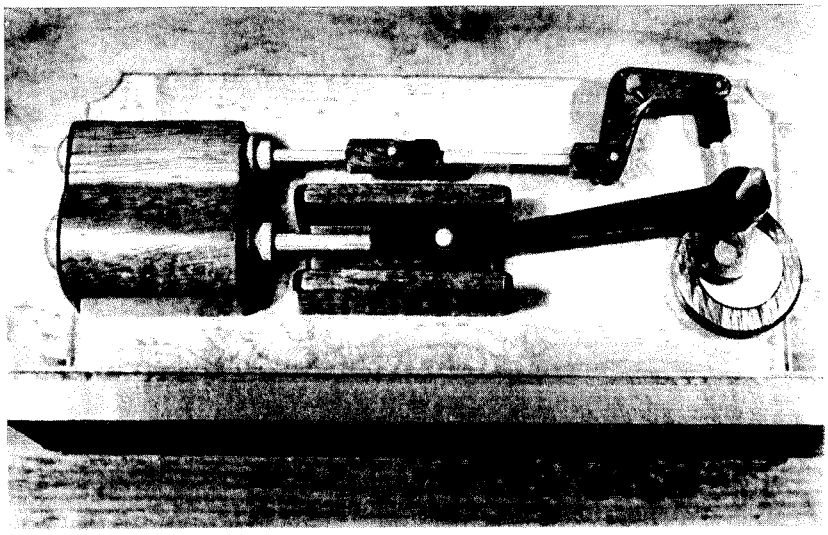


Illus. 3-73. Final assembly: Step two.

the connecting rod on the crank handle. (See Illus. 3-74.) Turn the crank to the left, and slide the crosshead over the small end of the rod, until the holes line up. Push in the wrist pin. The model is complete.

If you ever need to disassemble the model, center the wrist pin over the hole in the middle of the slideway. Push the wrist pin out of the crosshead; the parts can now be removed in the reverse order of assembly. Now you have something unique to put on the mantel.

Illus. 3-74. Final assembly: Step three.



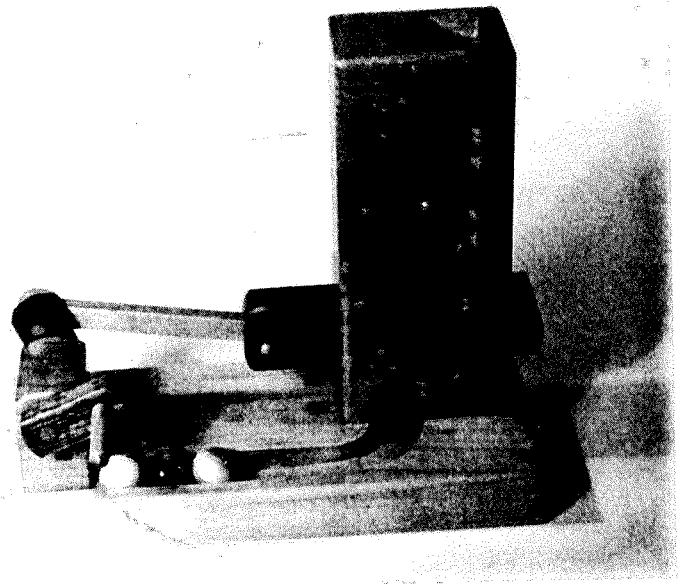
CHAPTER 4

Single-Part Feed Mechanism

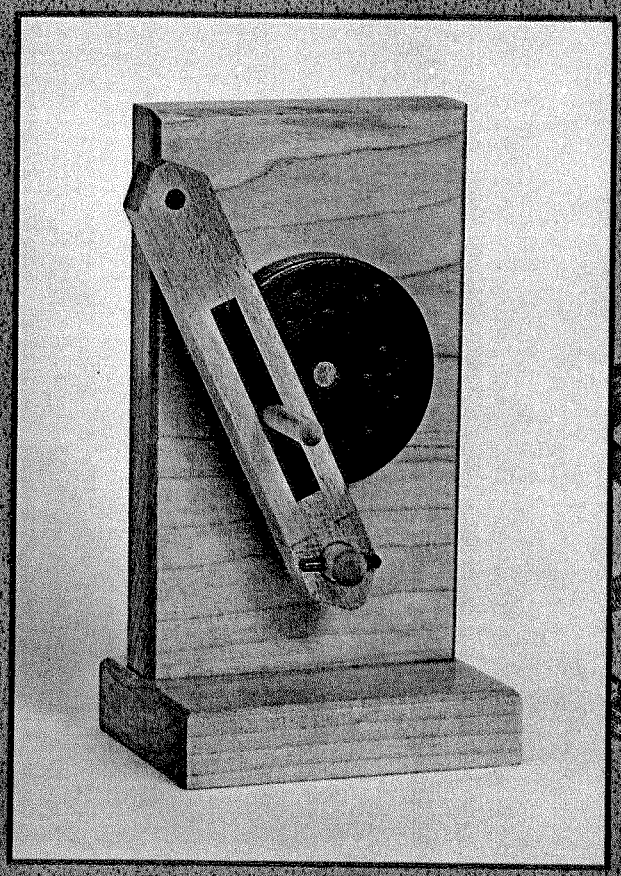
In automatic-assembly equipment, a part often has to be delivered to a work station at exactly the right time so that it can be assembled with its mating components. The feed mechanism must, therefore, be synchronized with the other machinery.

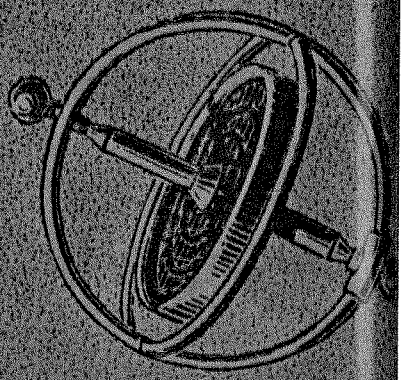
This model is a wooden version of a very common feeding system which was also sometimes used in early mechanical coin-operated vending machines. The device adapts well to other equipment. People have built models from the photograph that appears in my magazine article (*American Woodworker,* September/October, 1989) and incorporated them in other marble mechanisms.

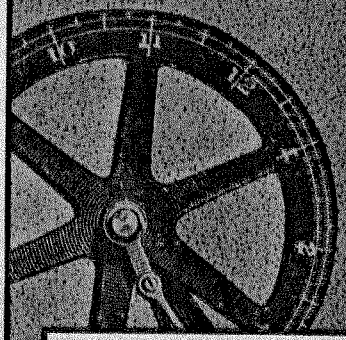
I have redesigned my original model for home workshop construction. The one described and shown here has a few more pieces, but you don't need three-dimensional routing capability to make it. You must, however, work closely to the drawing dimensions if you want a smoothly functioning model.

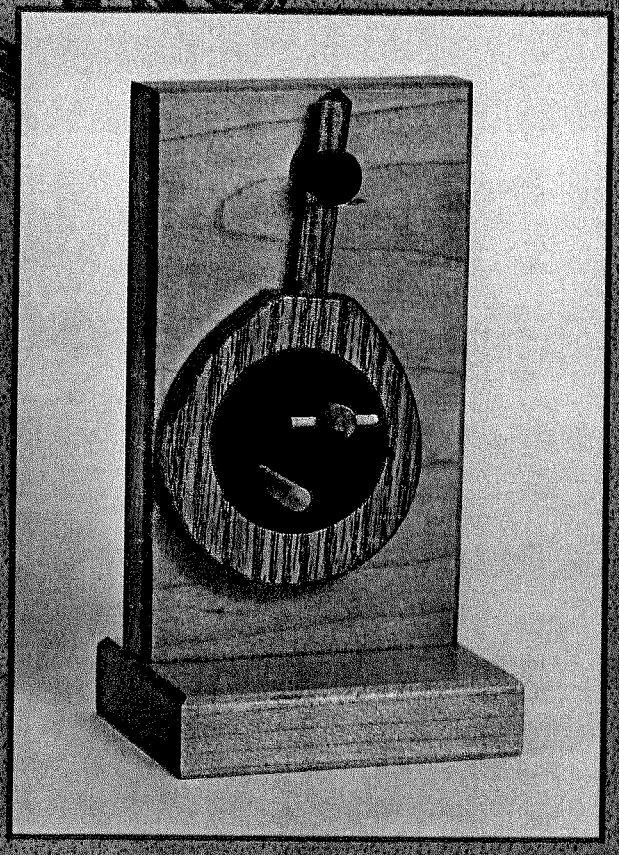


Illus. 4-1. The Single-Part Feed mechanism.

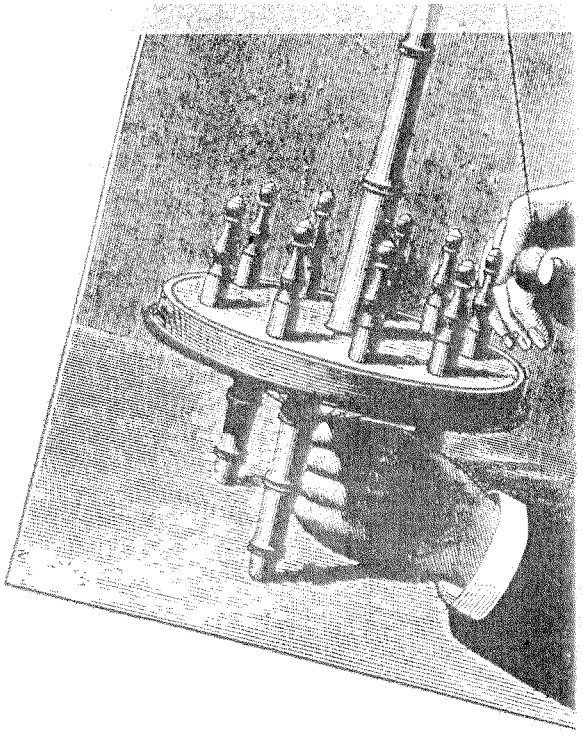


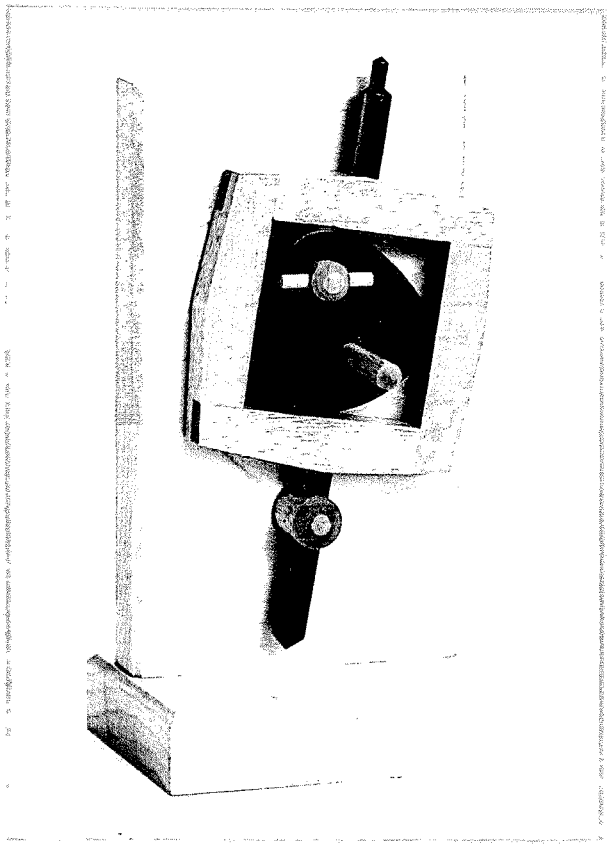


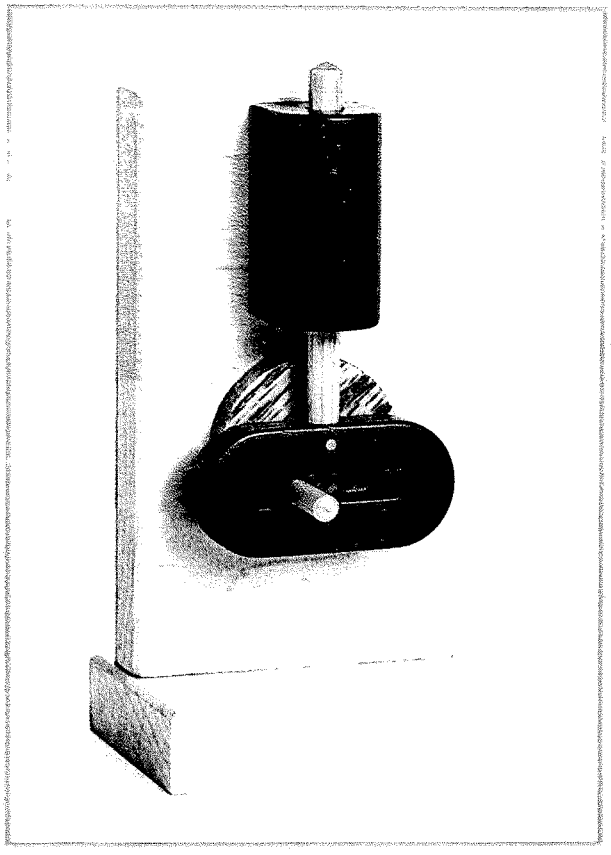




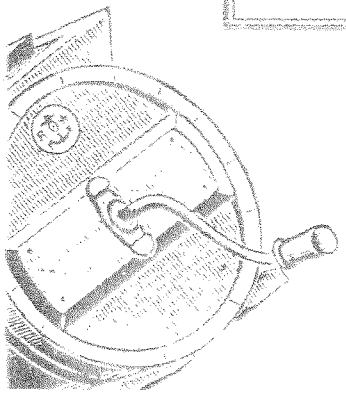
(Above) The Fast-Return Actuator has a slow, powerful working stroke and a rapid return stroke. This type of movement can be found on many machine tools. (Right) The Eccentric, which has a much-larger-than-normal crankpin, is used to drive high-pressure piston pumps and steam-engine valve gear.



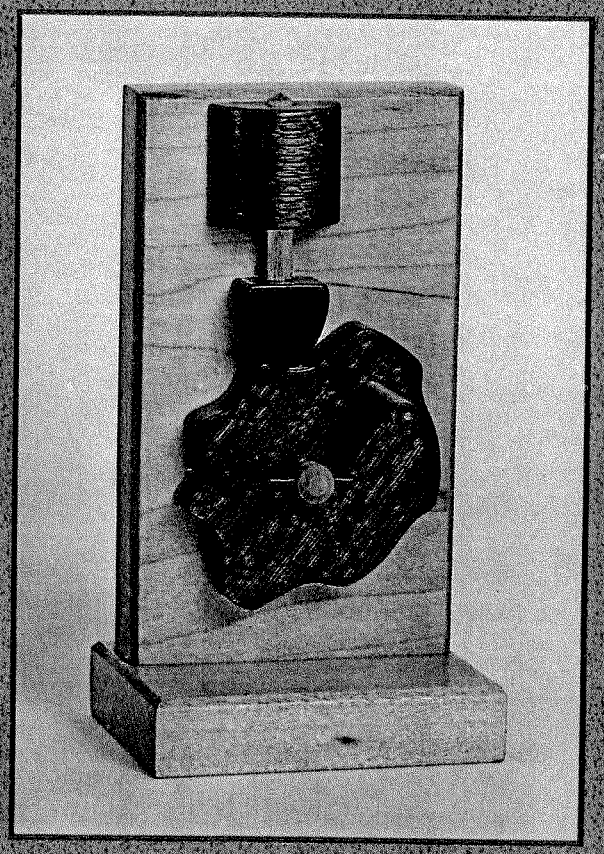


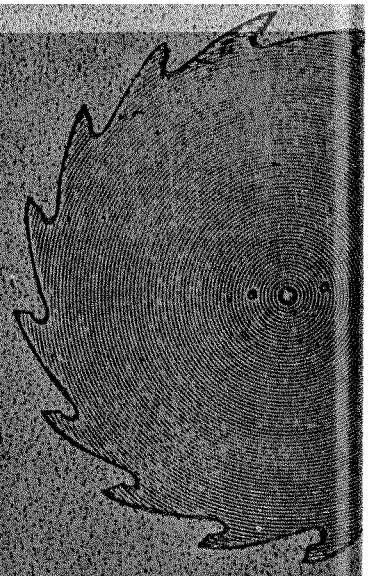


(Above) The Self-Conjugate Cam, which can operate at high speeds, has an unusual motion that makes it an interesting display model. (Right) The Scotch Yoke is a very compact substitute for the crankshaft-and-connecting rod used in most engines.

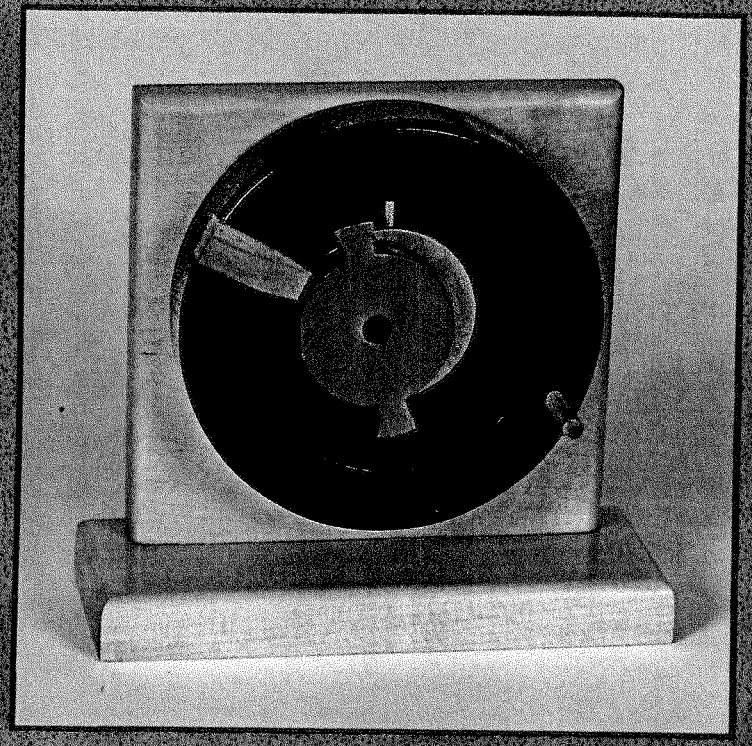


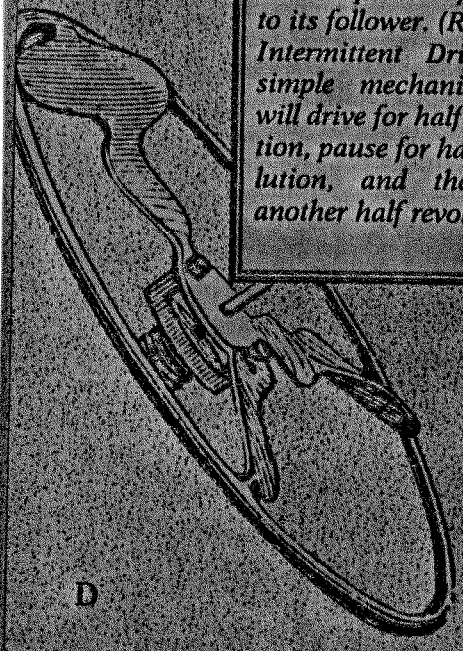
C



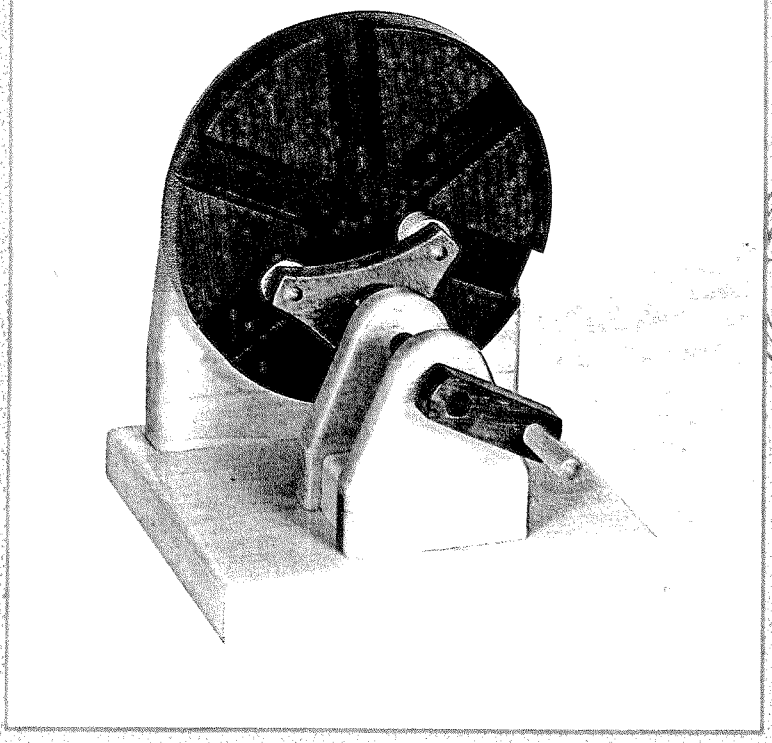


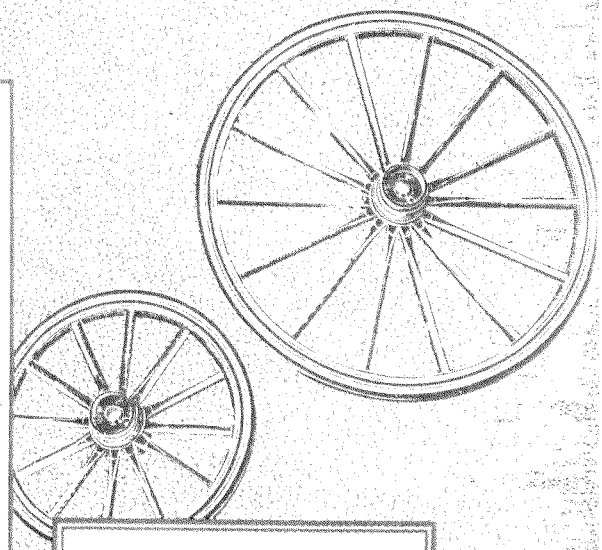
(Above) The Cam-and-Follower has a contoured rotary cam that gives a desired sequence of motions to its follower. (Right) The Intermittent Drive is a simple mechanism that will drive for half a revolution, pause for half a revolution, and then drive another half revolution.



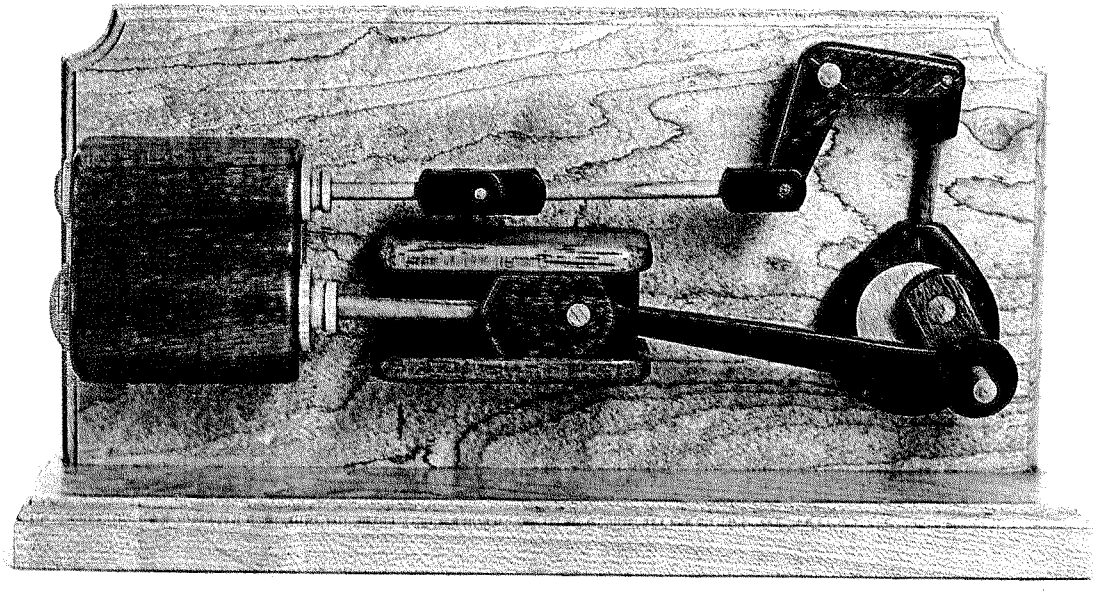


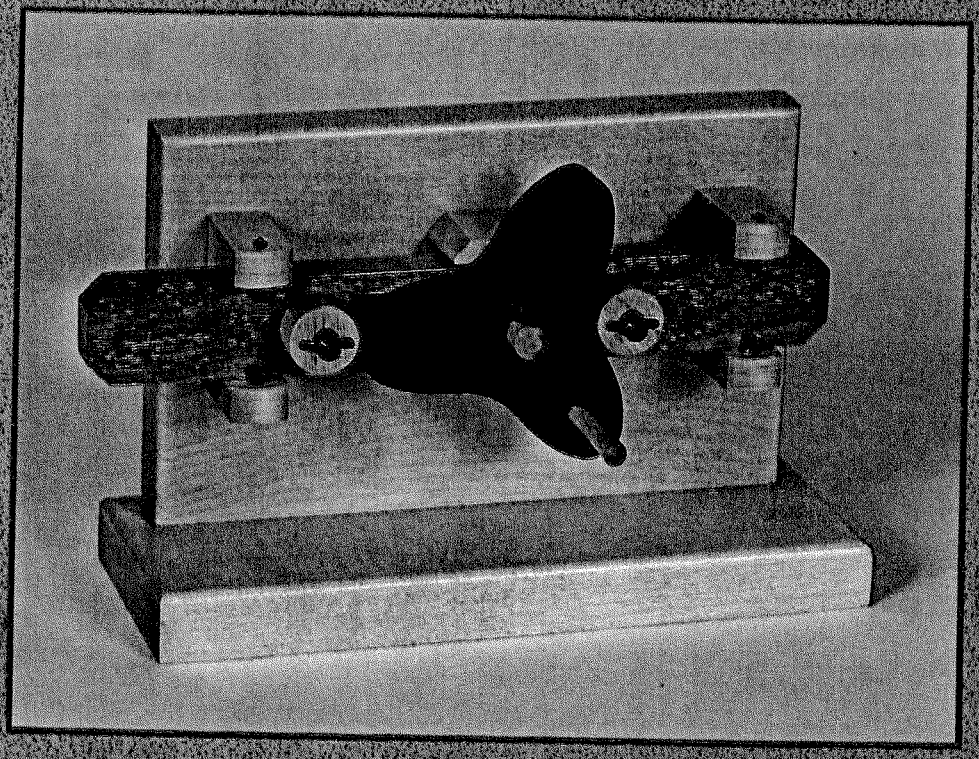
D

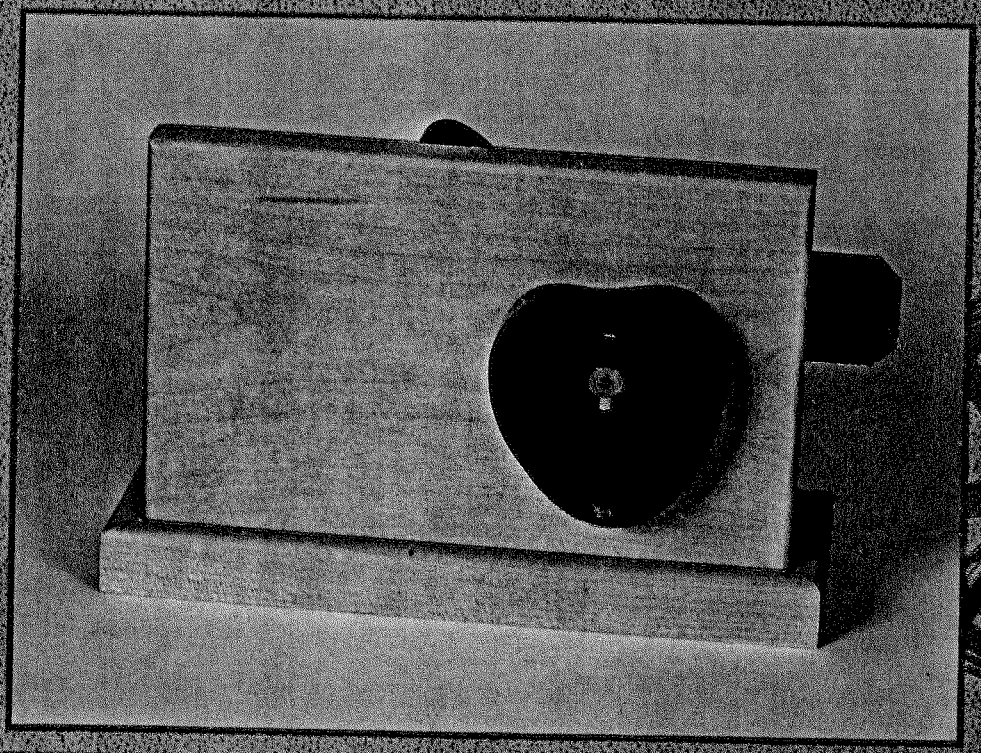




(Left) The Roller-Gearing model is a compact mechanism that requires less lubrication than other gears. (Below) The Stationary Steam Engine is modelled after a type of engine that was in use in the United States until the middle of the twentieth century.

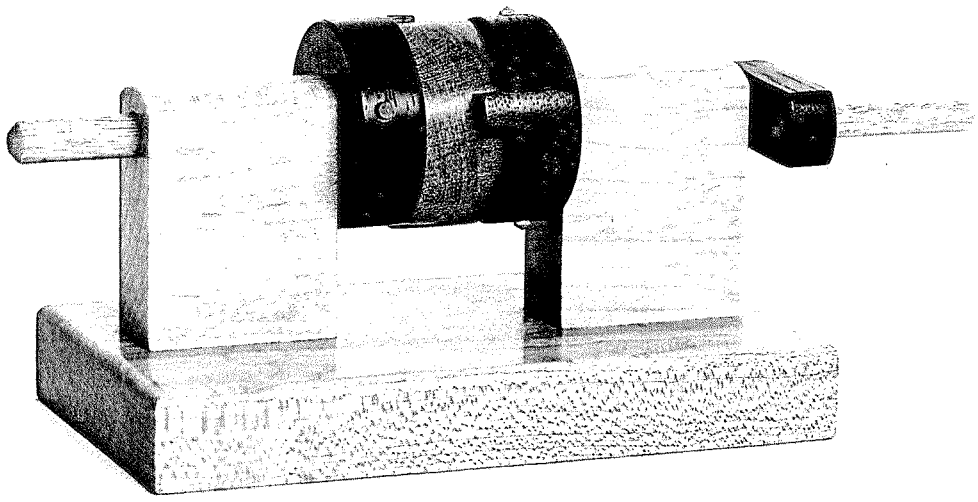




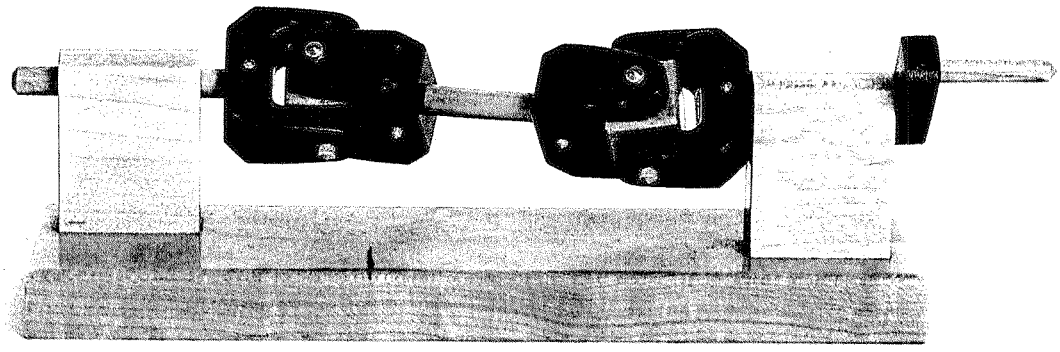


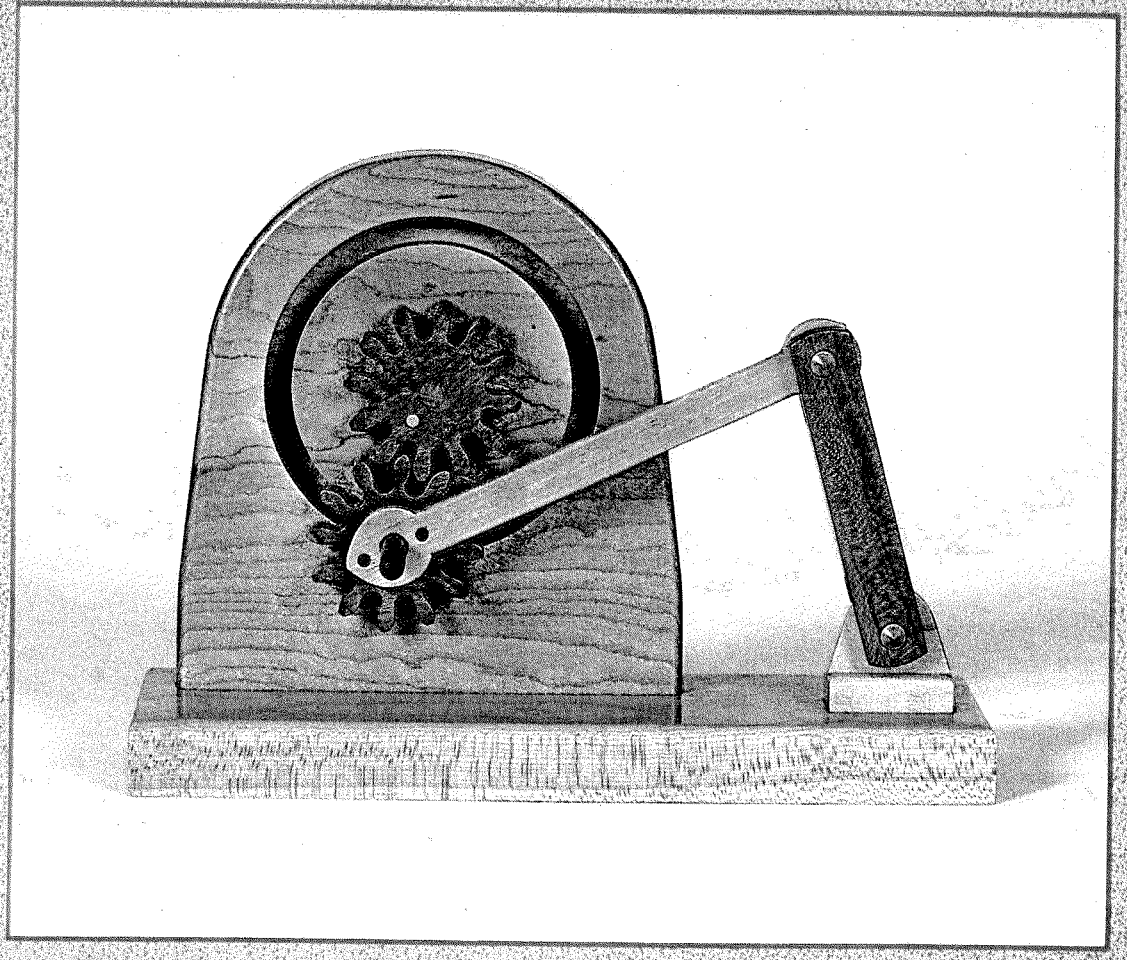
The Positive-Action Cam provides absolute control of the position of its follower, under all conditions of operation. Top: a front view of the Positive Action Cam. Above: a rear view.

F

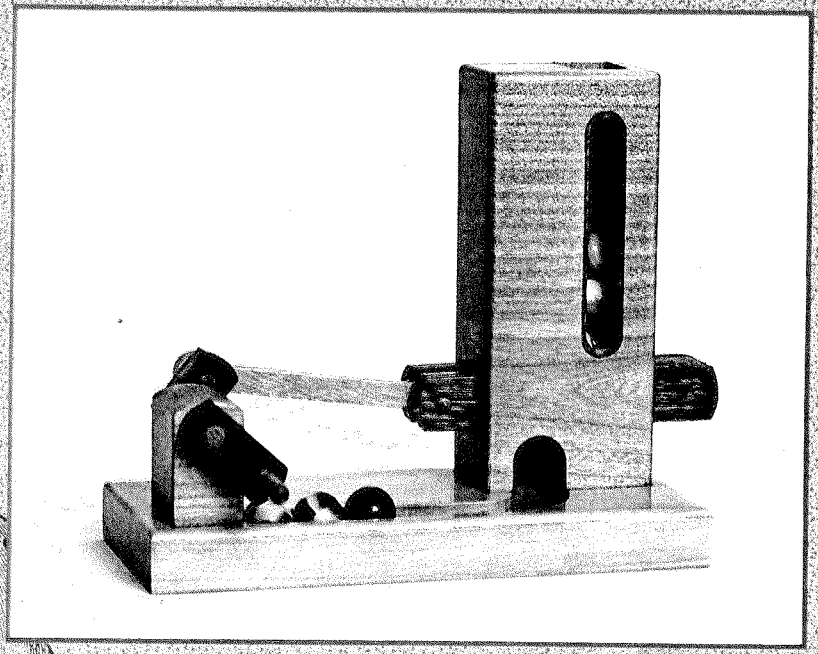


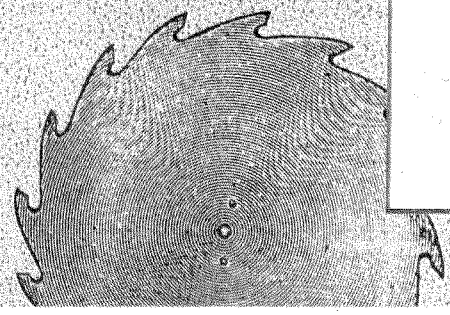
(Above) The shafts in the Double-Slider coupler have a 1/4-inch offset, but still turn smoothly. (Below) The Universal Joint actually has two sets of universal joints that, when assembled, are known as a Constant-Velocity coupler.

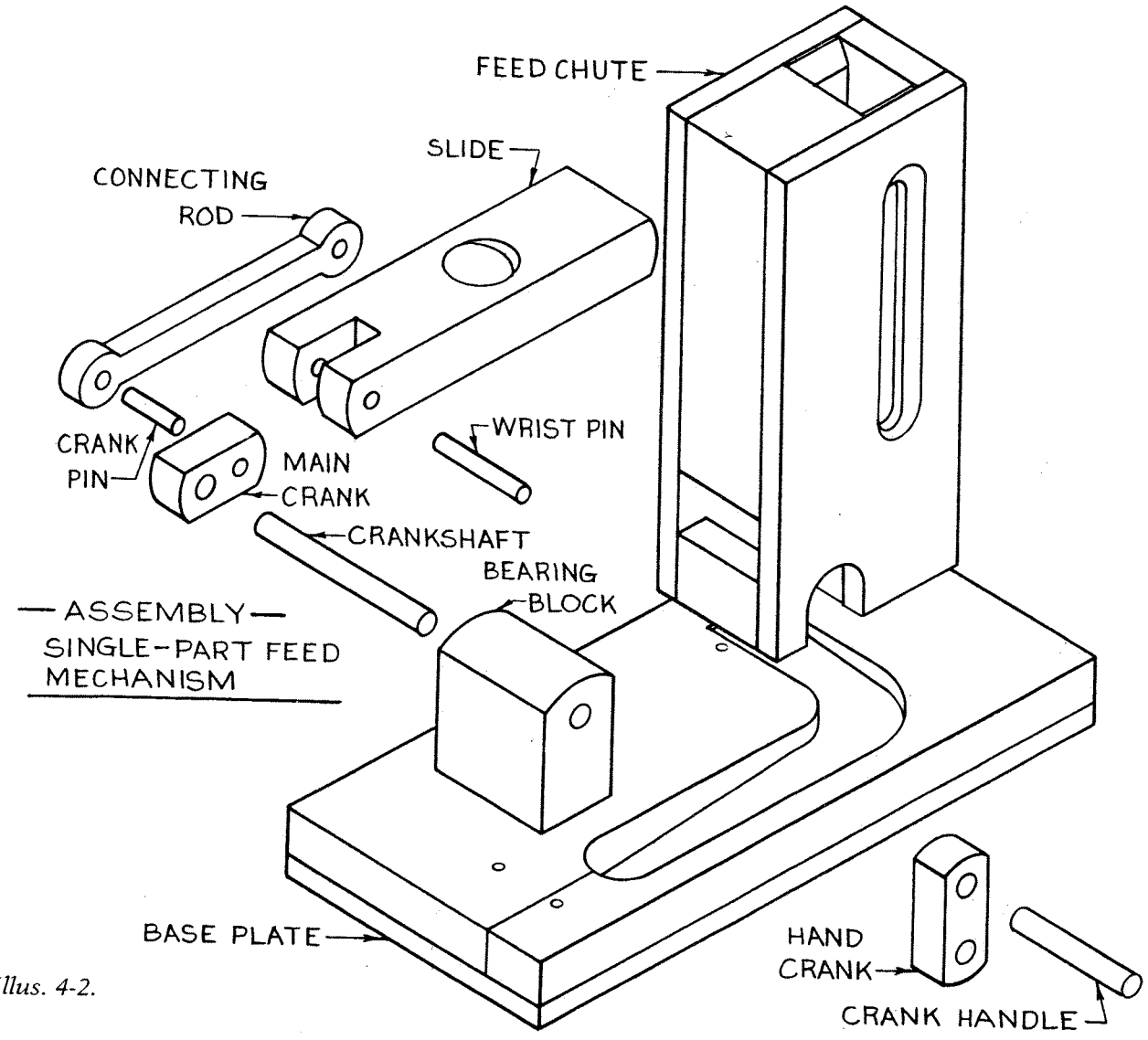




The Sun-and-Planet mechanism (above) was invented in 1775 by James Watt as a substitute for the more common crankshaft. (Right) The Single-Part Feed mechanism is a wooden version of a very common feeding system.







Illus. 4-2.

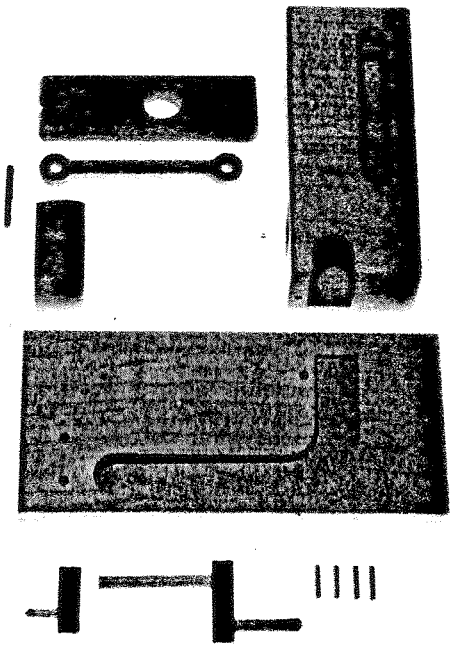
HOW THE MECHANISM WORKS

The workpieces, in this case marbles, are stacked in a supply chute. Rotation of the crank reciprocates a slide, shifting one part at a time to the delivery chute, where it drops into a storage track.

MAKING THE PARTS

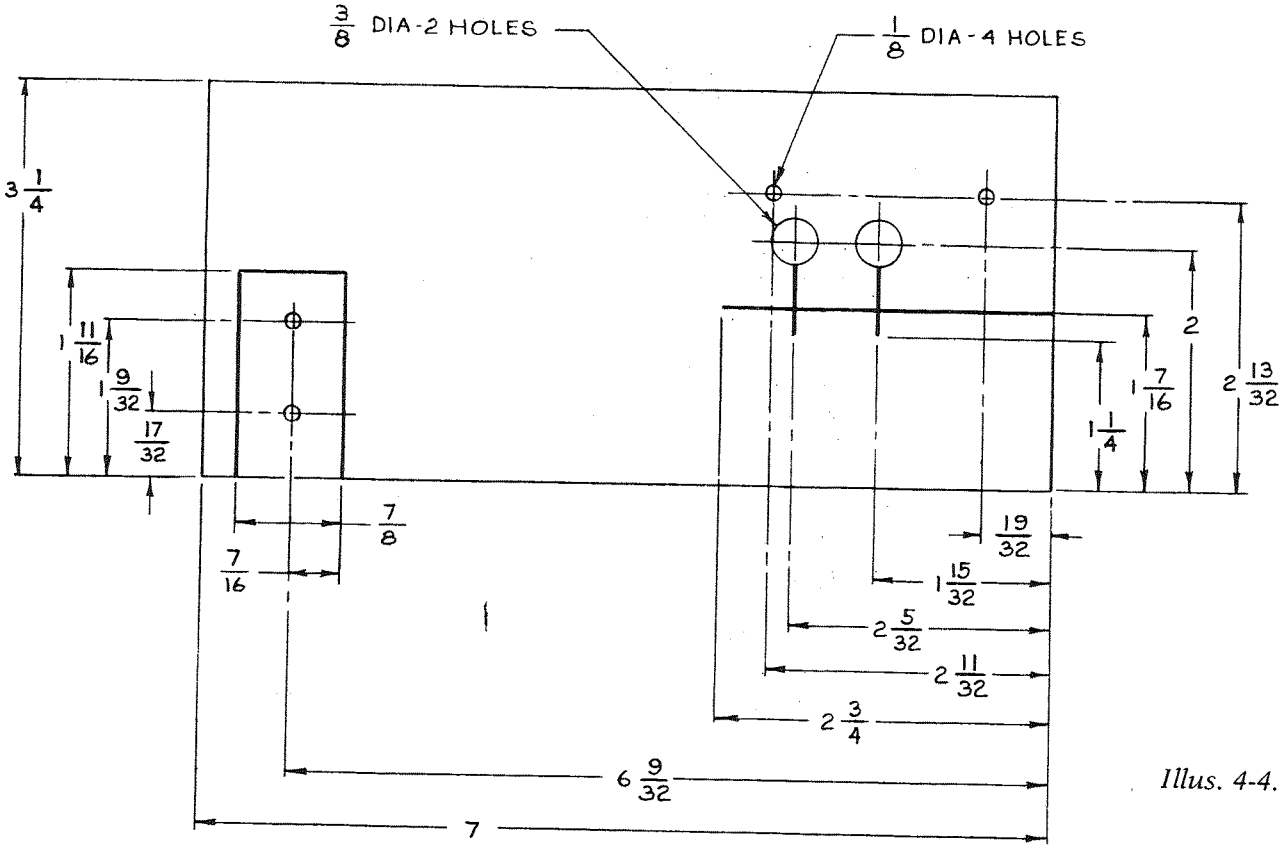
Drill Jig to Locate Dowel Holes

Make the jig from a piece of hardboard or hardwood plywood. Location of the parts is critical, and would be difficult to do satisfactorily without a jig. Mark heavy lines for the part locations, and drill the holes as shown in Illus. 4-4.

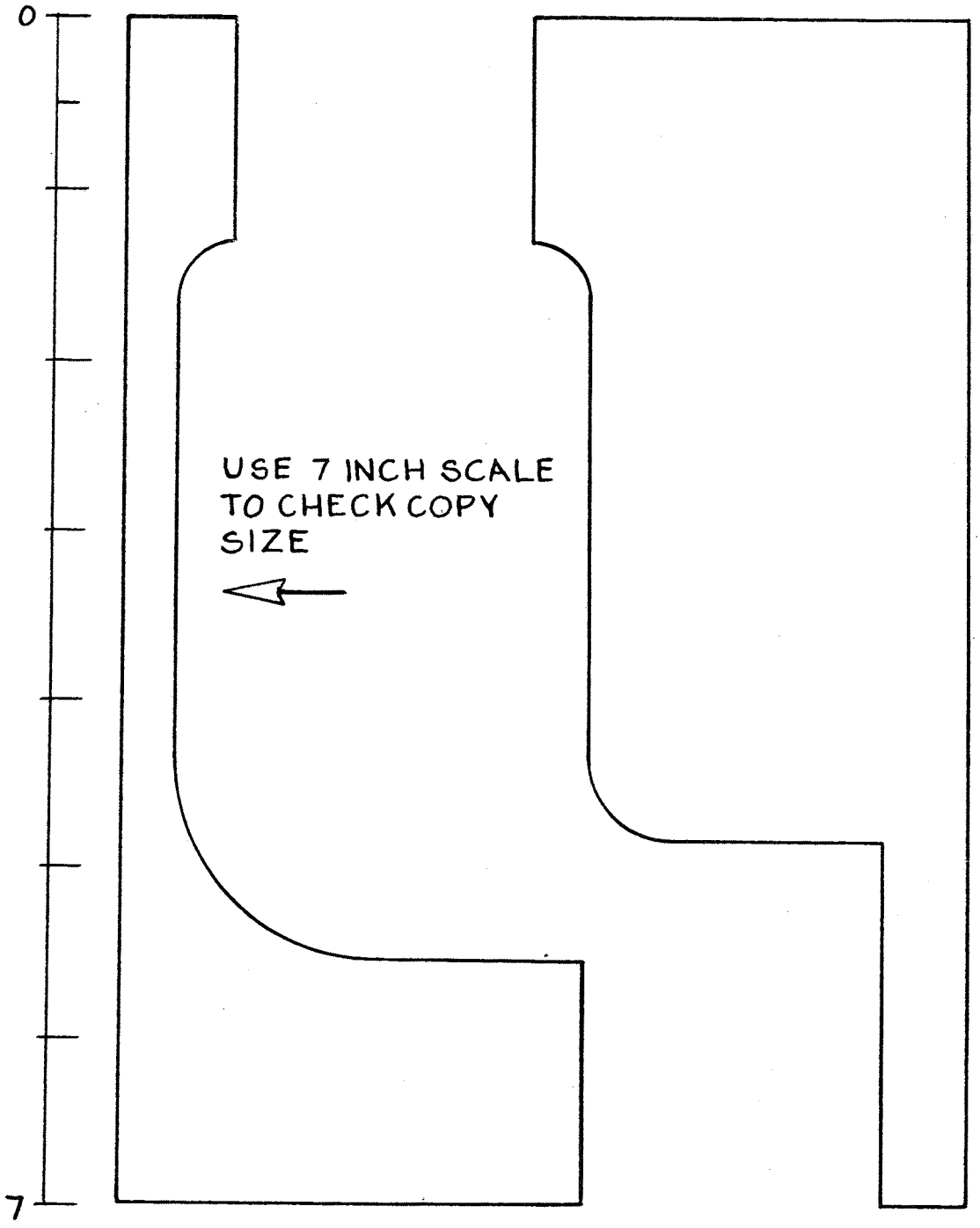


Illus. 4-3. All the parts for the Single-Part Feed mechanism.

DRILL JIG



Illus. 4-4.



PATTERN FOR BASE PLATE - UPPER MEMBER - GLUE TO $\frac{1}{2}$ INCH STOCK

Illus. 4-5.

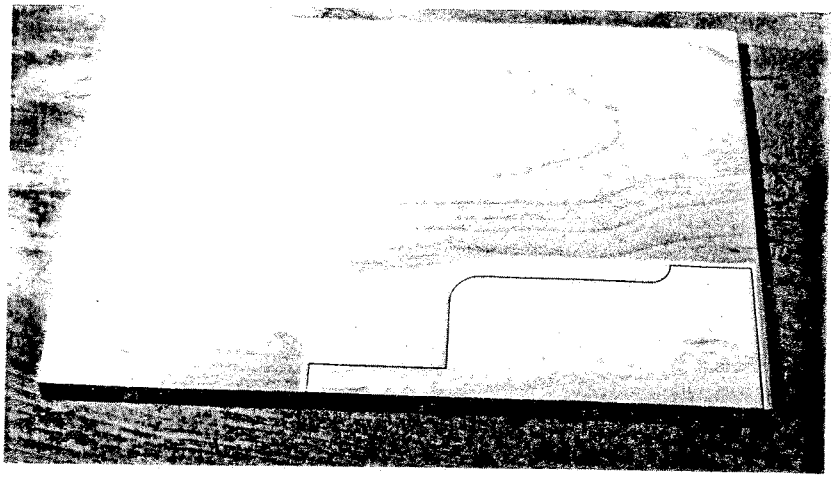
Baseplate Subassembly

Plane the material so that you have two thicknesses of ¼ and ½ inch. For a superior job, saw the bottom plate off a thick block, plane the minimum amount necessary to remove saw marks, and align the grain when gluing the assembly.

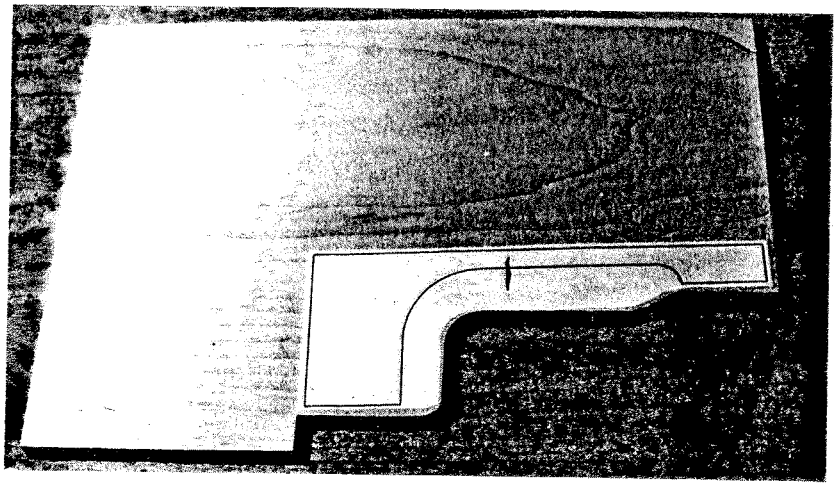
Photocopy or trace the upper base-plate member patterns in Illus. 4-5. If you have photocopied the patterns, check their sizes by comparing the seven-inch gradations on the left with those of a steel scale. Many self-service copiers are adjusted to give copies that are 102% of the original size. Most large-copy businesses have at least one machine that has infinitely variable magnification, and that will make copies at 100% of the original size.

Glue on the first half of the pattern. (See Illus. 4-6.) If you follow the sequence shown in Illus. 4-6–4-8, the end grain on the base-plate pieces will match, and you will get the most economic use out of the material. Cut the part out with a band saw and finish-sand it to the line. I use small drum sanders in the curves, and files and scrapers for the rest of the contour.

Glue on the second half of the pattern, and repeat the previous operations. (See Illus. 4-7.) Check the fits of the surfaces to be glued; if they are suitable, scrape the surfaces lightly and glue the two parts. When the glue has dried, flatten the bottom with a small plane and scrapers. If you use a small drum sander carefully, you will be able to blend in any small mismatch of the end-track radius. (See Illus. 4-8.)



Illus. 4-6. The first half of the pattern glued to the wood.



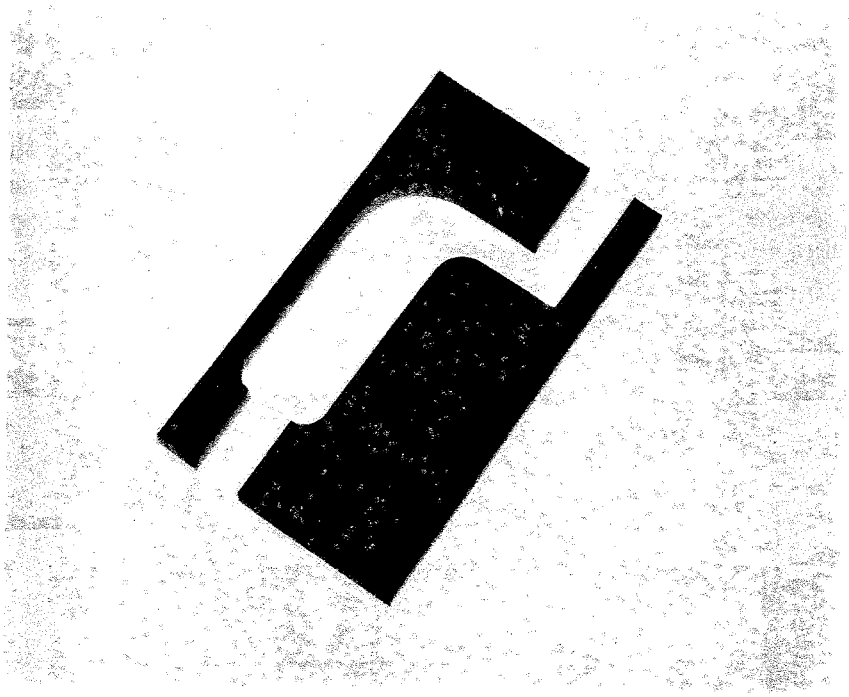
Illus. 4-7. The second half of the pattern glued onto the wood.

Track Insert

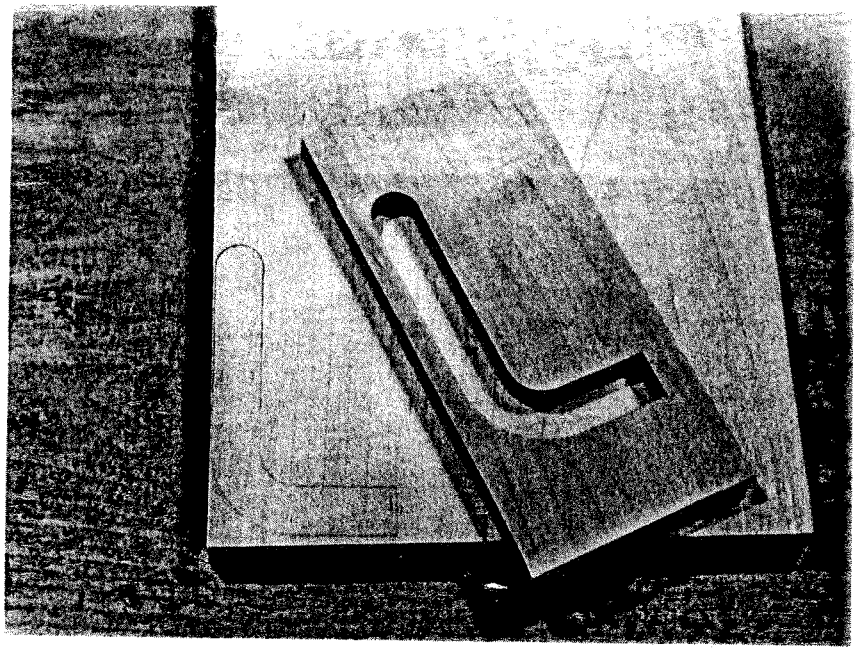
Clamp the upper member to a piece of the same stock, and trace the track outline. (See Illus. 4-9.) I use a very sharp, hard lead in a draftsman's lead holder for this. Cut out the part with a band saw and finish-sand it to the line, using a belt sander on the outside contours, and a drum sander on the inside curves. The part should fit snugly, but not tightly, into the track. (See Illus. 4-10.)

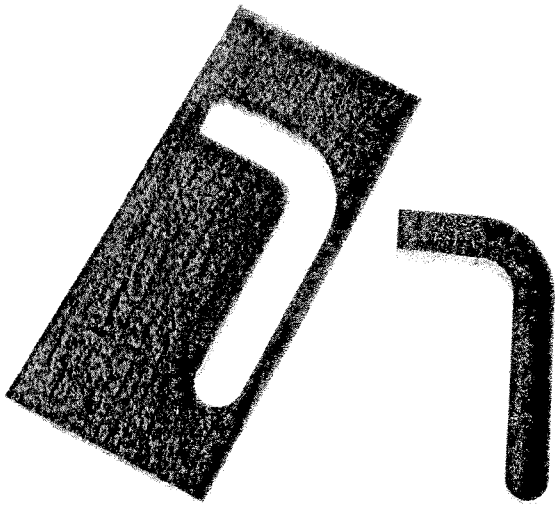
Cut the piece for the bottom member so that it is at least ⅛ inch longer and wider than specified. Center the upper member on

Illus. 4-8. The completed parts of the upper baseplate member.

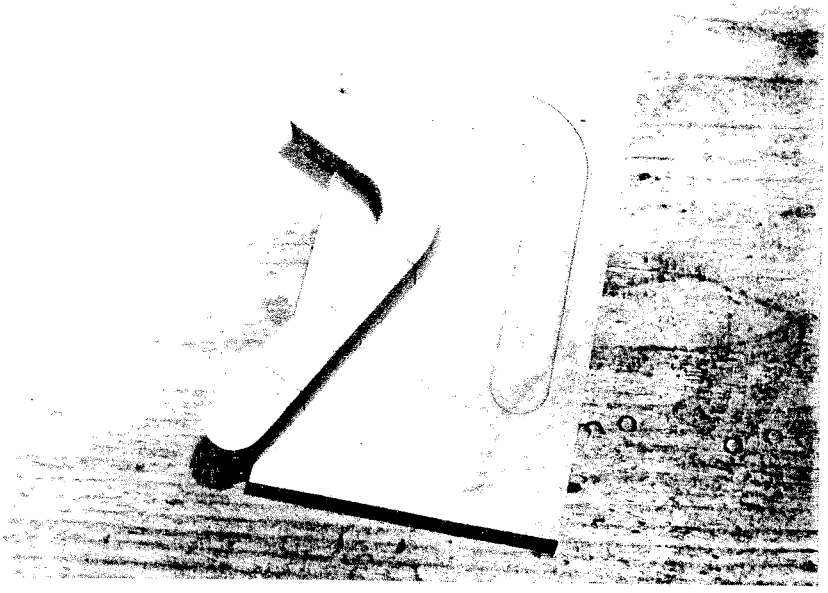


Illus. 4-9. Tracing the track insert.





Illus. 4-10. The track insert and the upper member.

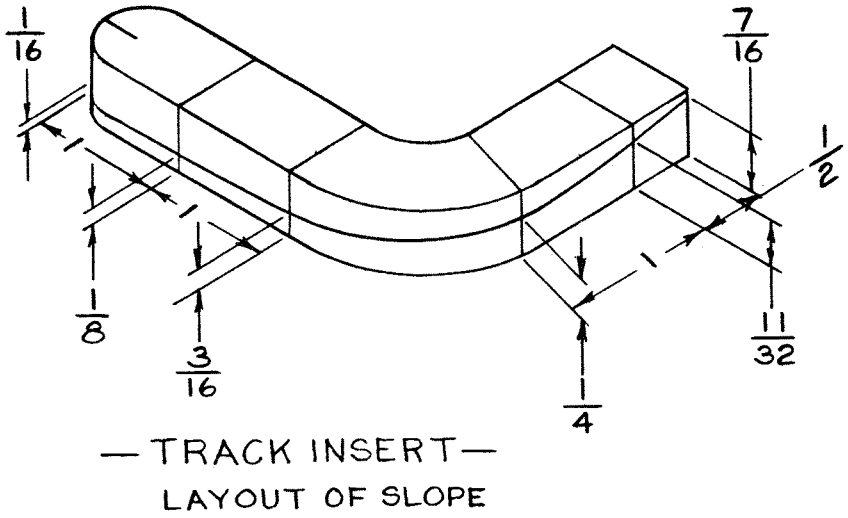


Illus. 4-11. The insert and the baseplate with the traced outline.

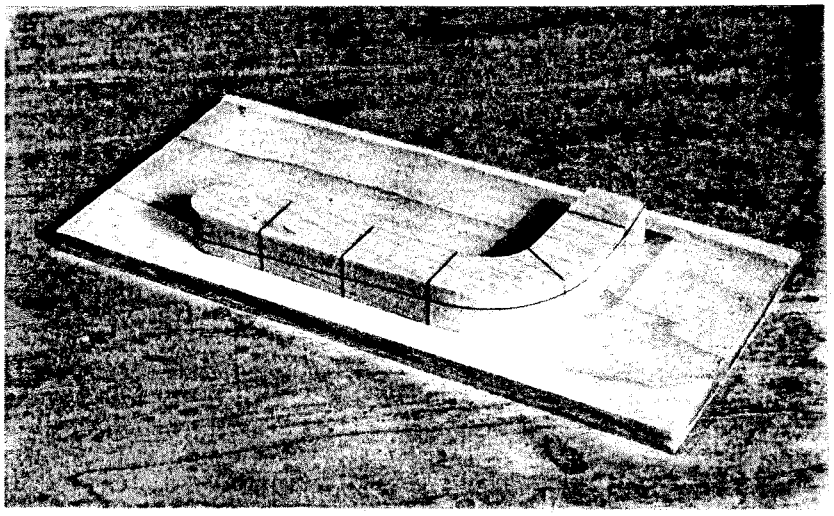
the part, and trace the track outline, to show the location of the insert. (See Illus. 4-11.) Lay out the slope of the insert as shown in Illus. 4-12, but don't cut it yet; this operation is a lot easier when the part is glued to the lower member. Scrape the bottom of the insert clean, apply a thin, narrow bead of glue, and set the insert in place in the pencilled outline. Use several small clamps, and check that the part doesn't move while you are clamping it. (See Illus. 4-13.)

Allow the part to dry overnight, and then clamp it to the workbench, using the lowest profile clamps you can find. Carefully cut the slope of the insert, keeping its narrow width parallel to the base all around the part. I remove most of the stock with a chisel, and finish trimming to the line with a round-

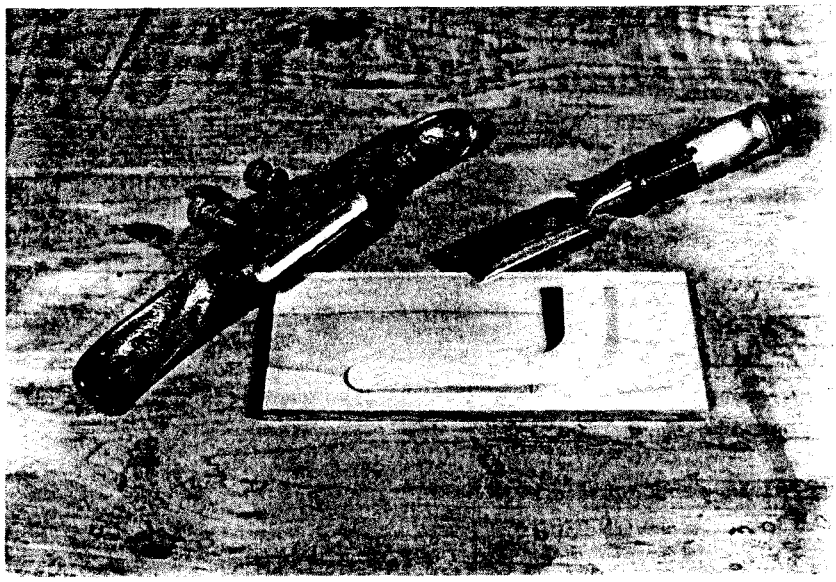
Illus. 4-12.



Illus. 4-13. The insert glued to the baseplate.



Illus. 4-14. You can remove most of the stock with a chisel and trim to the line with a spokeshave.



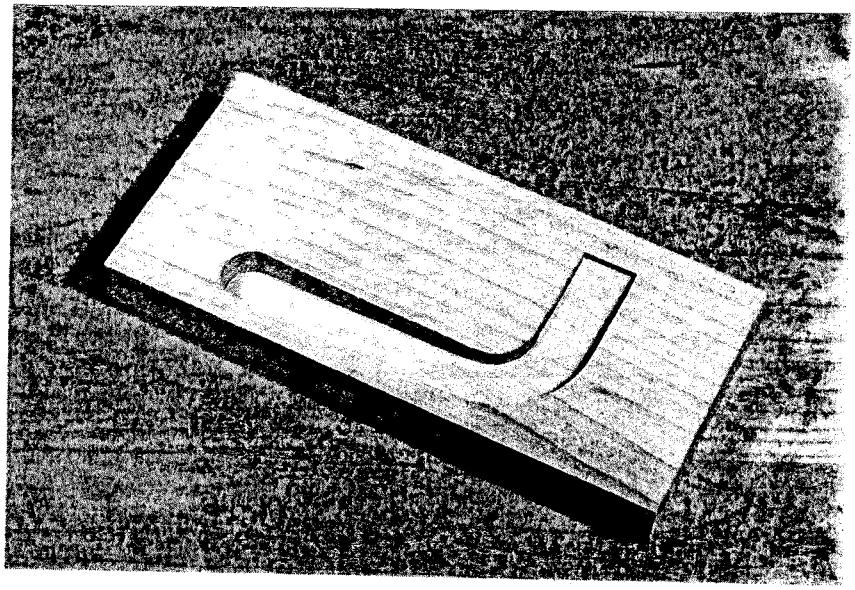
bottom spokeshave, but you could use a file and sandpaper. (See Illus. 4-14.) Try to achieve a smooth sloping surface, without bumps or hollows. If the wood needs to have its grain raised, do it now, as the surface of the track is unworkable after assembly.

Completing the Base

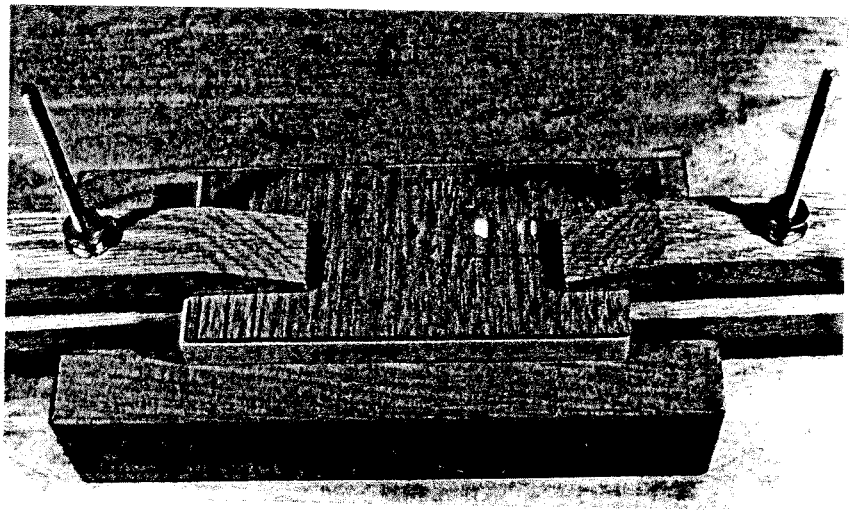
Set the upper member in place, and check its fit with the lower member. If a gentle warpage has occurred on the thin plate, clamp the parts lightly before checking the fit. Make any indicated corrections, apply a film of glue to both surfaces, keeping the glue well clear of the track and the insert, and clamp the parts. It's best to use a thick caul block on the bottom to help produce a flat assembly.

Unless you are in a hurry, give the assembly two days to dry before removing the clamps. If you do, the assembly will have a better chance of remaining flat. Now trim the part to size and round or chamfer the upper edges. (See Illus. 4-15.)

Align the lower edge of the drill jig with that of the baseplate. Look through the two ⅜-inch holes, and line up the edges of the track with the short vertical lines on the jig. (See Illus. 4-16.) Clamp the jig in place, and



Illus. 4-15. The finished base.



Illus. 4-16. The drill jig clamped to the base.

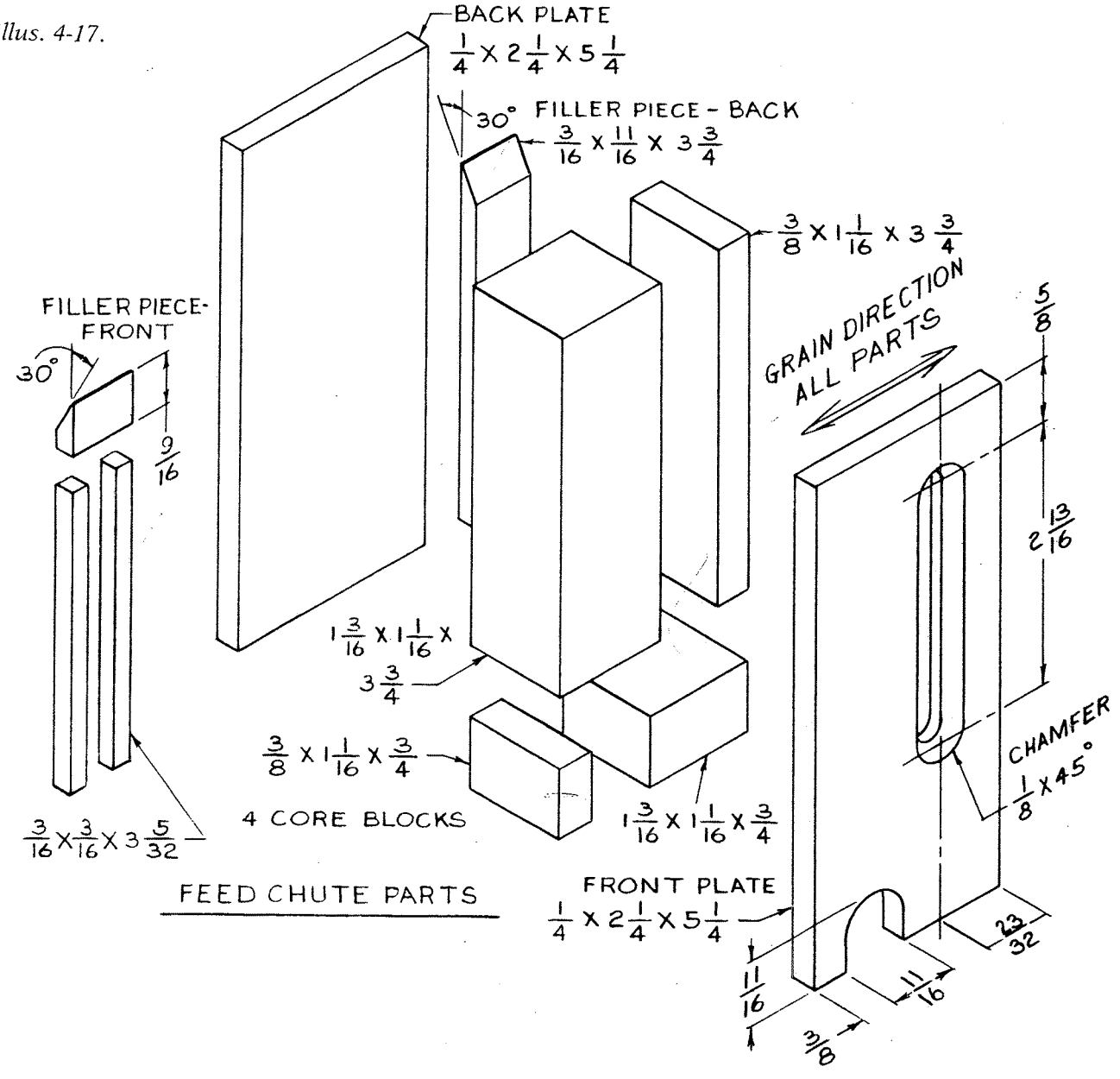
drill the four dowel holes. This completes the baseplate.

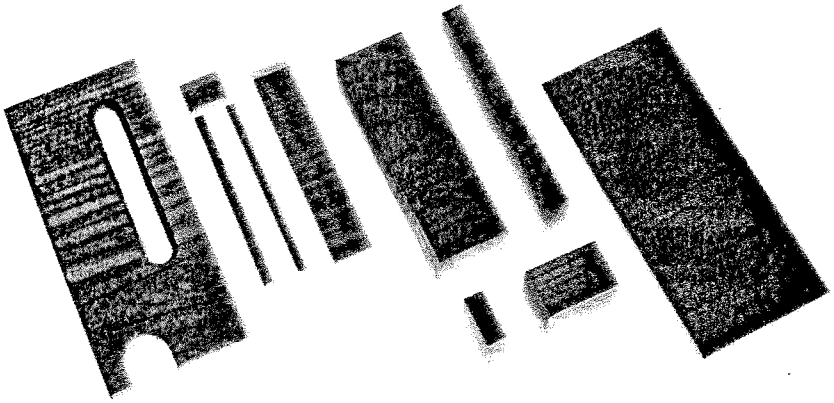
Feed Chute Subassembly (Illus. 4-17 and 4-18)

The feed chute subassembly will look best if all its parts are cut from one thick block. If this is not practical, at least try to match the grain. Plane to the two thicknesses, and cut the front and back plates and the four core blocks, observing the grain direction indicated in Illus. 4-17.

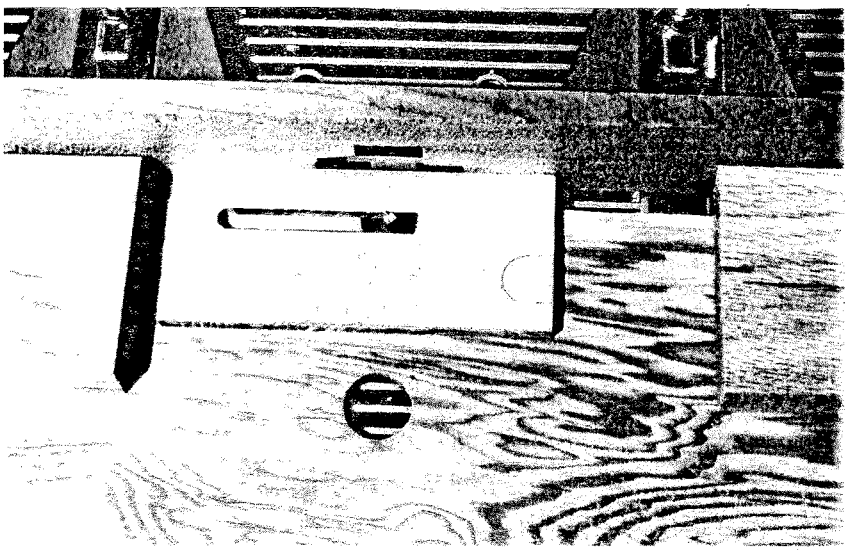
Set up a fence on the router table so that the centerline of the viewing slot is in line with the spindle of the router. Clamp two end stops to control the length and position of the slot, and set up a ¼ inch router bit. Cut the slot in several passes, feeding the bit up to a maximum of 1/16 inch at a time.

Illus. 4-17.





Illus. 4-18. The parts for the feed-chute subassembly.



Illus. 4-19. Cut the viewing slot with a router.

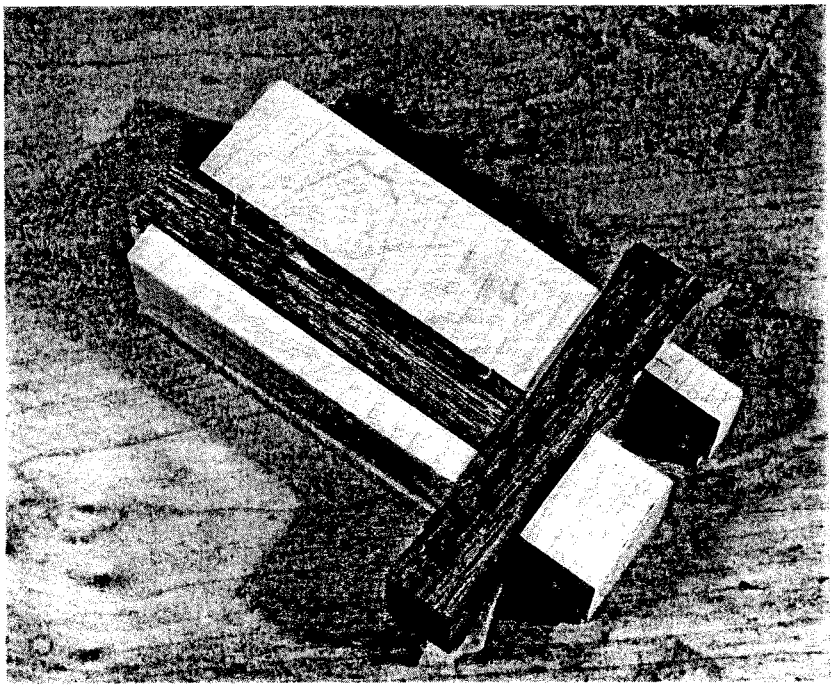
Hold one end of the part firmly against both an end block and the fence, and lower the other end slowly onto the spinning bit. Feed the piece along to the other end stop, and lift the end off the bit. Work safely; keep your fingers well away from the area of the cut, and control the part at all times.

When you have cut through the thickness, substitute a 5/16-inch bit for the first one, and cut the slot to size. Don't forget to check the positions of the two stop blocks, to avoid making the slot too long. (See Illus. 4-19.) I slow my router down so that it operates at about 40% of its top speed. This allows me to make cuts like this without having to worry about burning the wood. When the slot is cut to size, set up a 45° chamfering bit, if you own one, and cut the 1/8 inch × 45° chamfer.

Lay out the ball-exit cut on the plate, and make the cut with a band saw. Finish-sand to the line with a small sanding drum. Work very carefully, as the narrow piece on the side has a short-grain section, and can be easily broken.

Make the front and rear chute inserts by cutting them from a thick piece of stock. With the block upright against the table saw rip fence, and the fence adjusted 3/16 inch from the blade, make cuts 3/4 inch deep in the end grain on both sides of the piece. Then crosscut an 1 1/16-inch-wide piece from each face. Repeat the operation to cut the two narrow pieces. Making the cuts this way results in much straighter parts than cutting them from thin stock. Complete the parts as shown in Illus. 4-17. The narrow front inserts are very

Illus. 4-20. The core blocks in place with the spacers inserted.



fragile, but they don't take any stress, and they ensure that the grain directions will match properly. (See Illus. 4-18.)

Now, cut and plane a piece of stock from which to make the slide. Make this at least twice as long as the part. After you have finish-sanded the stock to its proper width and thickness, cut two blanks the length of the slide. You will use these two pieces as gluing spacers for the feed chute, thus establishing the correct fit for the completed slide.

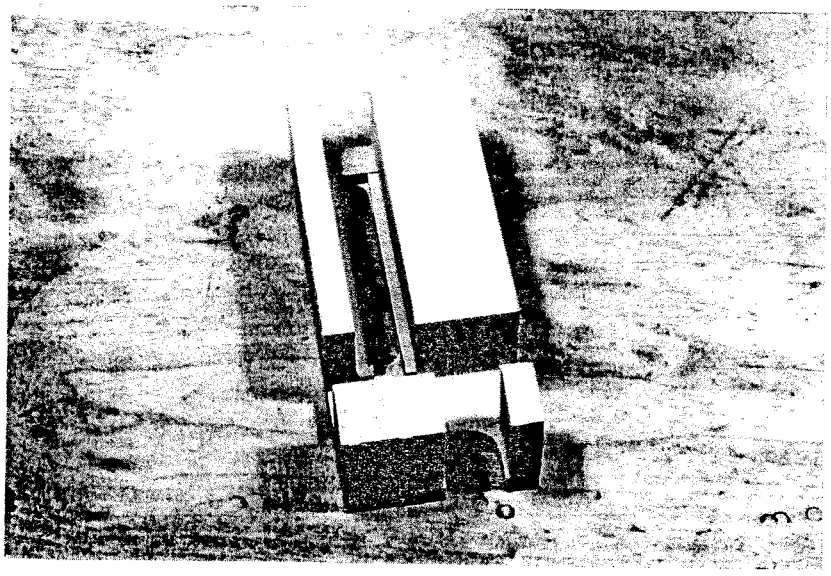
Finish-sand the inner edges of the four core blocks. Set the front plate, with its inner face up, on a pair of blocks that will give you clamping clearance. Cut a couple of pieces of waxed paper and wrap them around three sides of each of the two pieces of stock you cut for the slide. Wipe glue on the tall, narrow core block, and clamp it in place, flush with the top and the edge of the front plate. Now, put one of the waxed-paper-wrapped blocks against this piece and glue the tall, wide core block to the plate, pushing it against the waxed-paper-wrapped spacer block.

Set the other half of the slide stock against the lower ends of the core blocks, and check that both blocks are in line. When they are lined up properly, clamp the wide core block in place. Now, glue on the lower core blocks, keeping them snug against the slide piece, and clear of the ball exit gate. Put the parts aside to dry. (See Illus. 4-20.)

Remove the clamps and the paper-wrapped spacer blocks, and do any necessary clean-up work. Put just a little glue on the short, upper piece of the front insert, and position it flush with the top surface of the assembly. Clamp it in place for approximately 15 minutes, to give the glue a chance to set.

Put the two narrow insert pieces in position on both sides of the viewing slot, using a very small amount of glue. Now, remove the clamp from the upper piece, and set the spacer block you used originally on top of the three insert parts. Clamp it lightly and look in the viewing slot to make sure that none of the pieces has shifted. Tighten the clamp and allow the assembly to dry. (See Illus. 4-21.)

Check the flatness of the assembly thus far. Make sure that the backplate fits well and does not have any gaps. Glue on the backplate, checking the chute openings for squeeze-out, and remove any glue before it hardens.



Illus. 4-21. The chute with the front inserts.

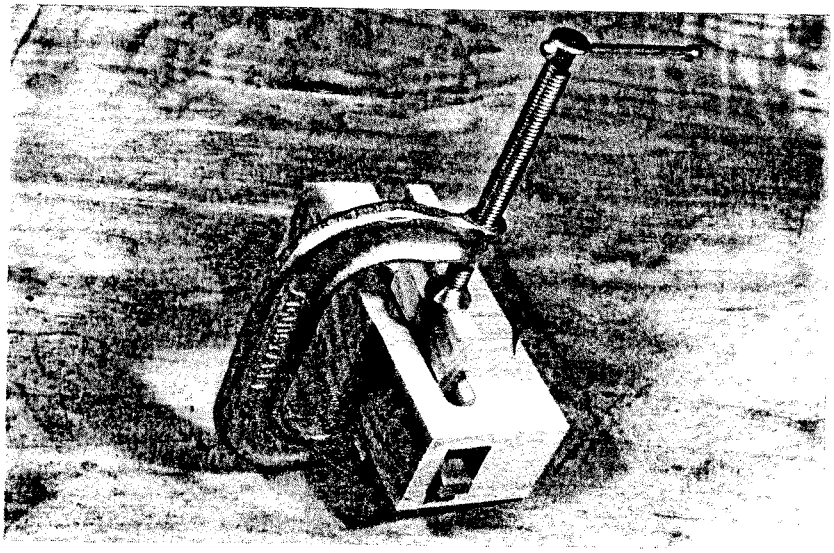
Wipe a film of glue on the back insert, and slide it into place. Cut a narrow caul block to go into the chute, and another piece that will go through the viewing slot. This will allow you to clamp the spacer, as shown in Illus. 4-22.

Sand the entire assembly and round or chamfer all the corners, except around the bottom. Place the part upright on the drill jig, with its front surface on the line, and align both sides of the ball-exit slot with the two short, vertical lines. Clamp it in place, invert it, and drill the two dowel holes 5/16 inch deep. (See Illus. 4-24.)

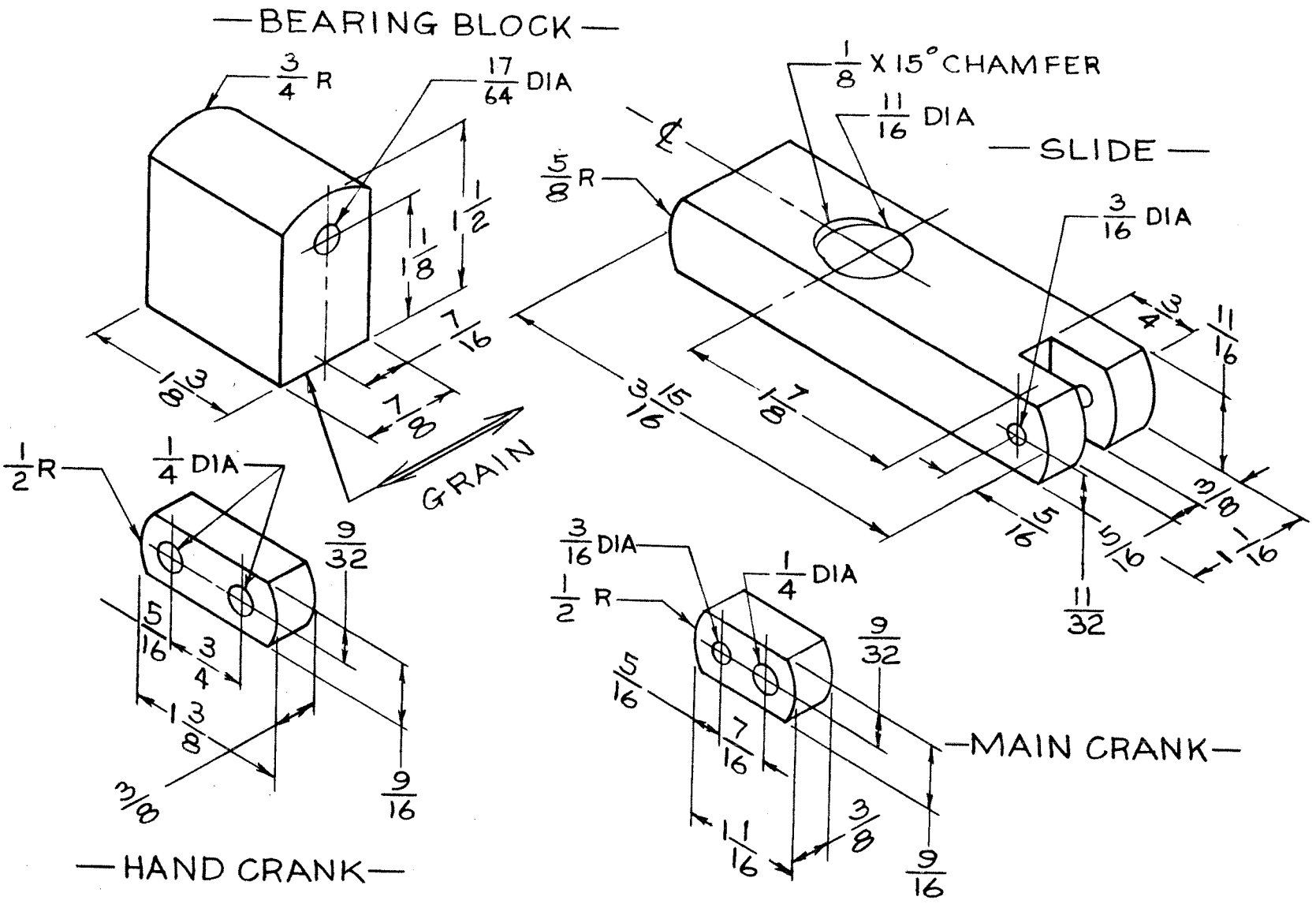
Bearing Block

This part requires 1½-inch-thick stock, but can be glued up of two thicknesses. Be sure to observe the grain direction shown in Illus. 4-23. Square up the block, and lay out the hole center on each end. Draw the radius using a pencil compass or a draftsman's circle template. Drill undersize holes halfway through from both ends, and then finish drilling the holes with a full-sized drill, all the way through from one end. Saw and sand the radius.

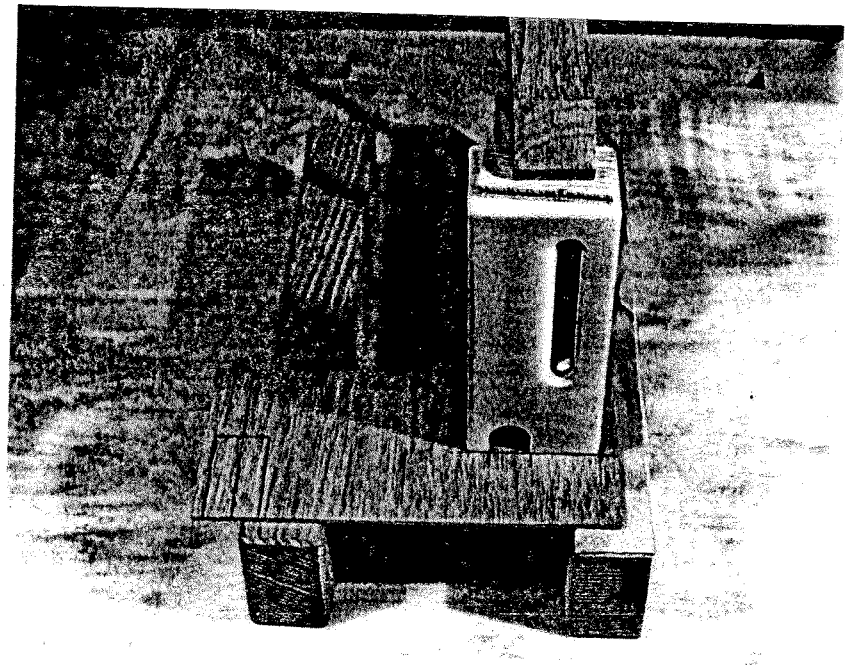
Center the block over the two vertical lines



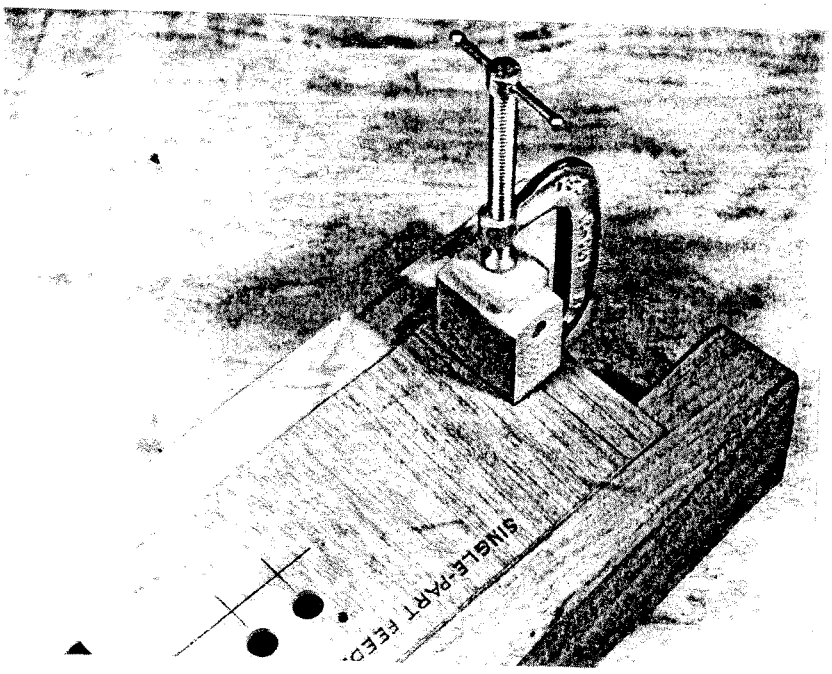
Illus. 4-22. Clamping the rear insert using a caul block and a spacer.


—BEARING BLOCK—
3/4 R
17/64 DIA
1 1/2
1 1/8
7/16
1 3/8
7/8
GRAIN
1/2 R
1/4 DIA
9/32
5/16
3/4
1 3/8
3/8
9/16
—HAND CRANK—
1/8 X 15° CHAMFER
11/16 DIA
—SLIDE—
5/8 R
3/16 DIA
3/4
11/16
3 15/16
1 7/8
15/16
3/8
1 1/16
11/32
3/16 DIA
1/4 DIA
1/2 R
9/32
5/16
7/16
1 1/16
3/8
9/16
—MAIN CRANK—

Illus. 4-23.



Illus. 4-24. The supply chute clamped to the jig.



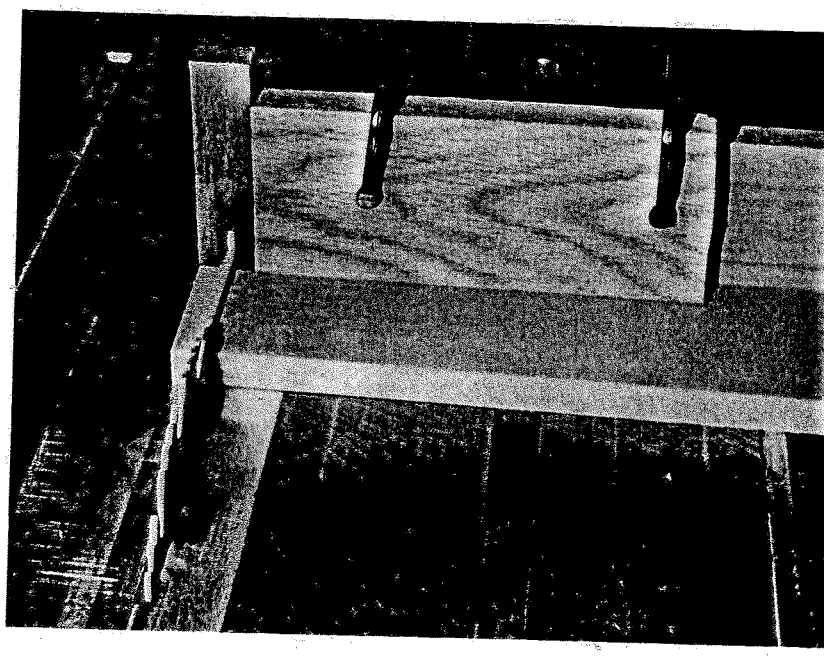
Illus. 4-25. The bearing block clamped to the jig.

on the jig, placing the upper end on the horizontal line. Clamp the block in place, and drill the dowel holes 5/16 inch deep. (See Illus. 4-25.)

Slide (Illus. 4-23)

Make this part from one of the pieces that you used as spacers. Lay out the hole centers on both sides, and draw the end radii. Drill from both sides to the center, before cutting the slot. Slotting is best done on the table saw; make several cuts to remove the material. Illus. 4-26 shows a right-angle jig that I use on the saw. It backs up the workpiece to help prevent splintering, and also permits the clamping of small pieces that would be unsafe to hold by hand.

Illus. 4-26. Cutting the slot in the slide.

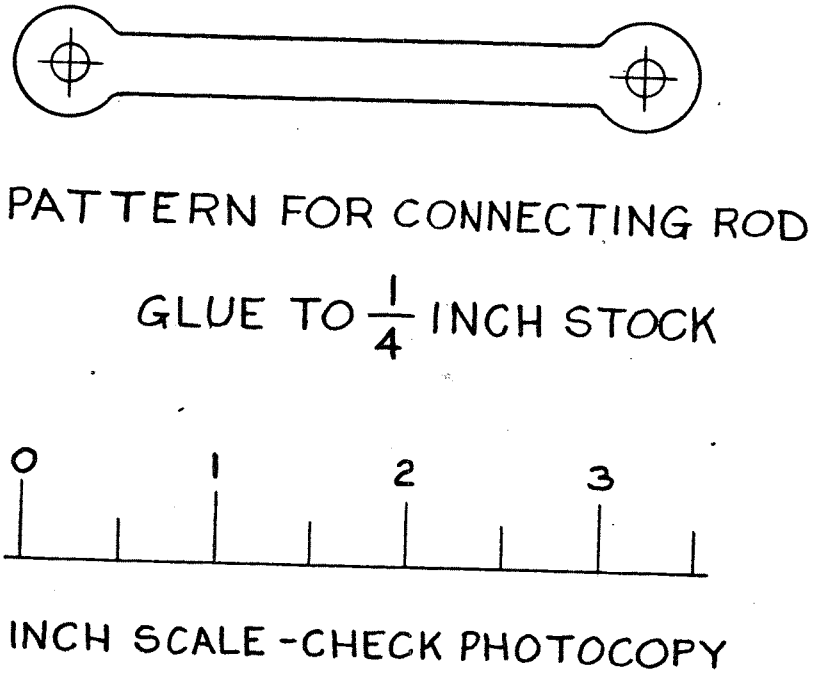


Drill the 1 1/16-inch-diameter hole, and cut the partial chamfer as shown in Illus. 4-23, using a gouge or a sharp knife. The chamfer dimensions are not critical, but this feature will make the action smoother on the backstroke.

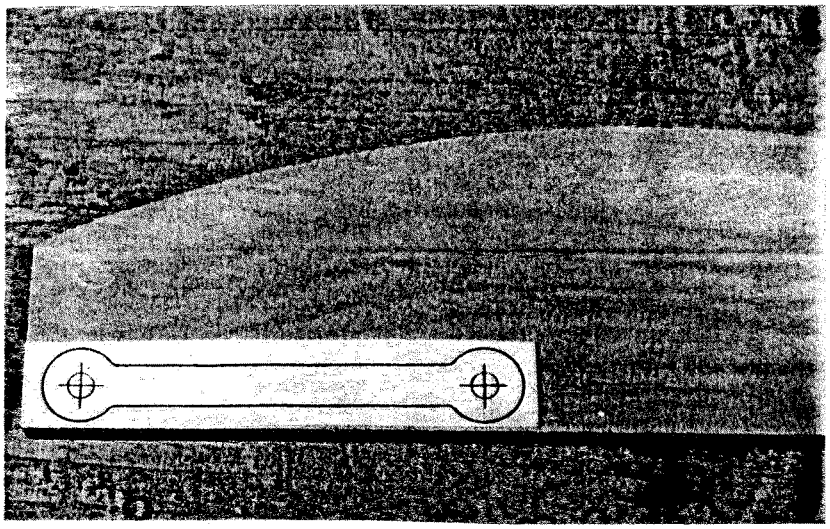
Lightly chamfer the four long corners, to provide clearance in the slot, and test the fit of the slide in the feed chute. It should move easily, without excessive shake. Fine-sand the part, raising the grain if your material requires this.

Connecting Rod

Plane the stock to the correct thickness, and glue on the photocopy of the pattern shown in Illus. 4-27; make sure that you have a full-size

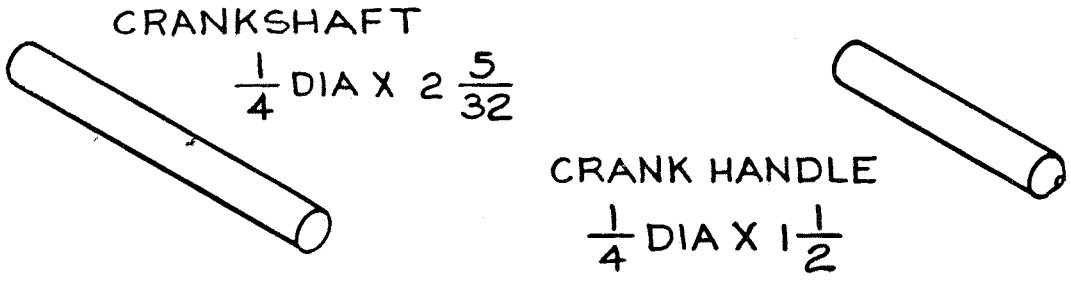


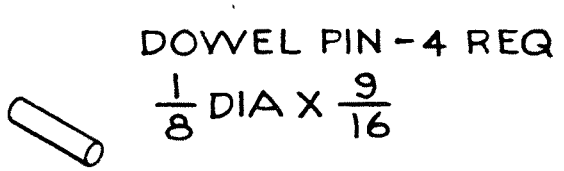
Illus. 4-27.



Illus. 4-28. The connecting-rod pattern glued to the wood.

Illus. 4-29.





photocopy, and not the normal oversize print. (See Illus. 4-28.) Drill the holes, and saw and file or sand the outline. Remove the pattern, and finish-sand the part.

Crankshaft Assembly (Illus. 4-29)

There are five pieces to this component, and they should be fitted together in the sequence outlined below. The parts are similar to those for the steam engine in Chapter 3, so I won't repeat the instructions here.

Cut the crankshaft so that it's slightly oversize, and check that it fits and works well in the bearing block. Glue the shaft into the hand crank, sanding the end flush when dry. Glue the crank handle into the hand crank and sand it flush with the back side of the piece. Glue the crankpin into the main crank and sand it flush.

Now, insert the crankshaft into its hole in the bearing block. In a piece of cardboard about 1/64 inch thick, cut a slot that will just clear the diameter of the crankshaft. Place this cardboard on the back face of the bearing block, around the crankshaft, and push the main crank onto the shaft until it is against the cardboard.

Now, place a marking knife or a chisel flat against the face of the main crank, with the cutting edge against the end of the shaft. Revolve the shaft a few turns to score a deep line around its circumference. Remove the main crank and cut off the end of the shaft, up to, but not past the line. Sand the end smooth, and lightly chamfer the sharp corner.

Remaining Parts

The remaining parts are the wrist pin and the four dowels. Fit the wrist pin so that you can push it into its hole in the slide with your thumbs. (See Illus. 4-3.)

ASSEMBLING THE MECHANISM

Make a trial assembly of all the parts, before gluing any of them. Set the feed chute and the bearing block in place, positioning them with the four dowels. Check that the dowels are not so long that they prevent proper assembly.

Put the crankshaft into its bearing, and push the main crank onto the inner end. Set the connecting rod on the wristpin. Now, insert the slide from the right side of the feed chute, pushing it to the left until the hole in the connecting rod is aligned with that of the slide, allowing you to push in the wristpin.

Drop a few marbles into the feed chute, and try the action. Turn the crank handle to reciprocate the slide. If the main crank is too free on the shaft, just turn it by holding the crankpin. The slide should pick up a marble at the right extremity of its stroke, and allow it to drop into the track when all the way to the left.

There is an extra 1/32 inch of travel designed into both ends of the stroke, to absorb small cumulative errors, so your model should work fine. If you have any trouble due to errors in the dimensions of the pieces, you may have to elongate the 1 1/16-inch hole on whichever end is necessary.

One word of caution is necessary: this device is designed to use standard 5/8-inch-diameter marbles. While marbles slightly smaller or larger can be used, marbles much too large or too small will not work. The slide will not be able to move. One way to gauge the size of the marbles for this project is to drop them through the holes in a draftsman's circle template; reject those that are more than 1/16-inch undersize or 1/32-inch oversize.

When all the pieces have been assembled properly, glue the two parts to the base. Don't use too much clamping force on the feed chute, or you may collapse the 1/4-inch walls. When the glue has dried, apply a finish to the parts. Soft pipe cleaners are handy for getting finish into narrow recesses.

Plug the hole in the main crank with a close-fitting dowel; use the dowel for a handle when applying a finish to the crank.

Tape the end 3/8 inch of the crankshaft to keep the finish off the gluing surface, and complete the finishing operations. Wax the parts when they have dried; work some wax into the bearing hole. Wax the crankshaft before removing the tape.

Now, insert the crankshaft into the bearing, remove the dowel from the main crank, and wipe a thin film of glue into the hole. Push the crank onto the shaft, so that the shaft is flush with the surface of the crank. Wipe away any excess glue with a damp cloth. The cranks look best when positioned 90° from each other, but it doesn't matter much.

Select seven nice marbles, and you are ready to display your handiwork. Children are fond of this device, so see to it that you have lots of extra marbles on hand.

CHAPTER 5

Couplings

The three models in this chapter demonstrate couplings used to join shafts that must be able to rotate together in spite of a certain amount of misalignment of their centerlines.

The first, and best known of these couplings is the universal joint. This unit is properly known as Hooke's Joint, after the 17th century inventor. While people are generally aware that these couplings are in their automobiles, not everyone knows what they look like. The mechanism in this chapter nicely displays the operation of the universal joint.

The second mechanism is a double-slider coupling. A double-slider coupling is used a great deal in industrial machinery, and is sold in a large range of sizes. This coupling allows a modest amount of offset between the two shaft ends, thereby compensating for the settling of buildings and similar misalignments.

The third model is a very old design that was used in farm equipment. It is quite loosely fitted, and has the advantage of being able to operate in dirty environments that would ruin more elegant couplings.

All three of these models are useful teaching tools, and can be incorporated into your own designs.

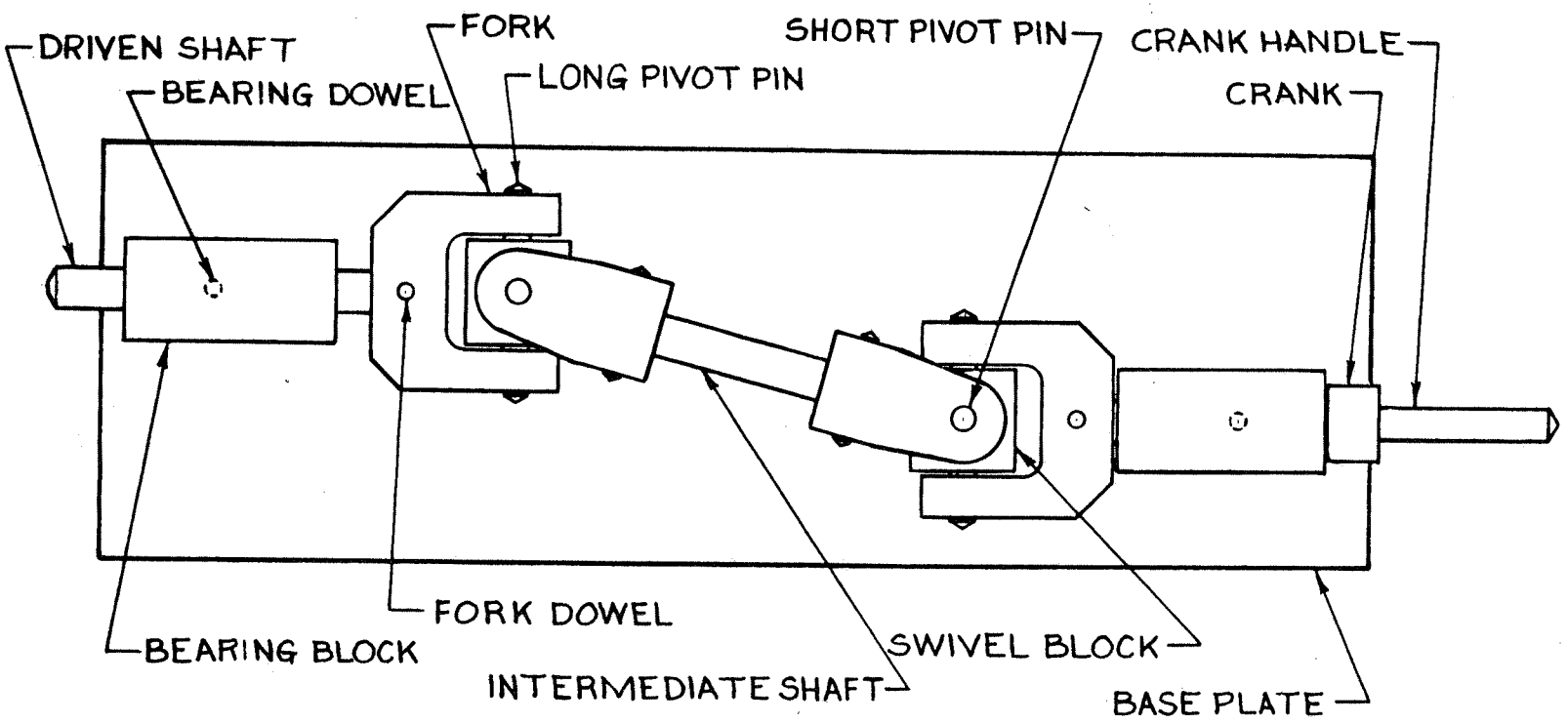
UNIVERSAL JOINT (ILLUS. 5-1 and 5-3)

This model consists of two sets of universal joints and an intermediate shaft that connects the driving and driven shafts. The assembly of these joints is known as a "constant-velocity" coupling, and is the normal application of the universal joint.

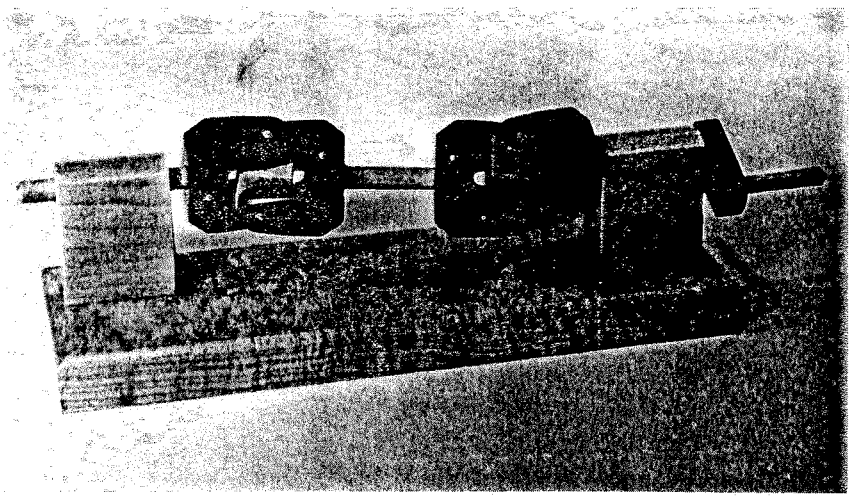
Building the Mechanism

If you plane a piece of lumber about 20 inches long and 3 inches wide, you can cut all three baseplates from it. For the bearing blocks, prepare a piece about 15 inches long, and round its upper edge on the router table. This gives material for six parts, with some extra material for emergencies. The hand cranks and their handles are common to all three units, so cut a strip long enough to make these and the two crank arms for the loose-

ASSEMBLY-UNIVERSAL JOINT



Illus. 5-1.



Illus. 5-2. The Universal Joint.

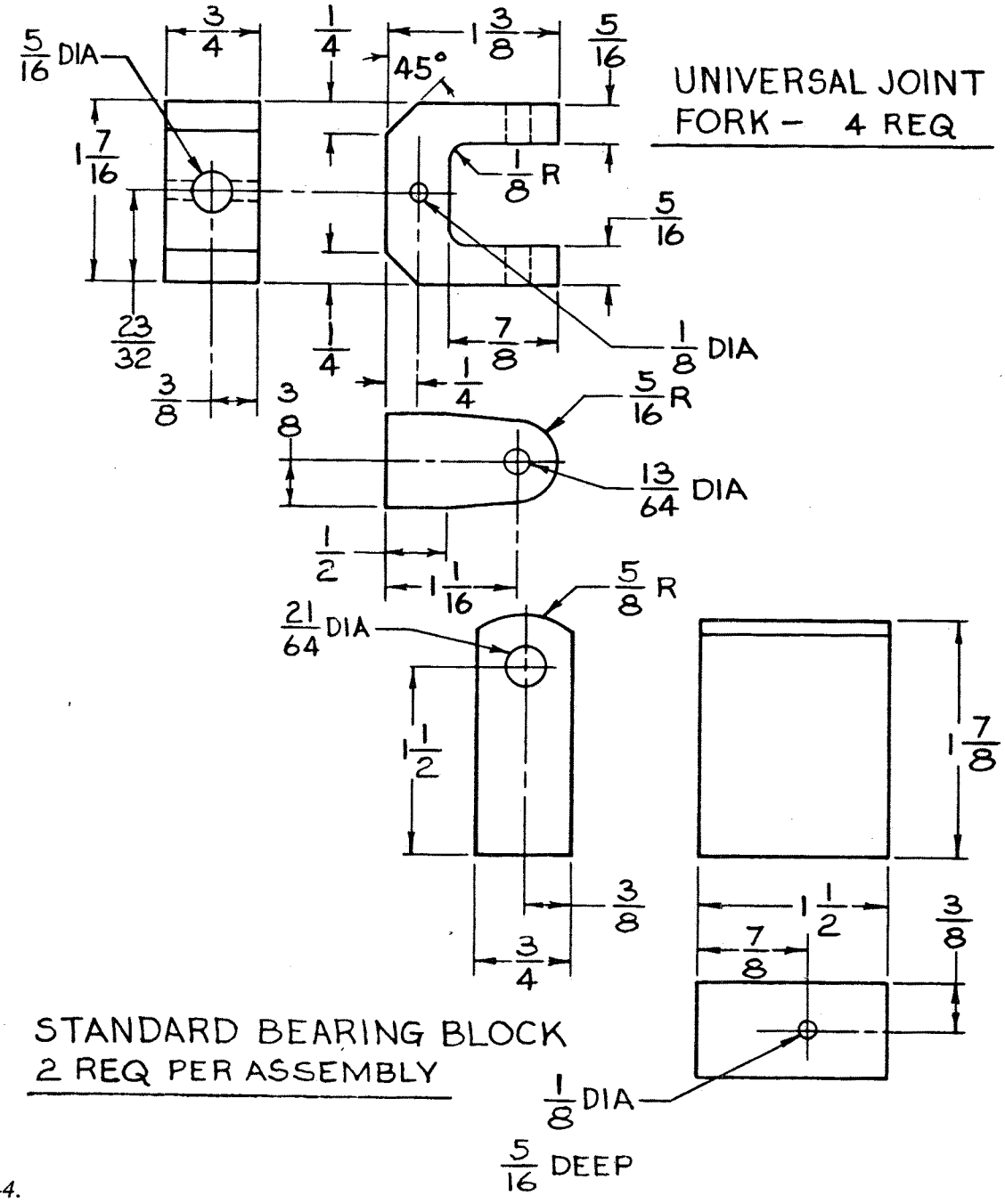
Illus. 5-3. All the parts for the Universal Joint.

link coupling mechanism, which have the same cross section.

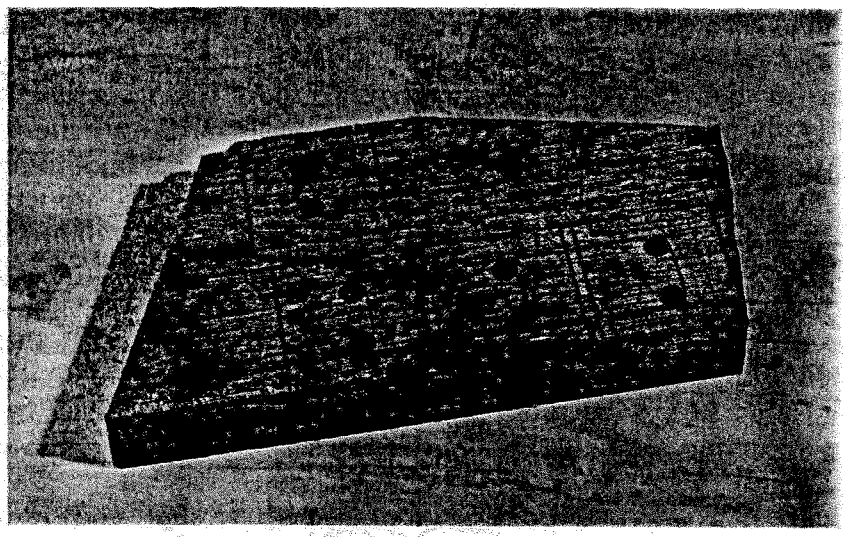
Many parts in these models are similar to those in the foregoing chapters, so I won't repeat those instructions here. As always, take pains to properly fit shafts and pins to their mating parts, because the small pieces can be easily split by excessive assembly force. Size most parts so that they will fit when firmly pushed together. The glued joints should have a slightly looser fit.

UNIVERSAL FORKS Lay out the parts on a large piece of stock; keep the parts attached to the stock for as long as possible. (See Illus. 5-5.) Drill the internal corner holes and the dowel pin holes. Cut and plane the blank to its proper width and lay out the end radii and the pivot pin holes on both edges. Drill the holes. (See Illus. 5-6.)

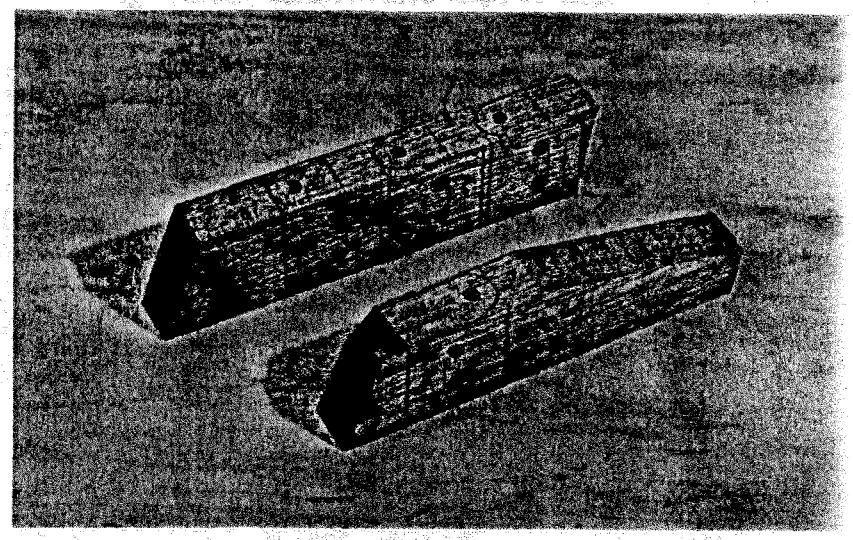
Cut the yokes to length, and lay out and drill the shaft holes in their ends. (See Illus. 5-7.) Now, cut out the inside contours of the forks with a band saw. A ⅛-inch saw blade



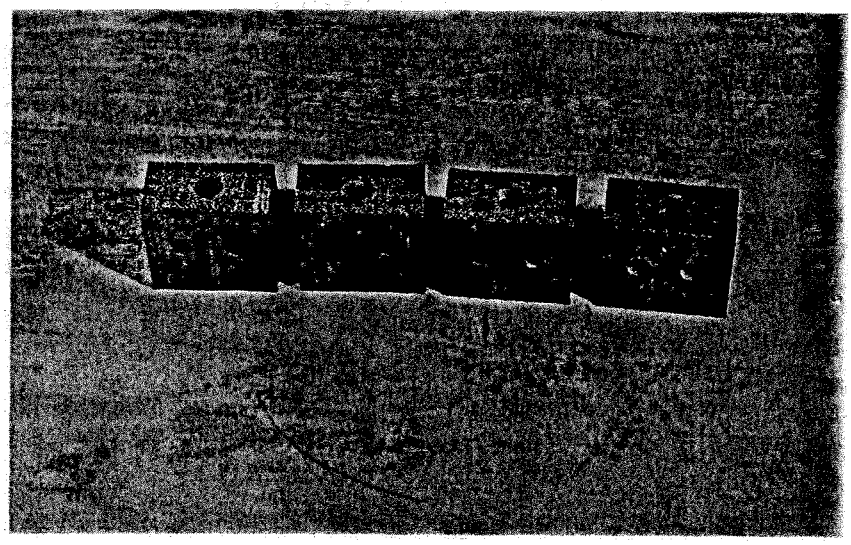
Illus. 5-4.



Illus. 5-5. The layout for the yokes.



Illus. 5-6. The yoke blanks drilled.



Illus. 5-7. The yokes cut to length.

turns around nicely in the ¼-inch corner holes. Smooth the insides of the forks using a file and sandpaper, and cut the corner chamfers and the fork end radii. Lightly chamfer all sharp corners. (See Illus. 5-8.)

THE REMAINING PARTS (ILLUS. 5-10) The base is a simple slab with its upper corners rounded and two dowel holes in its top face. To avoid making jigs, use one dowel per block to locate the bearings, aligning the parts with a square at assembly.

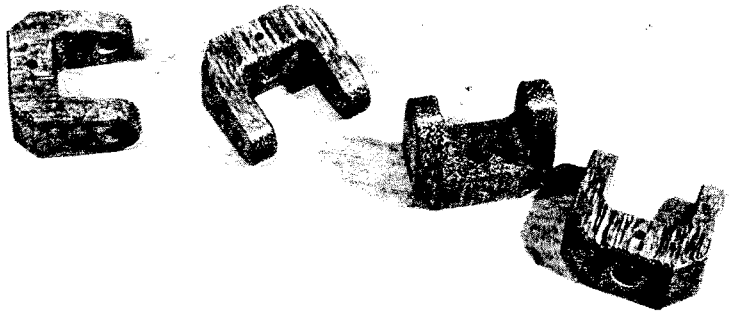
Cut the bearing blocks, drilling an undersized hole from each end, and then all the way through with the full-sized drill.

Lay out the swivel blocks on a squared piece of wood and drill all the holes; plug the first hole in each block with a short piece of dowel, before drilling the crossing hole. Cut in the layout lines with a marking knife to eliminate splintering. Do all the smoothing possible at each stage of cutting, so you will have only one surface left on each small block to smooth when you make the last cut. (See Illus. 5-9.)

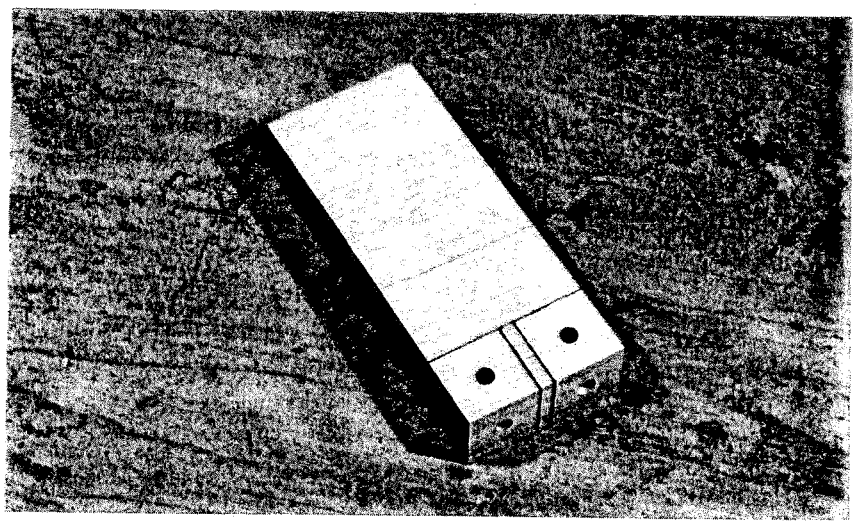
There are three pivot pins for each joint: one long, and two short ones. These pins must be fitted so that you can push them all the way through the blocks, or you won't be able to disassemble the model.

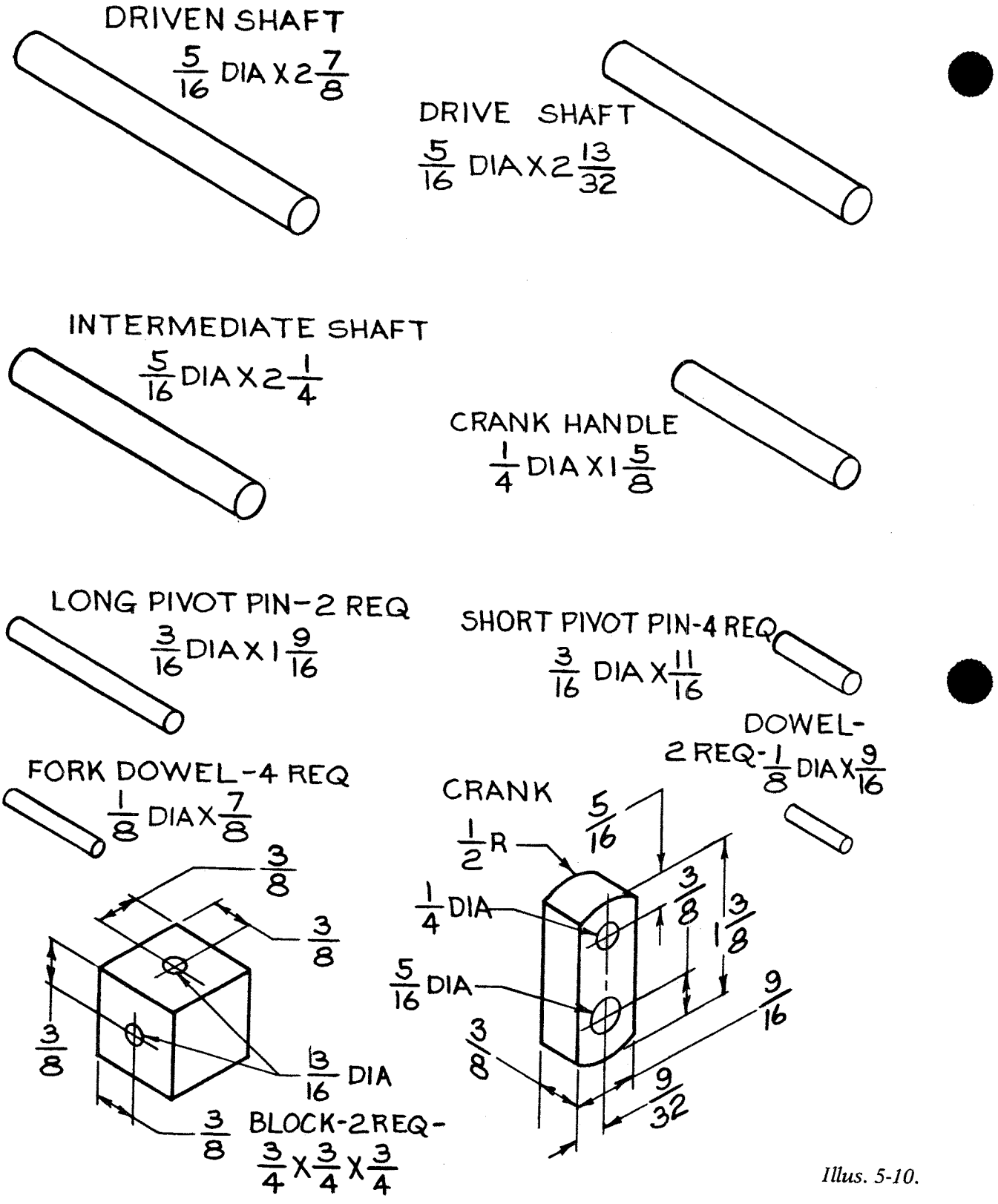
Fit one of the intermediate shaft ends into each of two forks, and drill through for the

Illus. 5-8. The completed yokes.

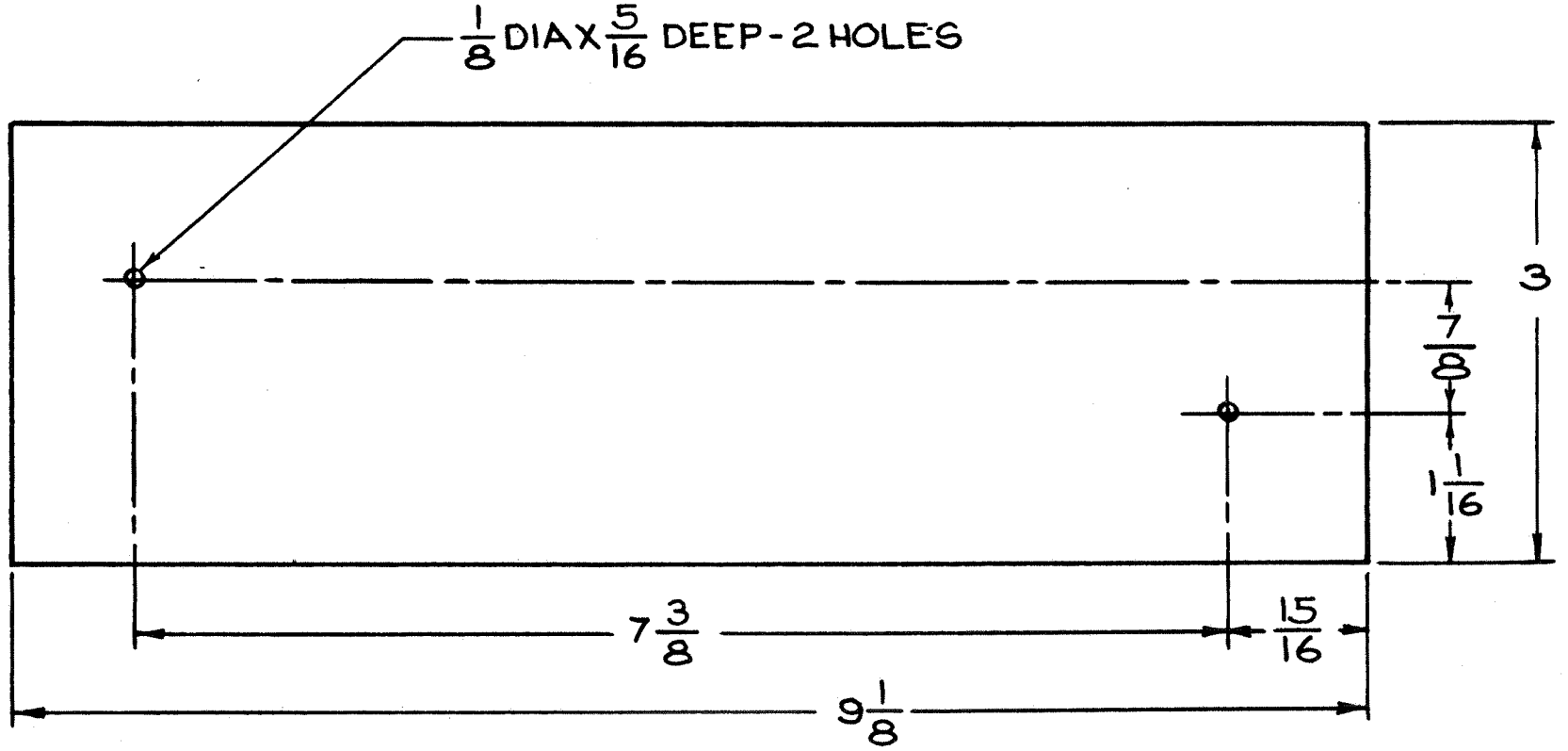


Illus. 5-9. The blank for the swivel blocks, laid out and drilled.




DRIVEN SHAFT
5/16 DIA X 2 7/8
DRIVE SHAFT
5/16 DIA X 2 13/32
INTERMEDIATE SHAFT
5/16 DIA X 2 1/4
CRANK HANDLE
1/4 DIA X 1 5/8
LONG PIVOT PIN-2 REQ
3/16 DIA X 1 9/16
SHORT PIVOT PIN-4 REQ
3/16 DIA X 11/16
DOWEL-
2 REQ-1/8 DIA X 9/16
FORK DOWEL-4 REQ
1/8 DIA X 7/8
CRANK
1/2 R
5/16
1/4 DIA
3/8
1 3/8
5/16 DIA
9/16
3/8
9/32
3/8
3/8
3/8
13/16 DIA
3/8 BLOCK-2 REQ-
3/4 X 3/4 X 3/4

Illus. 5-10.



BASE PLATE–UNIVERSAL JOINT

3/4 THICK

Illus. 5-11.

dowel pins. Make identifying marks to help you reassemble the parts the way they were drilled. One way is to use pencil dots on one side of each shaft, and just inside each hole. Remember, you have four shaft ends to identify at assembly, and their dowel pins probably won't go in unless the shafts are placed in their original positions.

Assemble the two remaining forks on the intermediate shaft, keeping them aligned, and drill the dowel holes. Though this member has dowels to keep things uniform, it can still be glued together, if you wish. It is, however, easier to apply a finish if the parts are all separate.

Select one of the bearing blocks for the drive end of the unit. Put the drive shaft with its fork through the hole, and push the crank onto the shaft end. Check the end play when the shaft is flush with the face of the crank; it should be about 1/64 inch or a little more. If necessary, trim the shaft or the block to achieve this fit. Make the four dowel pins. All the parts are now made. (See Illus. 5-3.)

Assembling the Mechanism

Set the baseplate so that the dowel hole farthest from its end of the plate is to your right. Put a dowel in place and set the bearing block, to which you fitted the crankshaft, on the dowel. Check the fit, and, if satisfied, glue the block in place, aligning it with a small square while slowly tightening the clamp. Do the same with the remaining bearing block, and let the assembly dry.

Glue the crankshaft and the handle into the crank, sanding the ends of both flush with the surface when dry. Fine-sand all the parts, and apply a couple of coats of finish. Wax all the bearing surfaces.

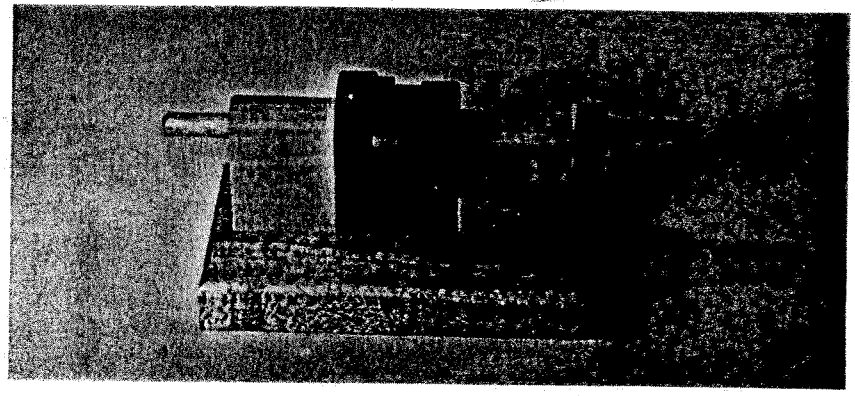
To assemble, put the crankshaft in place and push its fork onto the inboard end, checking your alignment marks. Push in the dowel. Put the driven shaft into its bearing and assemble its fork. Make the intermediate shaft assembly of two forks and their shaft.

Hold a block in the drive-end fork and push a long pivot pin through both parts. Center the block on the pin. Do the same for the driven shaft. Now, hold the intermediate shaft assembly in position and push the two short pins into each block. This completes the assembly.

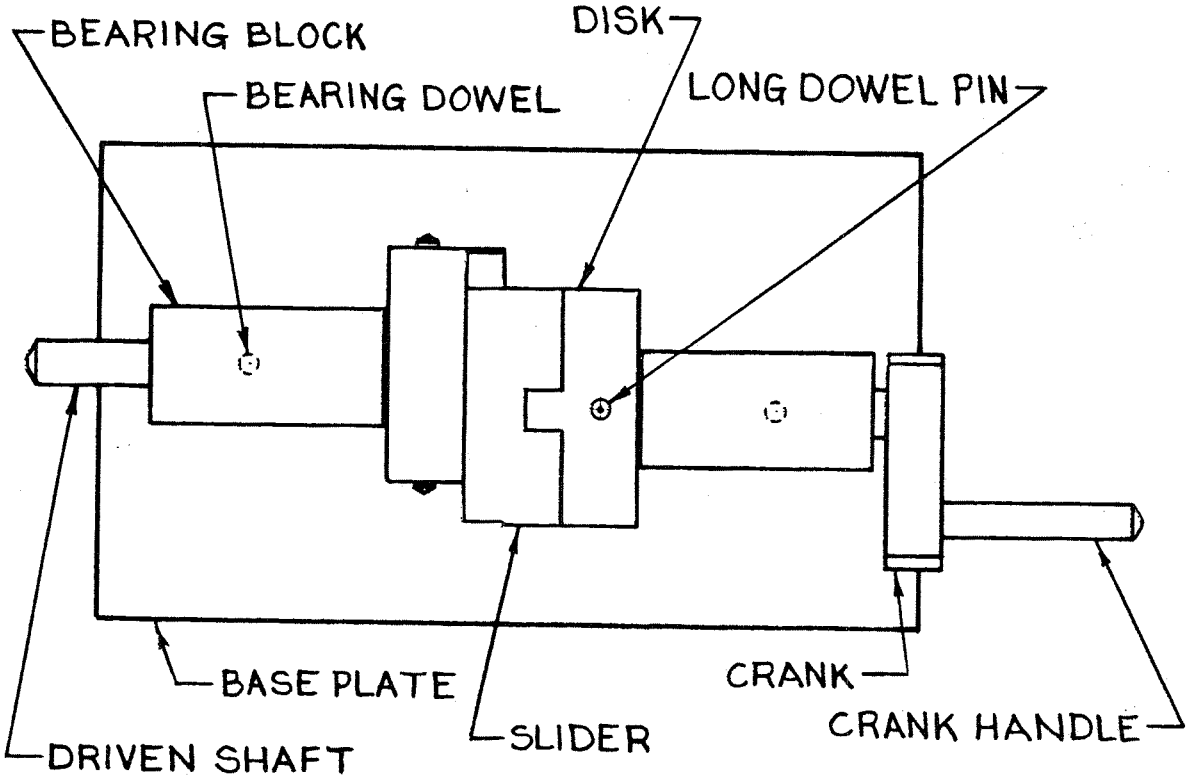
Turn the crank to test the action. The universal joints in your automobile would need replacing long before they became as loose as the ones in this model, but these clearances are just about right for a wooden coupling.

DOUBLE-SLIDER COUPLING (ILLUS. 5-12–5-14)

This device compensates for the small misalignments that gradually appear in large machinery, especially machinery which is fastened to a building structure. With the 1/4-inch offset of the two shafts in the model, it does not seem possible that the shafts could turn; in fact, they do so quite smoothly if things are properly fitted.

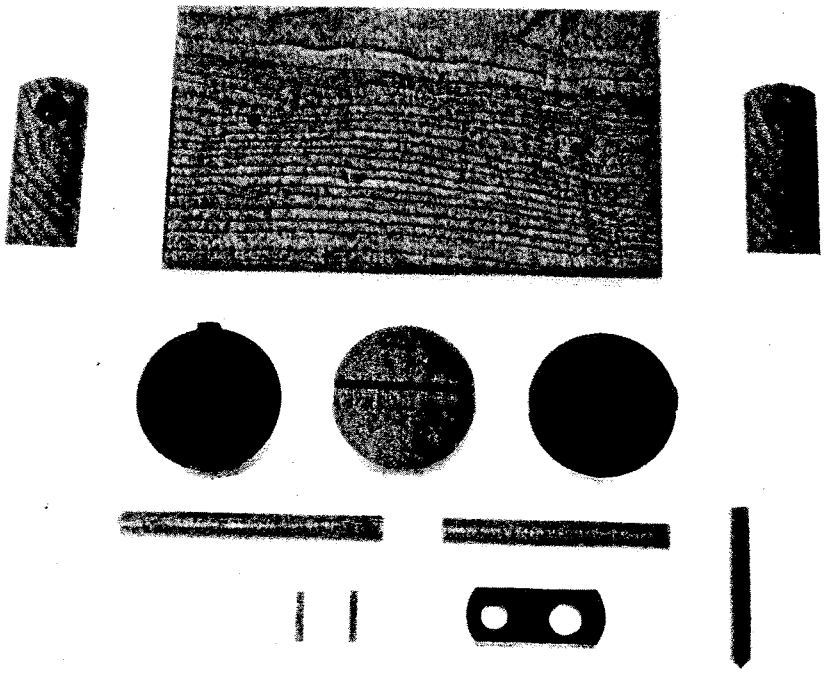


Illus. 5-12. The Double-Slider Coupling.

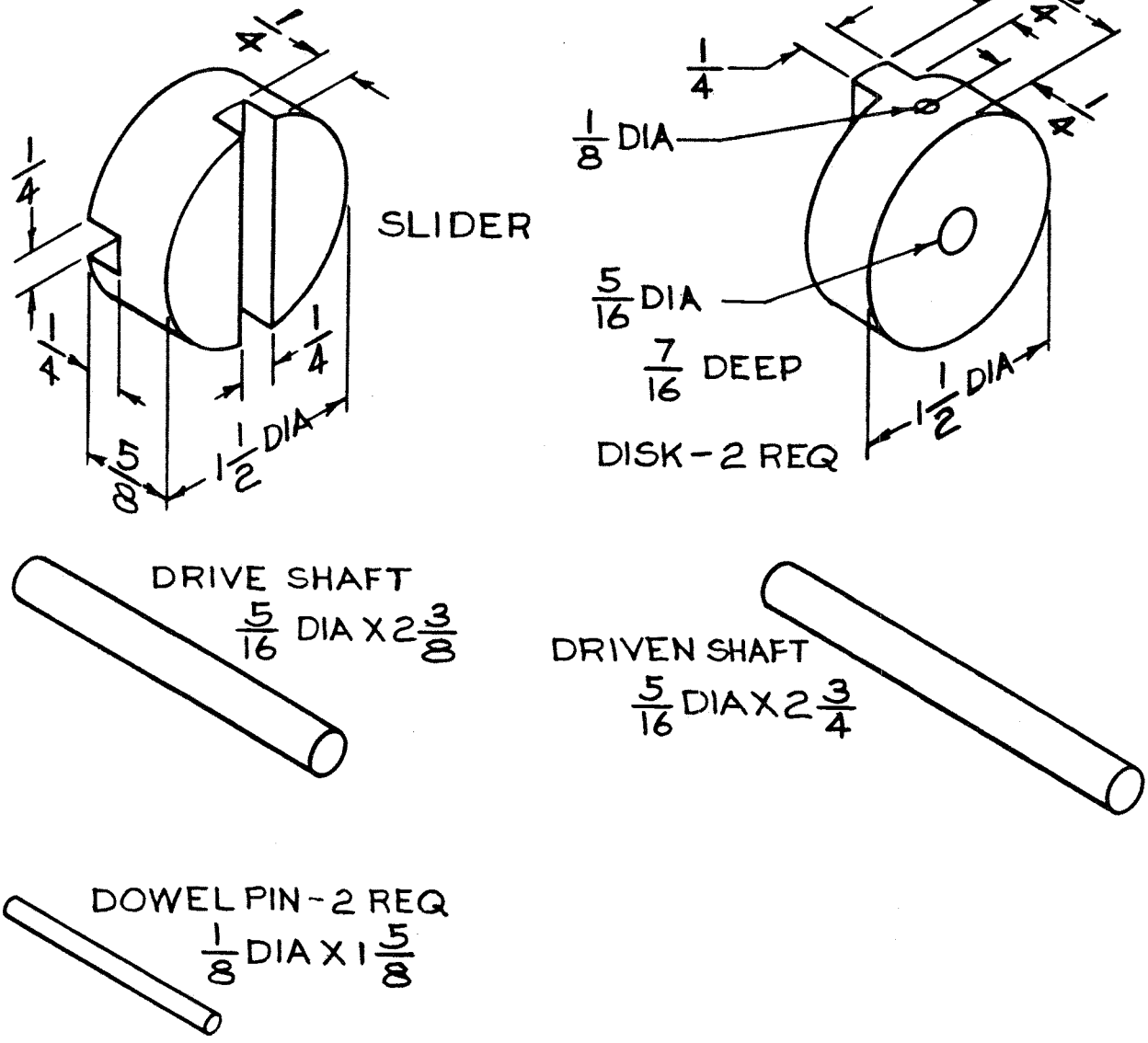


ASSEMBLY-DOUBLE SLIDER COUPLING

Illus. 5-13.



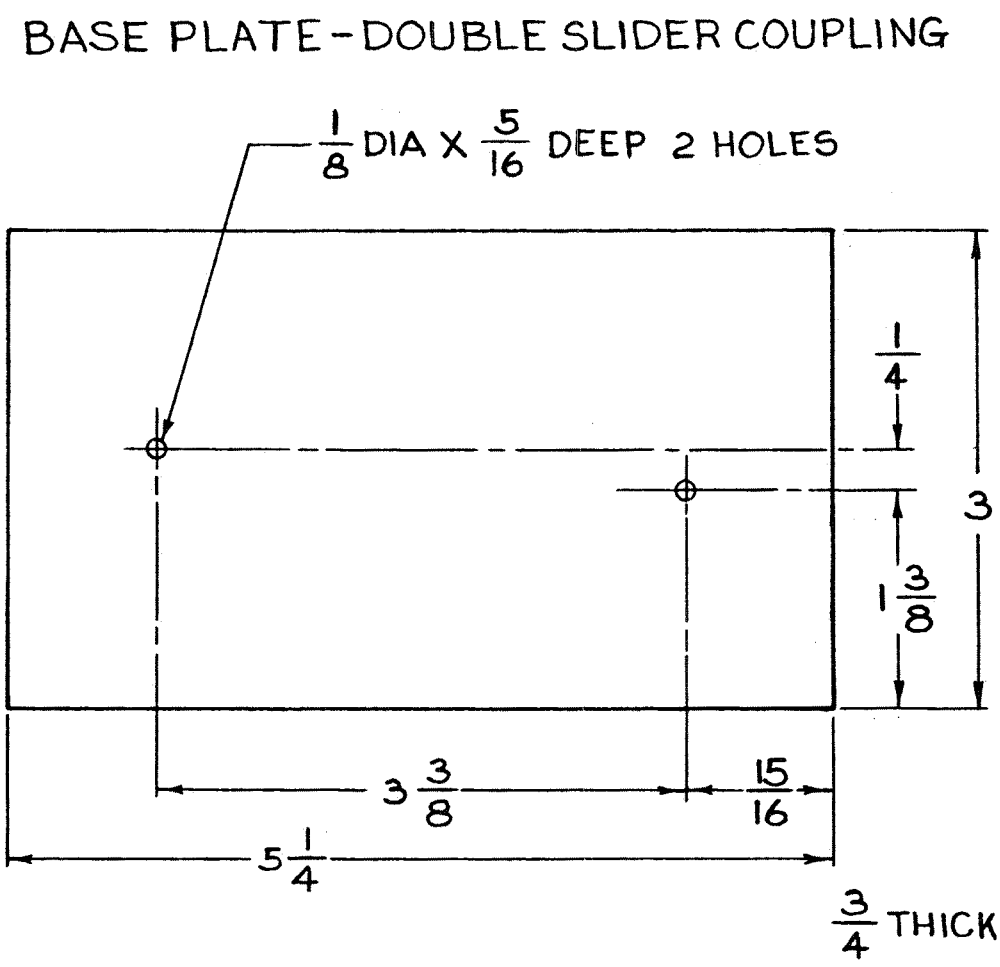
Illus. 5-14. All the parts for the Double-Slider Coupling.



NOTE - BEARING BLOCKS, CRANK, HANDLE, DOWELS, SAME AS UNIVERSAL JOINT

Illus. 5-15.

Illus. 5-16.



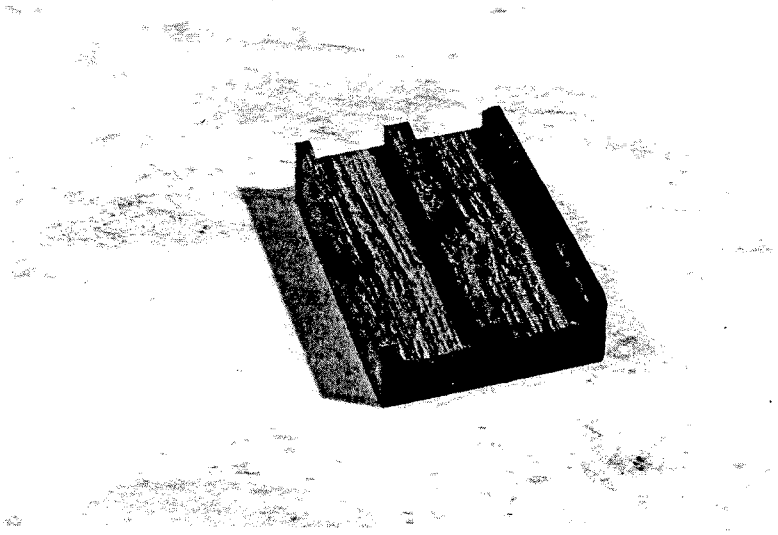
Making the Mechanism

The bearing blocks, crank, and handle are made the same way as those parts for the Universal Joint mechanism. The baseplate is similar to that for the Universal Joint mechanism except for length and hole layout. The only new parts are the two coupling disks and the slider.

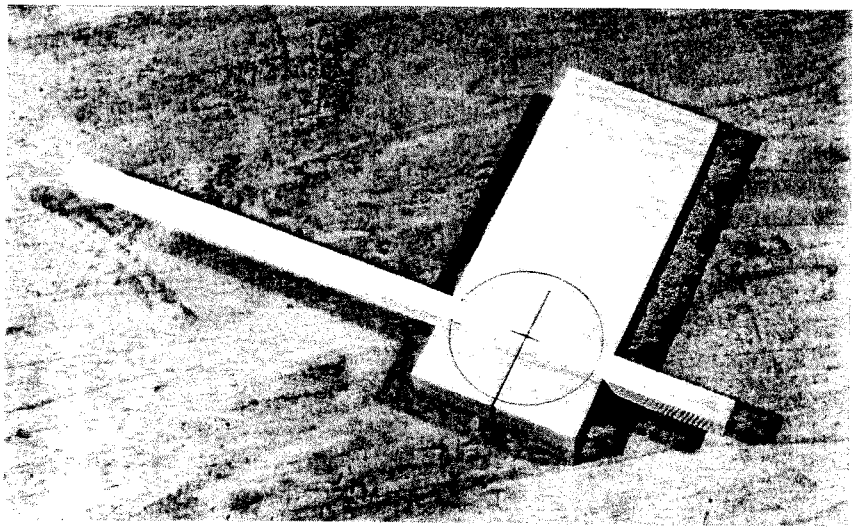
Cut rectangular blocks of the proper thickness and long enough to be safe to work on. Lay out the two slots on the piece for the slider, and the central tang on the piece for the disks. One way to cut both parts is to make multiple passes with a square-ground saw blade. In order to have a stable surface for drilling and sawing the disks, leave a narrow bit of material on each side of the blank, outside of the final part diameter. (See Illus. 5-17.)

When the slots and tangs are cut in both blanks, mark centerlines for drawing the circular outlines. Illus. 5-18 shows a slightly tapered stick wedged into one slot in the slider piece; this provides a surface for laying out the center of the circle.

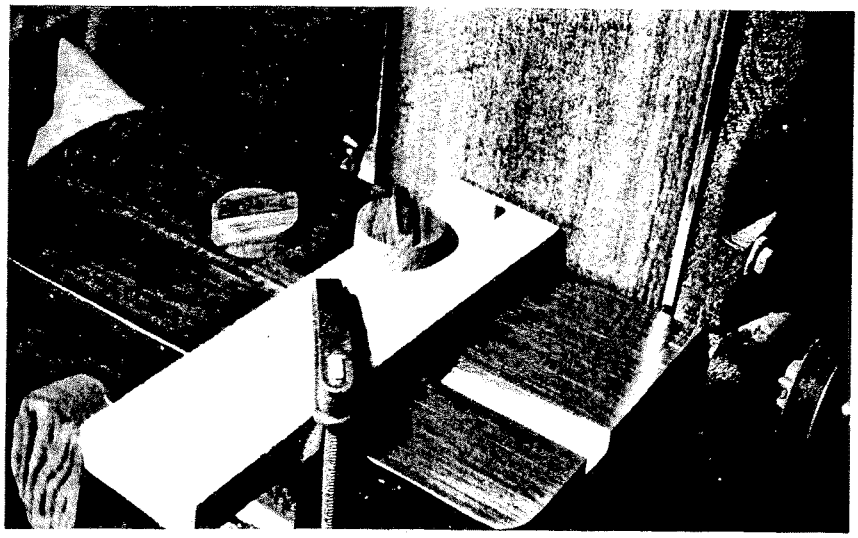
Lay out the centerline of the tangs on the blank for the disks. Square this line around to the flat face of the board, and draw the circles for the parts. Drill the shaft holes in the two disks, taking care not to break through them, and saw out the parts. Belt- or disk-sand to the lines; then fine-sand by hand in the direction of rotation. Illus. 5-19 shows a short



Illus. 5-17. A narrow "land" on each side of the blank supports the part while it is being drilled and bandsawed.



Illus. 5-18. The stick wedged into a slot in the slider provides a surface for laying out the center.



Illus. 5-19. The jig for sanding the disks, clamped to the belt sander.

dowel pressed into a board clamped to the sander table. I set each disk on the dowel, and tap the jig until the part makes contact with the moving belt. The part is revolved until the belt stops cutting; then I check its diameter and repeat the operation until the part is at its correct size.

Push the two shafts into their disks and drill the dowel pin holes through both members, making alignment marks as for the Universal Joint mechanism. Make the two long dowel pins, fitting them so that they enter the holes easily for about two-thirds of their lengths, and then require a light push to fully assemble.

Assembling the Mechanism

Put the drive shaft with disk attached into its hole in the bearing block. Push the crank onto the shaft end; adjust it so that it has about 1/64-inch clearance from the bearing block. Trim any excess from the end of the shaft.

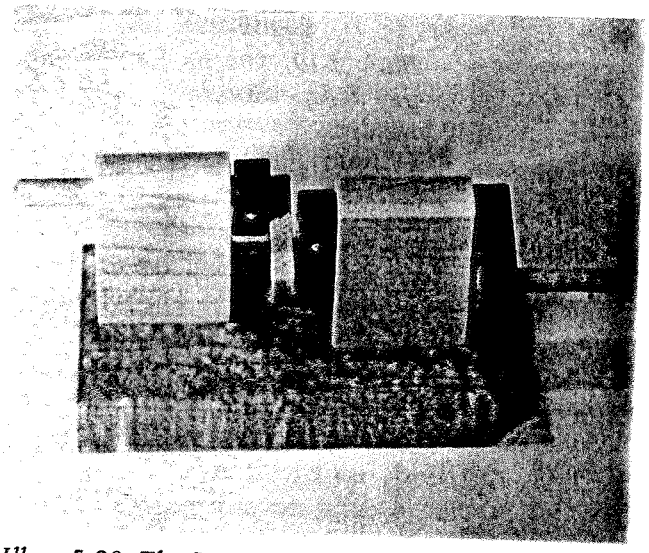
Fine-sand all the parts, making certain that the two tangs on the disks slide freely in their slots in the slider. (See Illus. 5-14.) Glue the bearing blocks to the base. When the glue is dry, stack together the three parts of the coupling, and try their fit between the bearing blocks. The assembly is dimensioned for zero clearance, so your coupling may be a free fit or too large to assemble, depending on the exact sizes of all your parts.

If you have at least 1/64-inch clearance, apply a finish to the parts. If the parts fit together too tightly, sand a little off their various flat faces. Make sure that the tangs don't extend to the bottom of their slots in the slider.

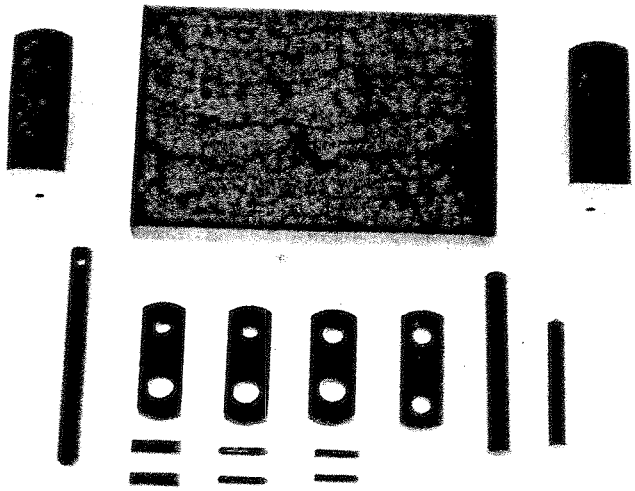
When the proper fit is achieved, apply a finish to and wax all the parts. To assemble the coupling, push one shaft through its bearing block and into its disk, securing the assembly with one of the long dowel pins. Assemble the other disk and the slider with the first disk, and hold the parts in place while you insert the other shaft and the dowel pin. The coupling should operate smoothly despite the large offset of the shafts.

LOOSE-LINK COUPLING (ILLUS. 5-20–5-22)

As stated before, this coupling will absorb a lot of dirt without becoming inoperative, and compensates for a fair amount of shaft misalignment. All parts are similar to those of the Universal Joint and Double Slider Coupling, and should require no special instruc-

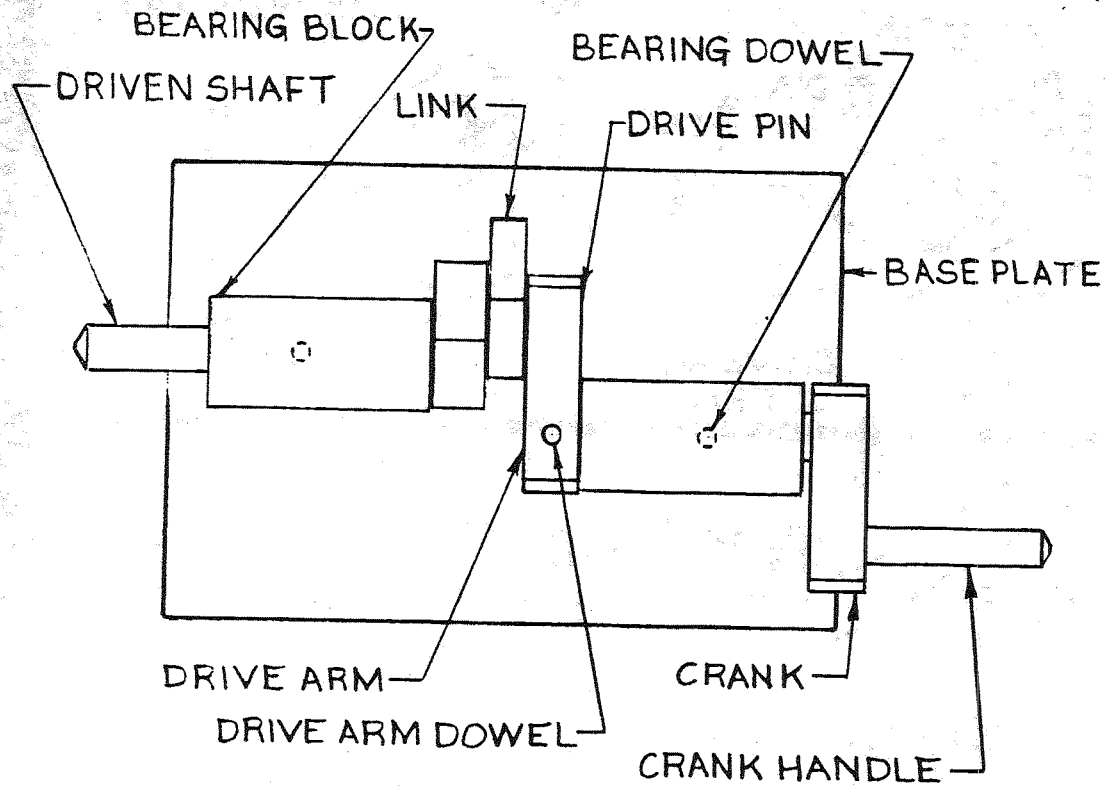


Illus. 5-20. The Loose-Link Coupling.



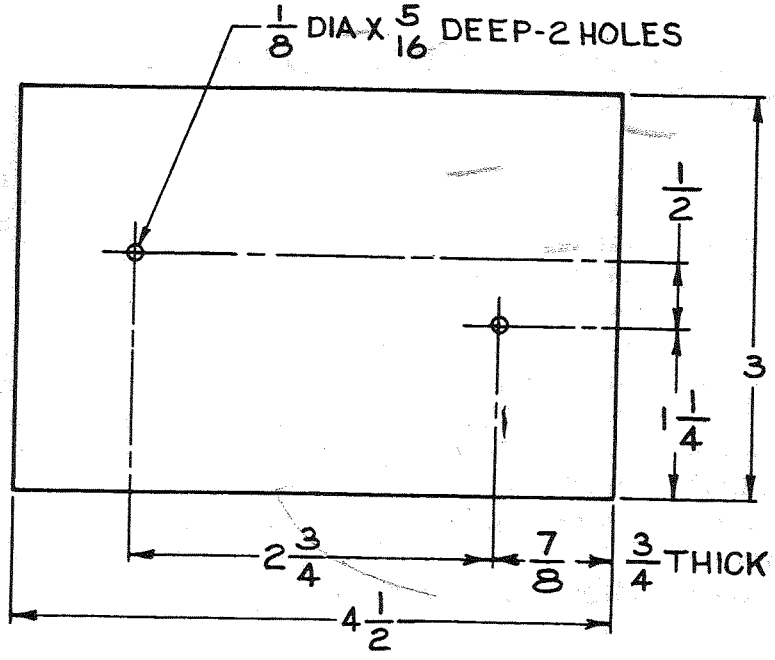
Illus. 5-21. All the parts for the Loose-Link Coupling.

ASSEMBLY–LOOSE-LINK COUPLING

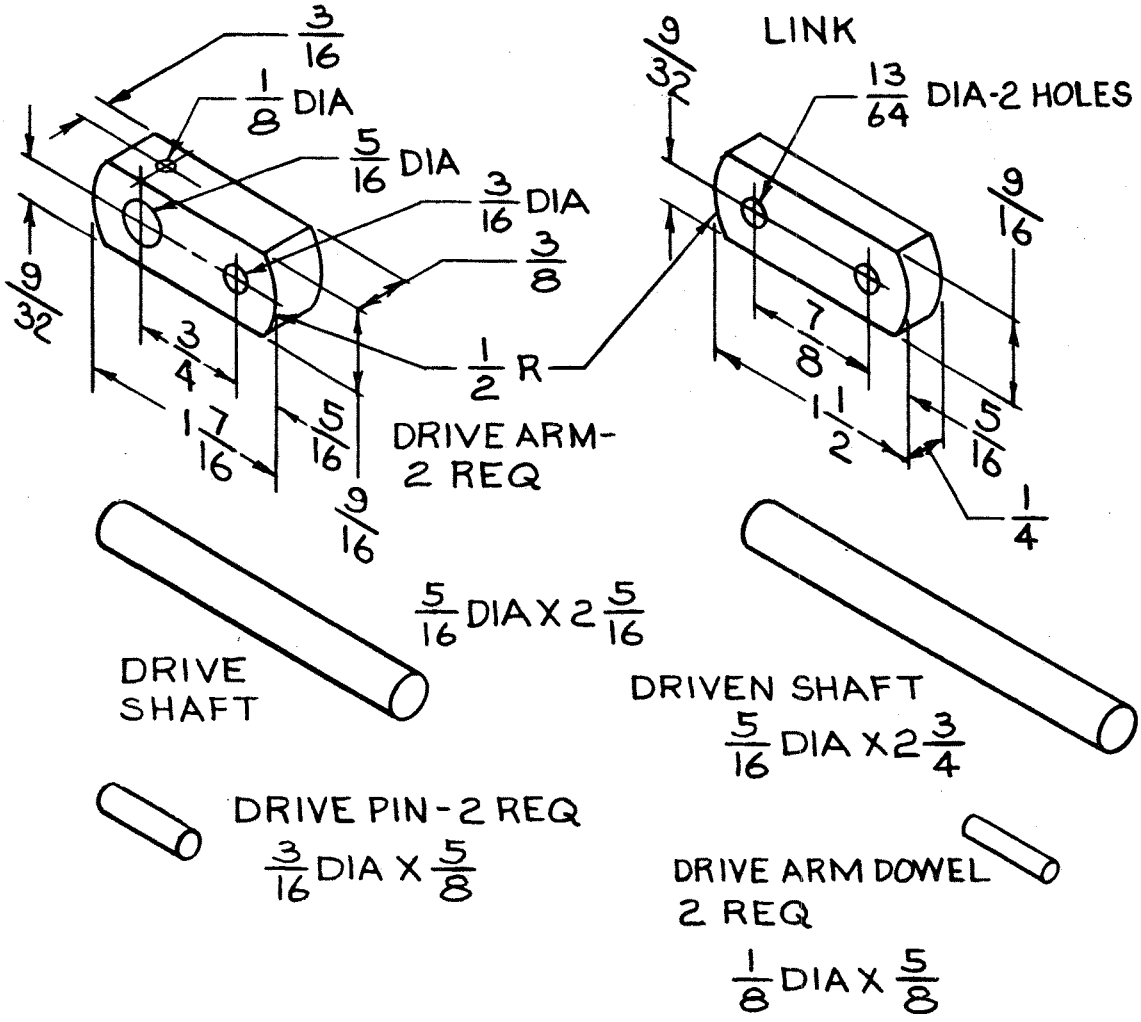


Illus. 5-22.

BASE PLATE-LOOSE-LINK COUPLING



Illus. 5-23.



Illus. 5-24.

tions. Adjust the end clearance of the drive shaft as before, and drill the dowel pin holes, remembering to make alignment marks.

Assembling the Mechanism

Add dowels to the bearing blocks and glue the blocks to the base. Glue the drive shaft into the crank, and the drive pins into the arms, taking care that they extend from the proper faces. Apply a finish and wax all the parts.

Insert the drive shaft into its bearing, and pin on the drive arm. Put the driven arm and the loose link in place, and slide the driven shaft through its bearing and into the arm, pinning it with the other dowel. You now have a coupling that will function in conditions that would defeat more sophisticated designs. The large shaft offset designed into this model gives an interesting intermittent motion to the driven shaft.

This completes the series of three different coupling mechanisms. You can build them to demonstrate their actions, or incorporate them into your own designs.

CHAPTER 6

Watt's Sun-and-Planet Motion

In 1775, when James Watt was perfecting the steam engine, the common crankshaft was thoroughly protected by someone else's patent. To avoid infringement, Watt devised this substitute, which has been named for him and is an early example of planetary, or epicyclic gearing.

HOW THE MECHANISM WORKS

A "sun gear" is attached to the engine shaft and rotates with it. A "planet gear" is fixed to the connecting rod, and does not rotate about its own axis, but is guided in an orbital path around the sun gear. Although this mechanism is often incorrectly drawn with a connecting link, which would have infringed upon the crankshaft patent, the design that follows is an accurate reproduction of Watt's engine in that it uses a circular slot to guide the planet gear in its orbital path. A unique feature of this device is that the sun gear makes two revolutions for each orbit of the planet gear.

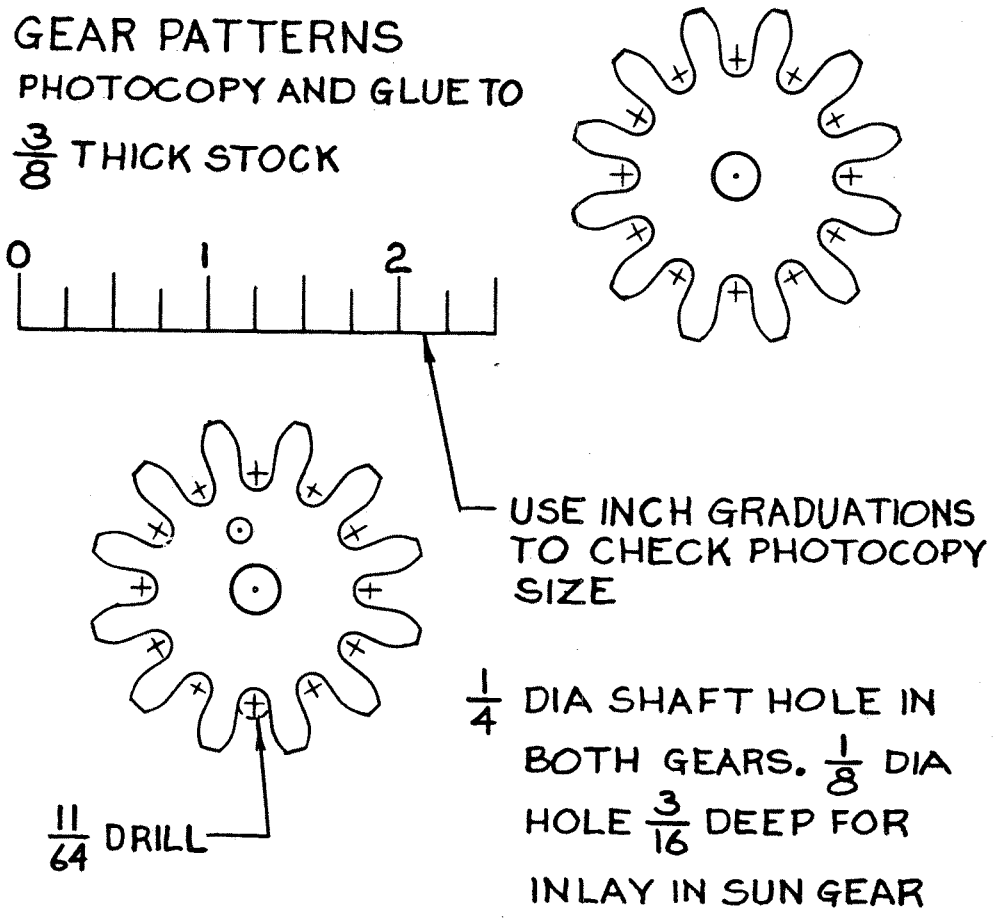
MAKING THE PARTS

Gears

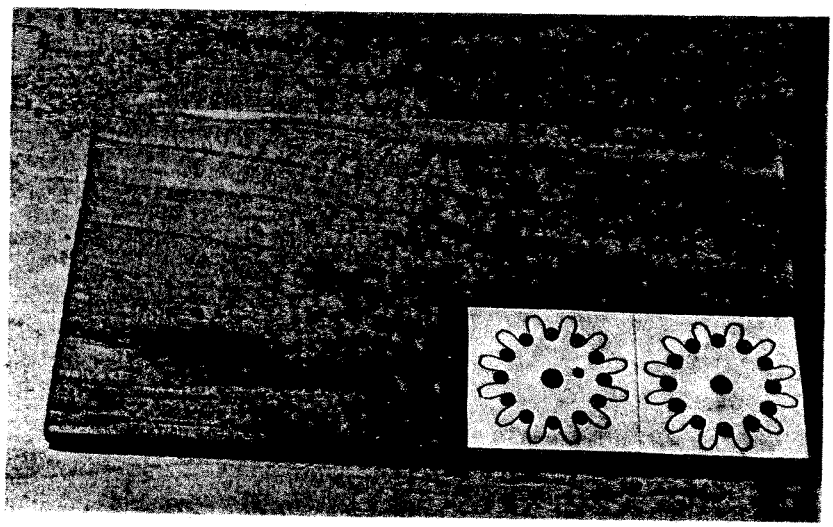
Don't let the gears frighten you away from this interesting project. I have laid them out so that they are easy to make. Select a wood that is both stable and strong, as some of the gear teeth will have short grain across their narrow widths. My gears are made of applewood salvaged from a firewood pile. Cherry and similar woods are also suitable.

Photocopy the patterns shown in Illus. 6-4, checking that they are not more than full-size, and glue them to the wood. Mark each hole center with an awl, and drill all the holes, including those at the "roots" of the teeth. Accuracy is important, so try this old machinist's technique: Drill each hole sufficiently undersize so that no likely amount of error will cut into the pattern outlines. Examine each hole in turn, using a magnifier. File any hole that appears to be off-center with a small, round file, to center it. When

Illus. 6-4.



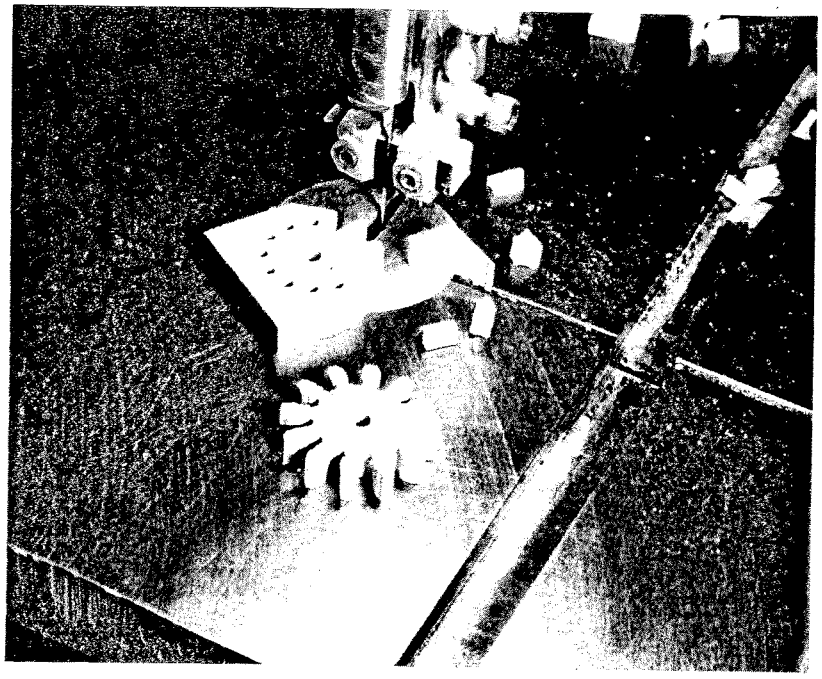
Illus. 6-5. The gear patterns glued to the wood, with the holes drilled.



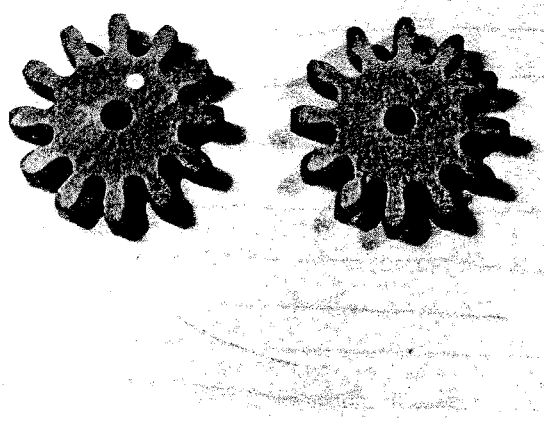
you have done this to all holes that need it, run the final-sized drill through each hole. You can do very accurate work this way. (See Illus. 6-5.)

Saw the gears to circular disks, and then sand them round and smooth. One way to sand them is to rotate them on a dowel in a block clamped to a belt sander, and tap them slowly into the belt to produce the desired diameter. Saw the teeth as close to the lines as you safely can. (See Illus. 6-6.) If you own a jigsaw, you can produce almost finished teeth on it.

Remove any remaining material with a small file, splitting or even removing the pattern lines. If you own a machinist's slide caliper, you can use it to get all the teeth to the same thickness. Remove the patterns, and lightly round all sharp corners. (See Illus. 6-7.)



Illus. 6-6. Cutting out the tooth profiles with a band saw.

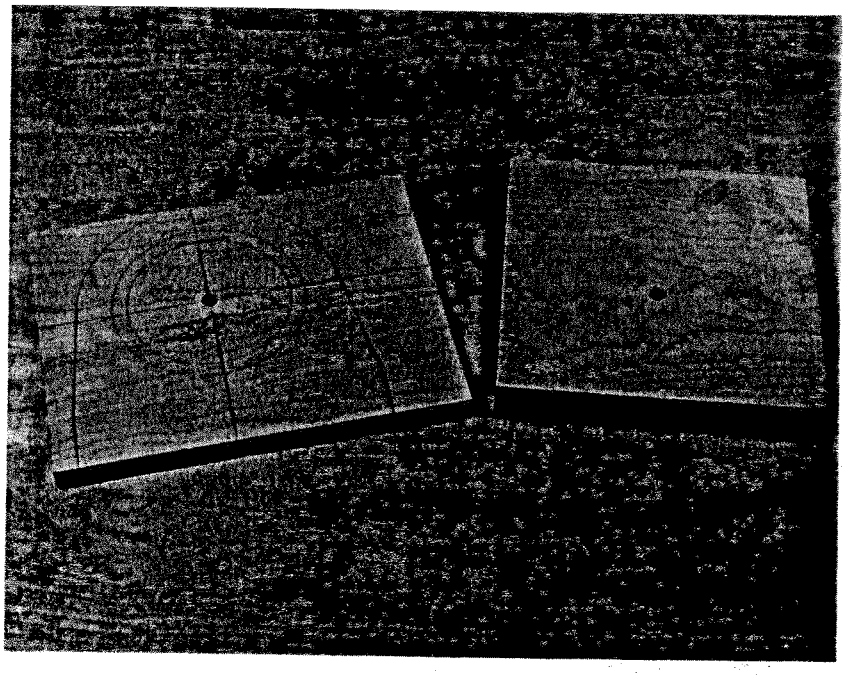


Illus. 6-7. The completed gears.

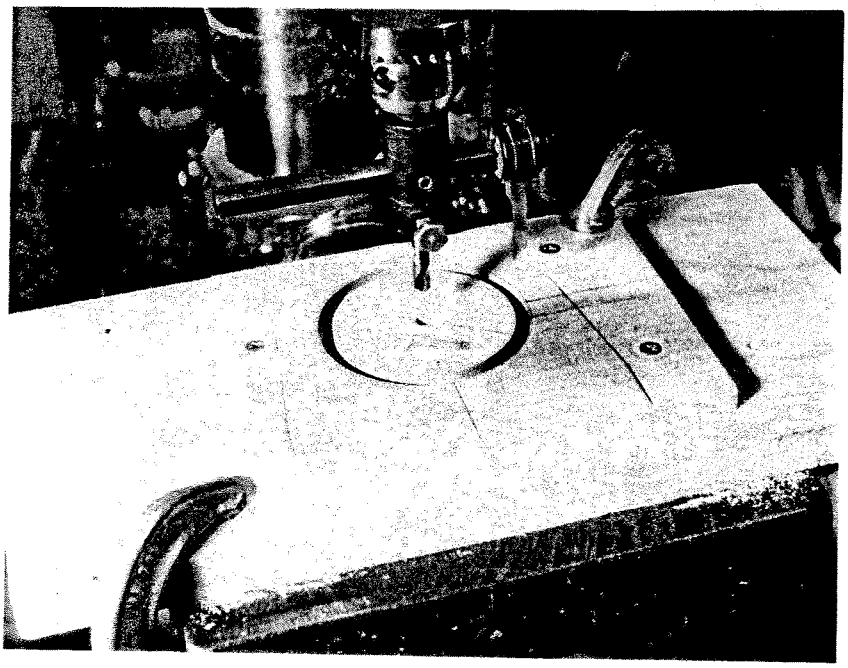
Backplate

While the circular groove can be plowed out of a solid block on a lathe, it is far better to use the built-up construction shown in Illus. 6-10, as it makes it easier to fine-sand the bearing surfaces of the groove.

You will need two razor-sharp tool bits for the circle cutter. If you do not have much experience using the circle cutter, review the equipment section. Plane the two thicknesses of stock for the backplate, and make the layout on the thin front member. Clamp the two blanks together and drill the center hole through them using the same size drill as is in your circle cutter. (See Illus. 6-8.)

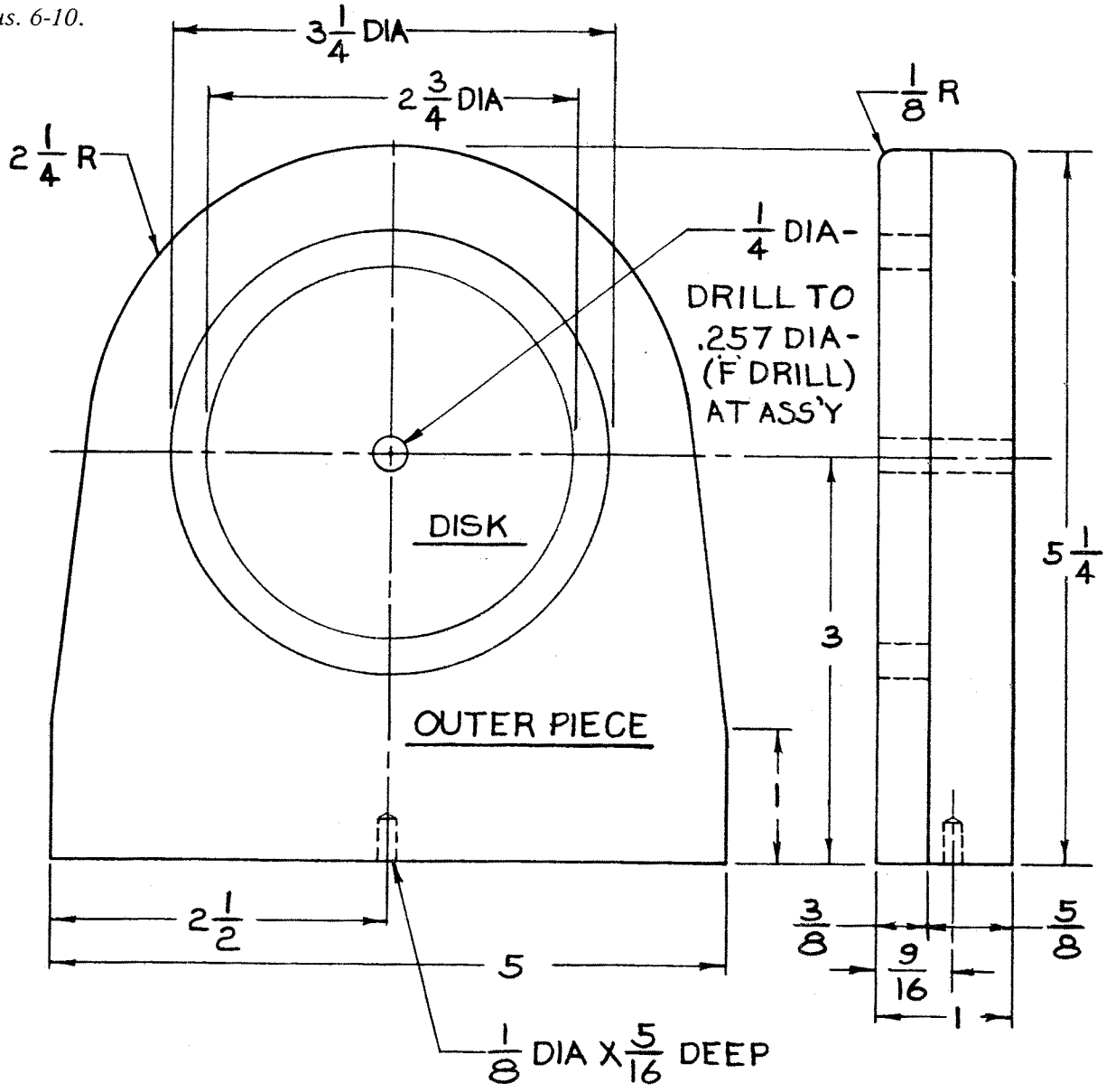


Illus. 6-8. The two blanks for the backplate.



Illus. 6-9. Cutting the disk on the drill press.

Illus. 6-10.



SEQUENCE FOR BACK PLATE

1- LAY OUT ON 3/8 THICK STOCK
2- CLAMP BOTH BLANKS TOGETHER AND DRILL 1/4 HOLE
3- CUT DISK AND LARGE HOLE TO SIZE
4- GLUE DISK TO REAR MEMBER
5- GLUE OUTER PIECE TO REAR MEMBER
6- DRILL CENTER HOLE WITH "F" (.257) DRILL
7- CUT TO OUTLINE