they should have square or hexagonal heads so that they can be held with a wrench.

THE HELICES

We are concerned to make four half helices, and the problem is how to arrive at the shape and area of such a surface in the flat, and then to shape it into a true helix. As this is intended for a potter's use, the potter's wherewithal, clay, is the obvious and very suitable material to use to do this. The potter's skill is also apposite for the purpose. The first move is to throw a solid clay cylinder, liberally oversized, so that when green hard (and turned) it will have the correct measurements. Fig. 7.10A shows the cylinder and its measurements are as follows. The diameter of $7\frac{1}{2}$ in (188 mm) is the diameter of the helix shown in Fig. 7.5D; the height of $3\frac{3}{4}$ in (94 mm) is the traverse of the end helix (two halves) in Fig. 7.5A; the diameter of the central hole is $1\frac{1}{2}$ in (38 mm) being the diameter of the blade shaft. Fig. 7.10B shows the cylinder cut in half. Fig. 7.10D is a triangle drawn on the curved outside face of the half cylinder and laid out flat. Its measurements are as follows.

— the base is the half circle from *x–z*
— the height is that of the cylinder *y–z*
— the hypotenuse is a line linking *x* with *y*

Fig. 7.10E is a triangle drawn on the inside curved face of the half cylinder and the measurements are as follows.

— the base is the half circle *u–v*
— the height is the same as in the triangle in Fig. 7.10D
— the hypotenuse is a line on the inside curved surface linking points *u–w*.

These two triangles should be cut out of thin sheet metal and bent to fit neatly against the inside and outside surfaces of the half cylinder in Fig. 7.10B. The hypotenuse of the two triangles will then follow the dotted lines shown in Fig. 7.10C. With an assistant to hold the triangles in place, draw a high tensile steel wire, held taut in a bow saw frame, from the points *w* and *y* all the way down to the points *x* and *u*, keeping the wire in firm contact with the hypotenuse all the way. The resulting two halves will expose perfect helices corresponding to those required on the blade shaft. Fig. 7.10G illustrates one of the halves thus cut.

There is one important detail to remember before bending the two triangles. That is, do you want to make a left-hand helix or a right-hand one, because this will decide which way the pug mill will have to rotate. It can be made to rotate either way, but there is one side on which the operator should stand when feeding the machine. If the prospective site for the machine allows the operator to stand on either side then it does not matter which way the machine rotates. However, it is better not to weld on the helices or blades before this point has been settled. In Fig. 7.10C, the dotted lines descend from *w* and *y*. If they are made to descend from *s* and *t* the shaft would have to rotate the other way. If that were the intention, the two triangles would simply have to be bent the opposite way to fit the curves of the cylinder. In Figs 7.4A and 7.5A the blades are drawn to indicate a clockwise rotation if viewed from the gearbox end. This means that the convenient position for the operator to stand when feeding the machine is as indicated in Fig. 7.4A.

Cutting out the flat plate needed to make a half helix: It is now necessary to interpret the face of the half helix, now exposed on the clay model in Fig. 7.10G, as a flat piece of $\frac{3}{16}$ in (5 mm) steel plate. There is no doubt a mathematical formula for arriving at this shape in the flat without going through the above steps. However, we wish to create a three dimensional form and therefore a blacksmith's approach is more appropriate. The method is as follows. A piece of soft paper

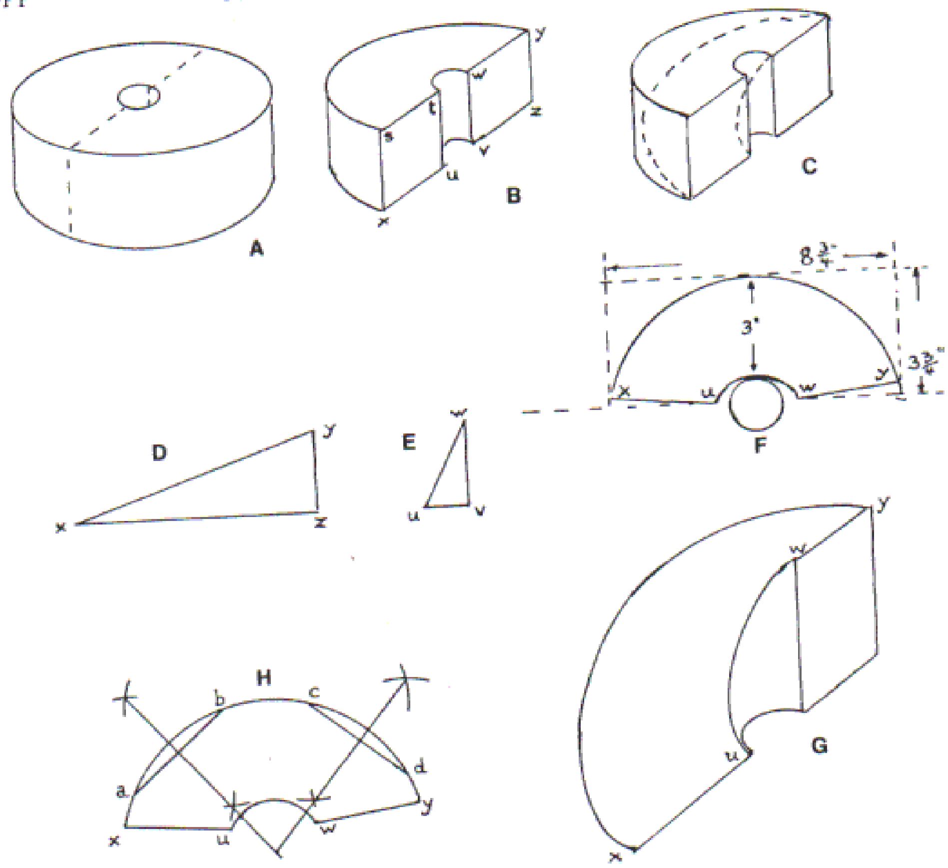

Fig. 7.10 Shaping a pattern for a helix in stiff clay
A shows a clay cylinder which, when cut in half (B), gives the points needed to shape the triangles in D and E. These triangles are made of sheet metal and when they are placed against the inner and outer faces of the cheese-hard half cylinder (B), a wire cut along their hypotenuses (the dotted lines in C), produces the shape seen in G. This cut has the form of a helix and its surface is the basis for the paper pattern which, when laid out flat, has the shape in F. The technique for finding the focal point of the circle x–y is shown in H

(newspaper does well) is lightly pressed down against the clay model and a marking of the outer curve taken with a soft pencil, and also of the two straight lines *w*−*y* and *x*−*u*. This shape should be cut out and the circles *x* to *y* traced onto a larger sheet of paper. The problem is to find the focal point of this circle so that a pilot hole can be made and the trepanning of the helices done. The method is shown in Fig. 7.10H. Draw the straight lines *a*−*b* and *c*−*d* any length anywhere on curve *x*−*y*. With the point of a compass at *a*, draw two arcs and intersect these with two drawn from *b*. Repeat this with *c* and *d* and join the intersecting points as shown. These two lines meet each other at the focal point of the curve *x*−*y*. In order to arrive at the inner curve of the helix, mark off 3 in (75 mm) inwards along one of the spokes and, using the same focal point, draw the inner curve from *u* to *w*. This is the resulting shape of our required flat plate and is shown in Fig. 7.10F, and should be marked out on metal and trepanned.

If further clarification is desired, an instructive exercise is possible at this point which makes clear exactly what has to be achieved in making these half helical forms. If one makes a $\frac{1}{4}$ in (6 mm) slab of plastic clay and cuts out a pattern based on the paper pattern mentioned above, and then drops it on the helical curve of Fig. 7.10G, it will immediately adapt itself to that curve. As the unit in G is no doubt quite stiff and strong by this time, the slab of clay can be left to harden. When stiff enough to pick up one can see exactly what kind of a shape has to be achieved in $\frac{3}{16}$ in (5 mm) steel plate.

Putting the twist in the helix: Fig. 7.11B shows the flattened protoform of the helix, previously seen in Fig. 7.10F, held in the jaws of a vice. Note that it is not held directly by the jaws, but by two pieces of steel square-stock. It is not necessary that they be square, but they must grip the plate with a contact very much narrower than the jaws of the vice. Fig. 7.11A shows the same helix in a vice, in perspective. The next step calls for some fast work and an assistant. The plate about to be worked has to be at a dull red heat, and is held in a pair of tongs with one hand, leaving the other hand free to screw up the vice.

An assistant is needed to manipulate the two pieces of square-stock while the vice is being tightened. Then, using a heavy hammer, the potential half helix is hammered in the manner indicated by arrows in Fig. 7.11B. Heavy blows are applied at the points indicated by *a*, and somewhat less heavy blows at the points marked *b*. In a matter of seconds the result will appear as in Fig. 7.11C. It will now be seen what function the pieces of square-stock have to perform; very quickly the jaws would impede the further development of the curve on the helix, and the square-stock pieces, being narrow, prevent this. Without them, a wide flat area would be created by the jaw faces.

After reheating the helix, it is put back in the vice, but gripped at about the three-quarter mark, so that when held it will appear as in Fig. 7.11D, and is then hammered in the same heavy manner at the point *a* and also at the point *b*. The heating for this will, of course, have been confined to the lower third of the helix. Now the operation is repeated, but heating the other end and reinserting in the vice and again hammering in the same manner. At this stage, or maybe earlier, it is an excellent idea to compare the helix with the clay model previously made. The job can be lowered onto the negative template the better to see where more

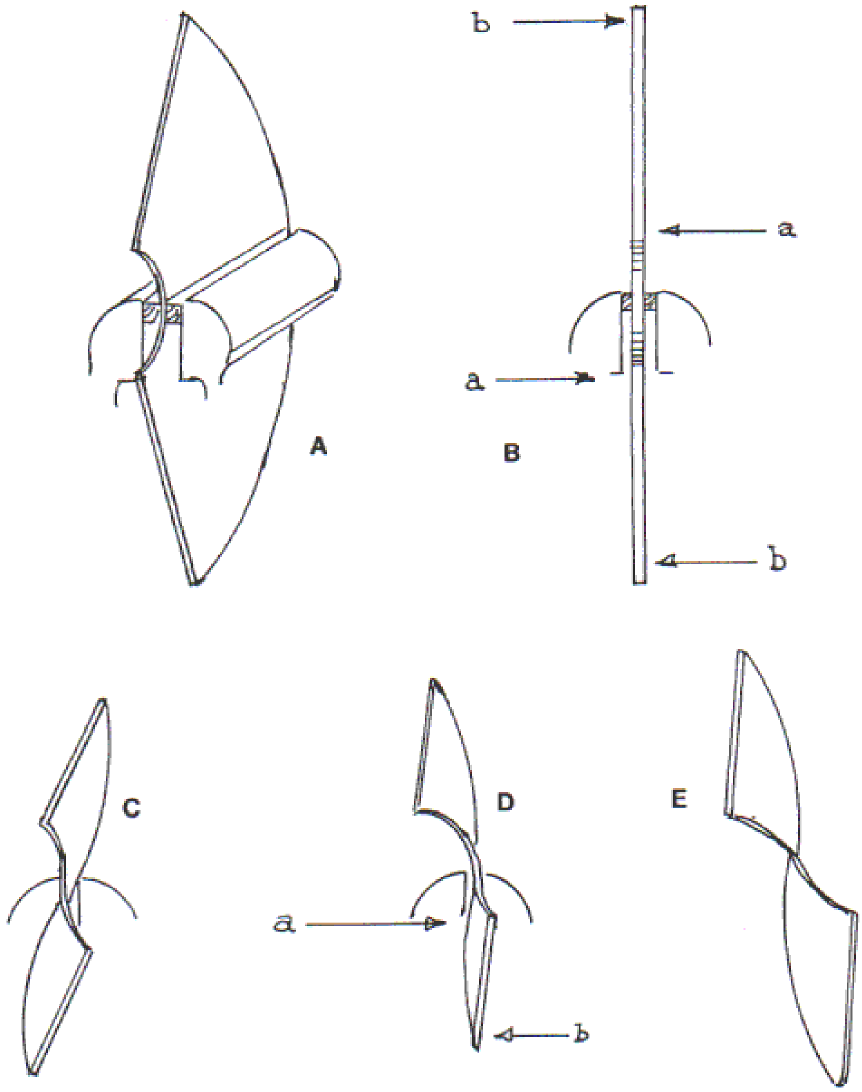

Fig. 7.11 *Shaping a half helix from the flat piece*

A *The flat form held in a vice between two pieces of 1 in (25 mm) square-stock to prevent the wider jaws of the vice from inhibiting the shaping*

B *A restatement of A drawn in section*

C *The shape takes form as the result of hammering on the points a and b indicated in B*

D *The unit is held now below the centre and the shaping continues by hammering*

E *The finished half helix*

shaping and hammering is needed. Fig. 7.11E illustrates the half helix in its final shape. It will be noted that the two ends are parallel, and it is the distance between them that constitutes the 3¾ in (94 mm) traverse referred to earlier and shown in Fig. 7.5A. The same clay template and paper pattern can be used to make the other pair with only a 3 in (75 mm) traverse, as a little grinding on the outer tips, and a small amount of weld filler under the inner tips, will suffice to adapt the shape to the shorter traverse.

From the above it could be assumed that the job cannot be done without a blacksmith's forge. This is not so, though to have one would certainly help. When May and I acquired the property at Crowan, in Cornwall, it was already equipped with a complete little blacksmith's shop with tools and a blower. With these I taught myself such crude blacksmith's skills as I have, and pathetically incomplete though they are, they have been quite incredibly useful and valuable. So much so that I have seen to it that I have never had to be without a forge and skeleton set of tools ever since.

To heat the flattened helical form described above requires something very elementary that can be put together in minutes. In these days one does not have to look very far for a vacuum cleaner, and one only has to put the pipe in the other end to provide a blower. Even an electric cooling fan is adequate to heat such a small piece of metal. With half-a-dozen bricks one can make a shallow hearth with an entry hole beneath through which to direct the current of air. Coal or charcoal is not necessary either, as a wood fire will soon produce a residue of charcoal sufficient to do the job, and I would add in conclusion that a very dull red heat is adequate for the purpose. If one does not have tongs, a pair of pliers or that wonderful tool of the mid-twentieth century — the vice grip — is very suitable.

THE BLADES

In cutting out blades from the $\frac{3}{16}$ in (5 mm) discs taken out of the flange units *d*, *k*, *m* and *n*, more is involved than just cutting the discs into three parts. The discs are 7⅝ in (194 mm) in diameter and Fig. 7.6 is included to explain how one should go about taking three blades out of each disc. The small circle is the ½ in (13 mm) pilot hole for the trepanning tools. The dotted circle corresponds to the 1½ in (38 mm) shaft and the next circle is the one for cutting the inner curve of the blades. The reason the inside curve of the blades is $1\frac{11}{16}$ in (42 mm) is that they will be welded to the 1½ in (38 mm) shaft at 25° and 28° angles to the shaft (see Fig. 7.14A). When this is done a small section of each inner curve (shown in heavy black shading in Fig. 7.6) will be missing and will need to be filled in with weld later when attaching the blades to the shaft.

To cut out the blades, start by drawing three spokes on the disc at 120° intervals and then measure the 4¼ in (106 mm) width of each blade on the 7⅝ in (194 mm) circle through the centre of each spoke (eg. $x-u$ etc). Draw the two straight sides of each blade ($u-v$ etc) on tangential lines from the 1½ in (38 mm) dotted circle. These lines should be clearly marked with a scriber as incision lines will have to replace them.

To remove three blades from the disc attention should be given to the semi-triangles — two straight and one curved sides — which occur between the blades.

One of these is marked x, y and z in Fig. 7.6 and the first thing to do is to remove this pseudo triangle. Cutting along the lines $x-z$ and $y-z$ with a hacksaw makes a neat job. It can also be done using the cutting disc, and working by eye, to follow a line on the underside which corresponds to the one that can be seen on the top side. This is quicker but less controllable and one must take care regarding the danger of cutting into the next blade. If the disc is used it is better to finish the cut with a hacksaw anyway.

If one then cuts from w to v, it is any easy matter to fatigue the line from z to v. The line u to v is then very easily incised and fatigued to yield the first blade. Proceed to remove the last triangle in the same manner and then fatigue out the already incised 1$\frac{11}{16}$ in (42 mm) circle and the surplus $\frac{1}{4}$ in (6 mm) rim off each blade. As ten blades are needed, only one will have to be taken from the fourth disc.

ALIGNING THE SHAFT AND THE THRUST BEARING

The first thing to do is to find one of the locating discs of steel used to align the casing. It has a centre hole to fit the 1$\frac{1}{2}$ in (38 mm) shaft and an outside diameter to fit inside the bore of the pug mill (8 in [200 mm]). The mouth cone is then removed and the shaft is pushed through the 1$\frac{1}{2}$ in (38 mm) hole in the plate a. Then the pillow block bearing, seen in figure 7.4A is bolted to a bracket, and put on the shaft, followed by the shaft collar, and finally the thrust bearing is pushed on hard against the shoulder on the shaft. The bearing should be bolted to the bracket such that when the latter is later welded to plate a, the bearing will lie about $\frac{1}{2}$ in (13 mm) from that plate. The outer runner of the thrust bearing fitted into its housing (see Fig. 7.9) is pressed onto the bearing and everything is then forced hard against the end plate of the gearbox. At this point the locating disc is pushed on the shaft at the mouth cone end and inserted just inside the barrel of the pug. This locates the thrust bearing housing, and the shaft is thus correctly aligned. While held there, a few spots of weld can be used to attach the bearing housing to the end plate, which can then be removed for drilling via the four holes in the housing. This is then bolted on and the end plate put back.

The spots of weld can be left, but if they are removed punch marks should be made close together on the end plate and the housing for future relocation. With the end plate back in position, the shaft and thrust bearing must again be held firmly against it while the pillow block bearing and its bracket are clamped to plate a in the up-ended manner shown in Fig. 7.12A. The bracket is then welded to plate a. With that done the collar is tightened on the shaft in firm contact with the pillow block bearing, and the shaft is ready to have the blades and helices welded on. The hole in a can now be enlarged to $\frac{5}{8}$ in (16 mm) by filing so that the rotating shaft will not touch the plate.

WELDING THE BLADES AND HELICES ONTO THE SHAFT

Before this can be done, the cutting edges of the four half helices and the blades should be ground on the lee side as shown in Fig. 7.14A. This is important because it maximises the thrust plane, and minimises the power absorption of an otherwise excessively blunt edge. The sharpness of the cutting edge should not be overdone.

If the leading edge is reduced from ¼ in (6 mm) to 1/16 in (1–2 mm) that is sharp enough. Although this should be done before welding on, it is vital to plan the position of each blade first to be sure of grinding the right edge.

Referring back to Fig. 7.5, the order of attachment can be studied. The two pairs of half helices come first; the one with the 3¾ in (94 mm) traverse at the mouth cone end of the shaft. The other pair with a 3 in (75 mm) traverse must be welded on just clear of the shredding screens (say ½ in [13 mm] on the gearbox side of the screens). To obtain a 3 in (75 mm) traverse for the second pair, a little grinding on the outer tips and some weld filler on the inner tips will be needed. Next, the two groups of blades can be welded on, starting with either no. 5 or no. 10 as shown in Fig. 7.5A. Blades 1 to 5 are set at 25° and blades 6 to 10 are set at 28° to the shaft. These are placed with the tails of the blades just in front of the leading or cutting edges of the helices. The rest of the blades are welded on along the shaft in three rows at 2¼ in (56 mm) intervals centre to centre, being 120° apart round the shaft; see Fig. 7.5E.

Some slight adjustment may be necessary in allotting the spacing because blade no. 1 must be close to the plate *a* without actually touching it, and blade no. 6 must be similarly close to the screens without touching them. Fig. 7.13A shows a jig used in setting the blades at the correct angle, and B, C and D show how the jig is made up of three pieces of wood nailed together, *x* being the same width as the shaft. When the helices and blades are all attached, a check should be made to see that a ¼ in (6 mm) clearance exists between their peripheries and the inside barrel of the mill. Some grinding will be needed here and there to ensure that the clearance is correct.

THE BREATHER PLATE

This plate (see Fig. 7.14C) is best made up of four pieces of ⅛ in (3 mm) steel and these can all be taken from leftover metal as seen in Fig. 7.3A. The curve of the plate consists of two pieces 9½ in (238 mm) long, one 5 in (125 mm) wide and the other 1 in (25 mm) wide. These two pieces should be part rolled and part hammered to produce a curve slightly less than 7¾ in (194 mm) across the mouth. There are two possibilities for creating the breather slot. One can either grind a ⅛ in (3 mm) strip out of one side of the 1 in (25 mm) piece leaving 1½ in (38 mm) unground at each end where the two pieces will be welded together (see Fig. 7.14D). Alternatively, the narrow piece can be ⅞ in (22 mm) wide and be welded to the main piece with a ⅛ in (3 mm) gap about 6½ in (163 mm) long to create the slot.

The other two pieces of metal which complete the breather plate measure 3 in (75 mm) by 6 in (150 mm) in ⅛ in (3 mm) plate. These need to be welded on to the sides of the curved piece as seen in Fig. 7.14C so that the whole unit is no more than 8 in (200 mm) across and will therefore fit inside the vacuum chamber. To locate the breather plate inside the vacuum chamber, two or three strips of wood ⅛ in (3 mm) thick can be laid on the blades and the breather plate pressed down on them while it is held to the walls of the vacuum chamber with G-clamps — one each side. Check first that the plate is in the right way round, i.e., the slot is on the same side as the screens. Then the breather plate can be marked for drilling from the outside via the holes which should be already made in unit *i*; see Fig. 7.14H. The plate can now be taken out and drilled. The assumption here is that if the clay is wiped away close to the plate each time the blade passes, the vacuum above the plate will link up more readily with air cavities in the clay below it.

THE SCREEN COVERS

The first thing here is to make sure that the ends of *g1* and *g2*, and the sides of plates *f* and *h* do, in fact, present an even plane where the covers will have to rest. If that is satisfactory the four ½ in (13 mm) bolts (with heads removed) can be welded to the top of *g1* and the underside of *g2*. The two covers (*q*) are 12⅓ in (313 mm) long made of 1¼ in (31 mm) × ¼ in (6 mm) flat-stock. With the four bolts welded on, the 12⅓ in (313 mm) strips can be marked and drilled to suit the position of the bolts. The length of the stiffening fins, which have to be welded to these, is governed by the need to leave enough room for the nuts on the four bolts to turn. Finally, two pieces of sheet rubber must be cut to make an airtight gasket to go between the covers and the openings where the screens will enter.

OTHER AIR SEALS

A rubber gasket is also needed between plate *j* and flange *k*, and also under the lid *s* of the vacuum chamber. This last requires no bolt holes as the vacuum will suck the lid down to an airtight seal, but only if a really perfect surface has been created after welding the four pieces of angle iron, marked *r* in Fig. 7.2. No gasket is needed between flange *d* and plate *c*, but there is a case for putting one between flanges *m* and *n*, unless they make a very good flat join. The flatness of all plates and flanges should, incidentally, be studied before welding any of them onto their respective partners. This applies particularly to the flanges *d*, *k*, *m* and *n*, as if these are not flat, the task of centring them on a potter's wheel, as described above, would be extremely difficult.

THE GEARBOX

This part of the machine presents many options, which is why Fig. 7.12 is so undetailed. Fig. 7.4B does show a set of two 4:1 pairs of spur wheels and a V-pulley, which is the assembly I used in the original model.

As the blade shaft revolves at the low speed of 30 rpm maximum, it follows that several stages of gearing cannot be avoided between the blade shaft and the source of power. If an electric motor is used one is dealing with speeds between 1450 and 1750 rpm (depending where one lives). The double set of 4:1 spur wheels and a V-pulley is by no means the only arrangement of gearing, as there is a great variety of alternative combinations that would work. An easy solution to the problem, if one has the luck to pick up a bargain in reducion gearboxes designed for industrial use, is to install such a unit with a chain and sprocket drive which would have to be of a fairly heavy duty type. A chain and sprocket drive such as might be used on a 500 cc motor cycle would suffice, but a chain and sprocket as used on a pedal cycle would not do.

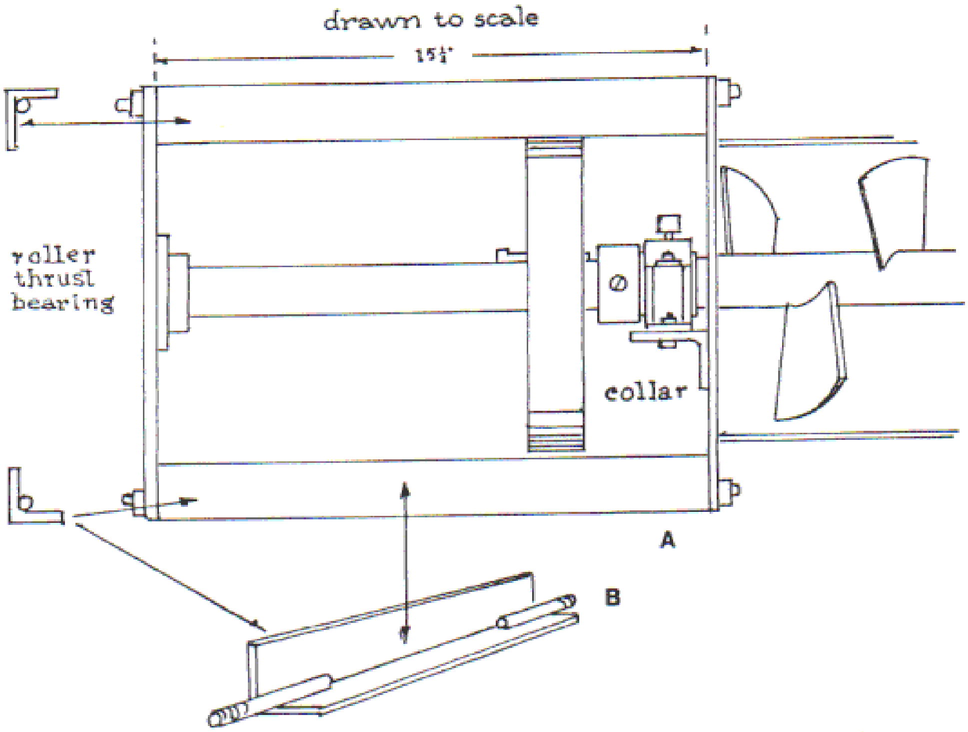

Fig. 7.12 The gearbox frame

A The gearbox frame seen from above with only one spur wheel installed. The pillow block bearing is on its side with a shaft collar hard against it

B A perspective view of one of the four corner units which hold the end plate of the gearbox on the left to the plate marked a in Fig. 7.2A. The bolts are welded to the angle iron

However, Fig. 7.12 does emphasise one vital detail regarding bearings. This deals with the distance between the roller thrust bearing at the far left, and the pillow block bearing to the right with a shaft collar pressing against it. These two bearings must be soundly located and properly aligned because they hold the whole of the blade shaft in position, there being no bearings inside the casing. Therefore, one might say that the greater the space between the two bearings the better.

The collar has an important function in that it prevents any forward movement of the shaft, if for any reason the machine is momentarily reversed. Such a reversal of direction would cause the thrust bearing to leave its housing at once if the collar were not there. The pillow block bearing is mounted on a bracket which is placed in a vertical position with the bearing on its side. This is done to prevent any clay that may escape backwards through the hole in *a* from piling up and getting into the bearing. If arranged thus, any clay will fall vertically away, and to facilitate this a space is left between the bearing and the face of *a*.

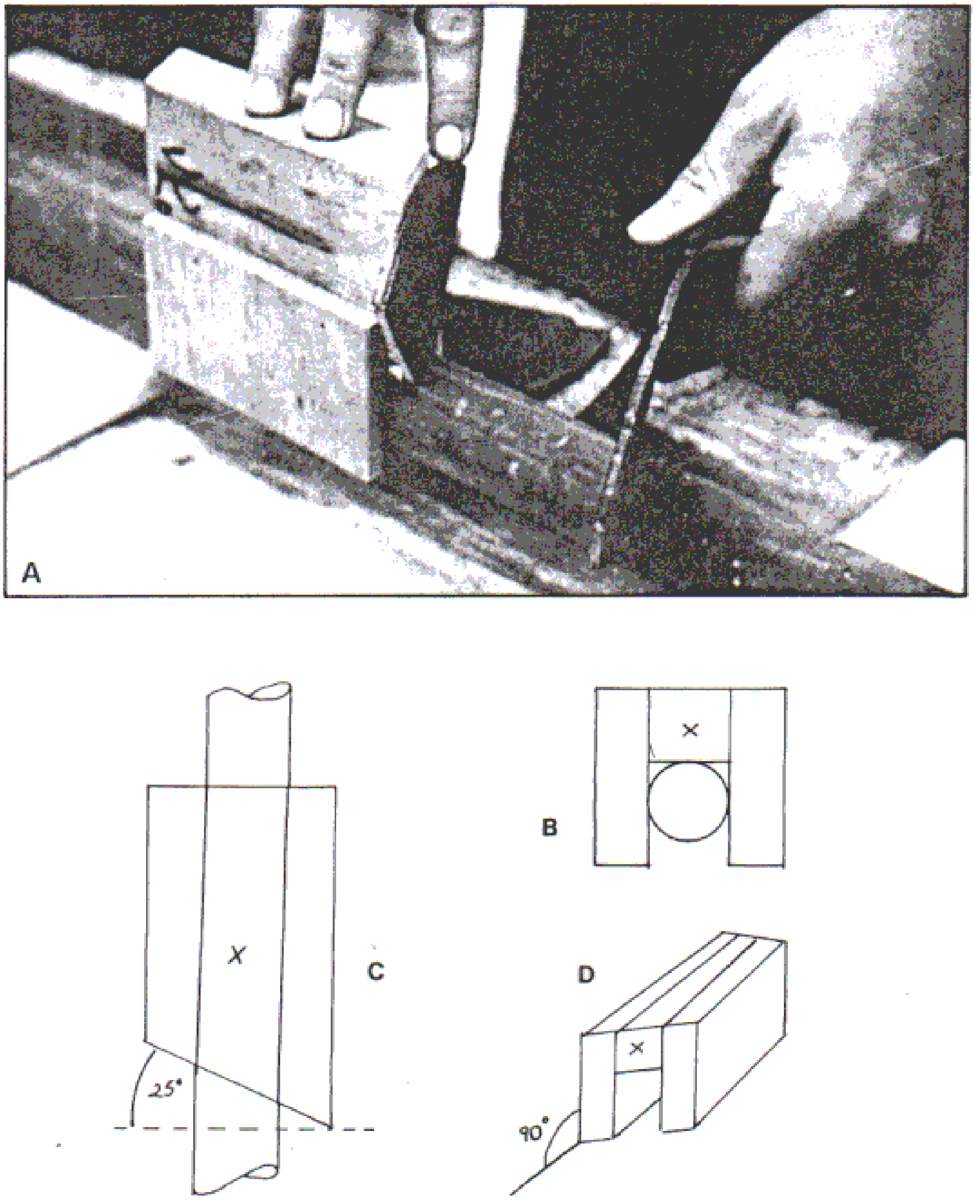

Fig. 7.13 A jig for setting the pitch of the blades

A The jig in use. The right-hand end of the jig is angled at either 25° or 28° to the axis of the shaft

B A sectional view of the jig resting on the shaft; x is the same width as the shaft and the other two pieces of wood are nailed to it

C The jig resting on a shaft as seen from above

D A perspective view of the jig