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The Harry Davis Single-Shaft Vacuum De-Airing Pugmill

Around 1976, Hank Murrow of Eugene, Oregon gave me a set of pug-mill plans designed and drawn by the late Harry Davis, Australian master potter and guru of studio self-sufficiency, and in 1979-80 I built the pugmill. Anyone thinking of building this pugmill should purchase a copy of Harry's book, *The Potter's Alternative*, because the plans and description in the book are far more extensive than the ones I used, which were in a handout passed out at Harry's workshops and lectures. The book was published in 1987, so the original plans were all I had to work with. Even if you are using the plans in *The Potter's Alternative*, the information in this document will prove valuable to you.

It is important that Harry Davis be given proper credit for the ingenuity of his design. Earlier deairing pugmills such as the Weiland were built on a German design featuring two parallel barrels with augers running at slightly different speeds. At the output end of the upper barrel, the clay is forced through shredder screens into a closed vacuum chamber, and drops into the lower barrel, where the second auger runs at a slightly higher speed, preventing backup and compaction of clay in the vacuum zone. This system requires a complex gear-reduction system providing outputs at two different speeds to run the augers. Harry came up with the idea of having a single auger, with the blades on the second half of the auger mounted at a slightly greater angle, causing the clay to move out of the vacuum zone slightly faster than it enters, accomplishing the same thing at a fraction of the complexity and price. Very large pugmills are still often built on the German plan, but Harry's design has become the standard of the industry for contemporary studio pugmills. Almost immediately after his discovery, the design was adopted for the well-known Australian Venco pugmills and the American Bluebird mills, and is now used by Bailey, Axner, Shimpo, and several other manufacturers. Even the "twin-shaft" studio pugmills produced today by several manufacturers are adaptations of Harry's design, because they just have two parallel shafts running in opposite directions in one oblong barrel.

Harry had a strong humanitarian streak, and with missionary zeal he set out to help invigorate or resurrect pottery production in remote parts of the world, where improvisation and self-sufficiency are a matter of survival. He produced a series of plans for pottery equipment that could be built on-site with minimal tools and equipment, and the pugmill plans and instructions I used were from this series.

Over time, Harry realized that in today's fine-craft world, improvisation and self-sufficiency are often a matter of economic survival for studio artists, and that realization provided the incentive to write *The Potter's Alternative*. In ceramics, unlike most other craft media areas, it is possible for a studio artist with a little ingenuity and mechanical savvy to build most or all of her/his own studio equipment. A fine home-built gas kiln is within the grasp of anyone, as is a power wheel using electronic variable-speed D.C. motor technology. A mechanical variable-speed Shimpo-style wheel or a pugmill are big jobs, requiring advanced mechanical, welding, and fabricating skills. But, given those skills and some creative scrounging for parts, you can build a $7500 pugmill for $1500 to $2000 in materials plus your labor. *The Potter's Alternative* deals with precisely this issue, and provides plans and descriptions for building a range of studio equipment.

I did some altering and adapting from Harry's original design, and my mill pug and deair 2000 lbs. of clay per hour, and has been working perfectly with no modifications and minimal maintenance for thirty-five years. In the following narrative I present Harry Davis's original written instructions verbatim, and then insert my own comments interpreting his instructions, and explaining what I did differently and why I chose to change the original design. In some cases the solutions I came up with were practical only because I found good deals on particular mechanical components. Anyone considering building this mill should plan to do some serious scrounging at scrap yards, used equipment dealers, and electric motor repair shops to cut down the cost, as I did.

Harry Davis's instructions jump right into the thick of it with no introduction, and throughout they refer to the diagrams. Since the diagrams are not included in this document, if you don't have a copy of "The Potter's Alternative," you can download the section about the pugmill from the Lue Pottery website at http://www.luepottery.hwy.com.au/clayart.htm. ***NOTE***: there is a picture of the mill in the gallery section of my website. The image does not include the vacuum pump, but otherwise it shows details of the mill fairly well, and it will help to refer to this image repeatedly when going over the directions, in order to clarify points in the description.

Harry Davis:
The differential pitch of the blades and the helixes on either side of the shredding screens is intended to hinder the build-up of shredded clay in the vacuum chamber. The breather valve unit serves to control this build-up that is a characteristic of de-airing pugmills. This unit, which is the special Crewenna contribution to the design, has the virtue of being cheap to build while serving the same purpose as the much more costly system used in some German models, wherein a supplementary auger and motor is mounted with reduction gears over the vacuum chamber.

My Notes:
In the first part of the mill, between the hopper and the shredding screens, the blades are welded onto the main shaft at a 25 degree angle, while in the section between the shredding screens and the extrusion opening, the blades are welded on at a 28 degree angle. Notice also that the double half-helixes directly before the shredding screens traverse 3" along the main shaft, while the ones at the extrusion end traverse 3 3/4". These specific measurements are critical. When the clay is forced through the screens, it enters the vacuum zone like spaghetti, in order to expose all of the clay to the vacuum. The blades and double-half-helix in the second half of the mill are designed to move the clay slightly faster than in the first half of the mill, which keeps the clay in the vacuum zone loose and open.

The breather valve is just a spring-loaded hinged door in the upper surface of the barrel in the vacuum zone. It opens once per revolution, when a tool-steel cam welded into a recess on one of the blades comes in contact with a corresponding cam on the underside of this door. Above this door is the vacuum chamber. The vacuum pump maintains 24-25" vacuum in this chamber, and each time the door snaps open the vacuum sucks the air out of the vacuum zone within the barrel. If this door is properly constructed, only a minute amount of clay will slip past with each revolution. It really is an ingenious design. The upper chamber only has to be cleaned about once a year, in comparison to the Venco system that has to be cleaned on a regular basis.

The German system that Harry refers to is of course the double-barrel deairing mill described earlier in this document. As a point of interest, the Weiland system does not require a second motor, as Harry Davis states. It simply requires a special gearbox with two outputs that operate the two shafts at slightly different speeds.

Harry Davis:
<u>The Breather-Valve Unit</u>
There are two details in the adjustment of this unit that are very critical. The drawing shows the cam blade engaging on the wedge that is welded to the pivoting half of the unit. On the end of this pivoting part is a 3/8" rod welded on. This rod presents a blunt edge to the clay that is forced up against it by the passing blades, and minimizes the upward passage of clay into the area above the breather-valve unit. It is very important that the 3/8" rod shall not touch the wall of the vacuum chamber when in the raised position. (Unfortunately, the drawing appears to indicate that it does touch. Hence the added indication that there should be a gap of 1/8 to 1/4" at this point.) When testing the empty machine with regard to this clearance one can very easily be deceived about this. The reason is that owing to the great length of unsupported blade shaft, the 3/8" rod can touch the wall without hindering the passage of the rotating blade-shaft, because the shaft will readily bend enough to permit this. However, when the machine is full of clay the shaft will not oblige in this way, and it is possible for the hinged part of the unit to remain jammed against the wall in the raised position. If this happens, the de-airing will stop.

The two critical details are: 1) there should be a clearance of at least 1/8" when the pivoting half of the unit is in the raised position, and 2) when the pivoting half of the unit is in the lowered position, it's inner face at the end by the 3/8" rod should clear the blades by a minimal amount, but should of course not actually touch. If these conditions are endured, clay adhering to the wall of the vacuum chamber will separate from the thin skin of clay adhering to the under face of the moving part and create an opening at every revolution of the shaft. It is via this opening that the vacuum maintains continuous contact with the shredded clay among the blades. It should be understood that if points #1 and #2 are not properly set, de-airing will not take place, but once properly set, no further adjustment is needed.

It should also be appreciated that there will be some slight passage of clay past the end of the valve, and this needs to be cleared from time to time. The object of the glass panel is to enable one to see that the valve is properly oscillating, and that clay is not accumulating excessively above the valve. The use of wing nuts to hold the lid in position is to speed up its removal for cleaning.

My Notes:
This section is extremely confusing, and I had a heck of a time figuring it out. Suffice to say that I came up with a solution better than the one indicated above and in the drawing. Locate the breather valve directly in the top of the barrel, equidistant from the front and back walls of the vacuum chamber, so that neither end of the breather valve is at all close to those walls. The leading and trailing edges of both the opening in the barrel and the door itself are beveled at approximately a 45 degree angle. On both ends of the opening and the door, the lower edge of this angle (inside the barrel) is pointed in the same direction as blade rotation. This is a superior design for a variety of reasons. It drastically reduces the passage of clay into the upper chamber. It eliminates the need to weld on the piece of 3/8" rod mentioned by Harry Davis above. Also, when the door shuts, the beveled edge of the door closes against the beveled edge of the opening, eliminating the need for an adjustable door stop in the breather-valve mechanism, as indicated on Harry Davis's plan. With this design, when the door is in the closed position, it is completely flush with the barrel, and works beautifully.

When you cut the opening for the breather door in the barrel, do not attempt to use the cut piece as the breather door, because the gap left by the cutting torch will make it a very sloppy fit, and it needs to be very snug to prevent the passage of clay into the vacuum chamber. To cut the breather-valve-opening and the door, first cut the opening in the top of the barrel. If you are really slick with a torch, you can cut the opening, including the bevels at both ends with minimal cleanup. If you are not so sure of yourself, cut the opening slightly small, especially at the beveled ends, and grind and file it to exact dimensions. The extra time will be worth it. Cut the door-piece oversized, grind it carefully to fit the door opening, including the leading-edge and trailing-edge angles.

Harry Davis makes a good point about the glass panel in the top of the vacuum chamber, although I do not believe it is really necessary, and it is a lot of trouble to install. If you do decide to have a "window," use 1/4" plexiglass. With or without a window, you will quickly get a feeling for the rate at which clay accumulates in the vacuum chamber, and as I said above, if the breather valve is properly constructed, the vacuum chamber only needs cleaning about once per year. As for watching to make sure the breather valve is oscillating properly, you will definitely know if it is not. I had to replace the tool-steel cams on the blade and door after about fifteen years of use. The mill quit properly de-airing the clay, and I noticed that it was also not making the comforting metallic squeak of the two cams contacting one another. If you think this might be the problem, remove the vacuum chamber lid, turn on the machine, and watch to see if the breather valve door is rising adequately with each revolution. If it isn't, you need new tool-steel cams.

The cams are just appropriate-size chunks of tool steel purchased from a machine shop or industrial supplier, and ground to fit this situation. Cut two one-inch pieces of 1/2" x 1/2" tool steel. You will have to cut them with a cut-off wheel or grind-stone (cooling frequently by dipping in water), because if you use a cutting torch you will take the temper out of the steel. That does not happen when you arc-weld them in place because the heat is quick and localized.

Grind a 1/2"-deep recess in the appropriate blade (the one that lines up with the location of the breather door), and arc-weld one of the pieces of tool steel to this recess, with the length of the piece at 90 degrees to the main shaft. Do not gas-weld the tool-steel blocks in place, because you will diminish the hardness of the material. Arc-weld the other piece of tool steel to the underside of the breather-valve-door (laid against the surface at 90 degrees to the main shaft) so that it lines up perfectly with the cam on the blade. The door-mounted cam should be welded close to the leading edge of the door (opposite edge from the hinge), as it requires considerably less effort to open the door at this edge, prolonging the life of the cams.

Once the cam blocks are welded in place, grind the exposed surface of each to a smooth curve with perhaps a 3/4" radius along the length of the piece. Once ground, the outer surface of the shaft-mounted cam should be flush with the outer edge of the blade. After the shaft, barrel, vacuum chamber, and complete breather door are all finished and assembled, minus the spring on the breather door, press down lightly on the breather door with a stick or rod, turn on the machine, and check the lift at the leading edge of the breather door when the cams come in contact, aiming for a lift of 1/4” to 3/8”. You will likely have to disassemble the barrel, grind the cams, and reassemble and check it again, and my may have to repeat this several times.

WARNING: After you grind the cams each time, completely reassemble the barrel before turning the machine on. The machine should NEVER be turned on without the barrel assembled, because there is far too much danger of catastrophic injury from the exposed auger and blades.

It is important to complete this process before installing the breather door spring, because even though the auger shaft seems very sturdy and inflexible, the pressure of the spring could cause it to deflect slightly, giving an inaccurate measurement. When the pugmill is in use, the pressure of the clay against the inside of the barrel keeps the auger centered, and the force exerted by the breather-door spring will not deflect the shaft.

Harry Davis:
The Rubber Seals
There are only four joints needing seals. The other joints between unit #1 and #2 and between #3 and #4 require no special care.

My Notes:
In other words, you need rubber gaskets at the right-hand end of unit #2 (which holds the vacuum), under the lid of the vacuum chamber, and under the removable access covers on the front and back of the housing containing the shredder screens. Good quality 1/8" reinforced rubber sheeting, available from an industrial supply store, works best for these gaskets.

Harry Davis:
The Collar
This needs an Allen screw to lock it in place. Its function is only to hold the blade-shaft firmly in the conical runner of the thrust race when the machine is empty.

My Notes:
Disregard the previous section. Instead of using a cone-bearing as Harry Davis suggests, use flange-mount ball-bearing units to mount the main shaft. They can absorb far more thrust than is created by this machine. Make sure to get bearings with twist-lock collars and set screws, and lock them very firmly with a hammer and punch before tightening the set screws. These bearings lock onto the shaft much more positively than ones with only set screws.

Harry Davis:
Vacuum
Details of the vacuum pump are not included in the drawing because this can either be incorporated in the machine, or treated as a separate unit with an independent motor. The volume of the vacuum chamber is small, and the rate of evacuation is extremely low. A very small vacuum and proportionately low powered motor could be used. I have my vacuum pump driven by a separate motor, but the 2 HP motor that drives the pug seems to have ample power to spare, and would, I suggest, be sufficient for both pug and vacuum pump.

My Notes:
I would under no circumstances run both the pugmill and the vacuum pump on the same motor. There are circumstances where you will want to run the mill without the vacuum pump, and I do not believe a 2 HP motor has much power to spare on this machine. At first, I tried to use a small piston vacuum pump with about a 1 1/2" bore, and it didn’t have enough oomph. Next, I found a good used rotary vacuum pump from a milking machine, which is gross overkill for this application, but it only cost me $35 and works great powered by a 3/4 HP motor. A piston-type air compressors with at least a 3" bore and pipe connections for both the inlet and outlet (such as are used for refrigeration systems) can usually be converted to a vacuum pump. I believe that the Venco uses a single cylinder pump with a 3" bore, running on a 1/2 HP motor. Vacuum pumps tend to be very expensive when purchased new, so it is worth it to scavenge a rotary vacuum pump from a milking machine, or convert a refrigeration compressor. If you do the latter, make sure it has at least a 3" bore.

Harry Davis:
The Vacuum Gauge
The reading for a good de-airing needs to be 24 to 25 Hg.

My Notes:
An appropriate vacuum gauge can be purchased at any auto supply or industrial supply store. Get one with the 1/4" pipe hookup at the bottom of the gauge rather than at the back. Drill and thread

a hole in the vacuum chamber lid (1/4" steel plate) to fit 1/4" pipe. With proper thread sealing compound or Teflon tape, install a 1/4" close nipple and a tee, and mount the gauge in the top of the tee. In the other leg of the tee, install an appropriate fitting to accept the rubber hose leading to the vacuum pump. Be sure to use a good heavy reinforced rubber hose, such as automotive fuel-line hose.

Harry Davis:

The Metal Screens

The use of metal screens instead of perforated plates is also my invention and has several advantages. Screens offer very low resistance to the clay flow and therefore low HP consumption. The life of the screens is considerable and they are easily replaced by grinding away the welds. It is important to use a screen with thick wire (18 gauge at the least). If the wire is too thin there is a tendency for the clay to reunite as it passes the wire, before the vacuum has had time to act.

Size of Holes in Screens

I first used 1/4" by 1/4" with good results, but later replaced with 1/8" by 1/8" with equally good results. (I suggest 3/16").

My Notes:

For the shredder screens, I used 1/8"-mesh 18-gauge stainless steel screen. Western Wire in Portland, Oregon sold me four square feet for a very reasonable price. I have replaced the screens three times in 35 years of use, so this amount of screen should last another ten years. I did not weld the screen to the frames. At a welding supply store I purchased a very high strength low-melting silver/tin alloy solder with appropriate flux that bonds to both mild steel and stainless steel. It works great, and makes it very easy to replace the screens without affecting the frames. When you eventually do have to replace the screens, be sure to grind or sandblast the contact surfaces on the frames so that the solder will adhere.

Harry Davis:

Grip Holes in the Screens

These 3/8" holes are intended to facilitate extraction of the screens by means of a 3/8" pin and levers. The initial removal of the screens is quite a task and an effective means of getting a grip on them is important. If units #3 and #4 are being taken off too for a general clean, it is easier because then the end of a box-opener lever can be forced between the two screens.

My Notes:

Forget about the above paragraph and the 3/8" holes in the screen frames. In the supplemental drawings I received, harry changed that design and suggests welding lengths of ½” by ½” square-stock to the top and bottom angle-iron members of one screen frame. With this addition, when the covers are removed, a 16" piece of ½” round stock or re-bar may be inserted from the opposite side so that it contacts these welded-on lugs, and one screen may be driven out by striking a hammer against this rod, alternating the rod frequently between the top and bottom lugs. Once the first frame is removed, the second frame may easily be driven out from the opposite side. When removing the second screen, be sure to place the rod against the angle iron at the top and bottom, and not against the middle part of the screen-frame.

Also as an important note, with this improved system, the lugs welded onto one screen frame must extend beyond that frame half and partially overlap the top and bottom of the other half in order to support it centered vertically within the slot, since the slot will have to be taller to accommodate these lugs.

The housing for these frames should be designed and built so that the screen frames fit snugly with very little movement top and bottom. Make sure to construct the frame slot and the screen frames so that when the access covers are bolted in place with the rubber gaskets, the frames are held tightly together in the center with no more gaps than necessary.

In the plan Harry Davis specifies using ¾” angle iron for the outer members of the screen frame, but he does not specify thickness. If you are going to use angle, go for ¼” by ¾” angle for the outer members and ¾” by ⅛” flat bar for the rest of the screen frame. I used ½” square stock for the outer members and ½” by ⅛” for the rest of the frame supporting the screens.

Fasten the screen securely to the frame on the same side as the angle-iron flange, and install the frames so that the flange and screen face the hopper end of the pugmill. This is important, as very little clay will accumulate in the corners of the screen-frame housing. If the angle-iron flange were facing the vacuum zone, the spaces in the corners of the screen-frame housings would become packed with clay, making screen-removal much more difficult.

When designing the screen-frame housing, be sure to allow sufficient space to accommodate the thickness of the frames *and the screen*.

When the output of the mill slows down it is almost always because of clogged screens. When driving the screen-frames out for cleaning, there will be a great deal of material stuck in the screens, but you will be amazed at how much material remains inside the barrel imbedded in the clay face on the hopper side of the screens. If this debris is left in place after you clean the screens and re-start the mill, it will immediately be pressed into the clean screens. I took a 16" piece of ⅛” by 1 ½” flat bar, and bent the last ½” at one end at a 90 degree angle, forming a tool for “raking” any debris from the clay face inside the barrel on the hopper side of the screen-frame chamber, before reinstalling the screen-frames.

Harry Davis:
<u>The Casing</u>
The flat faces of the vacuum chamber should be heavy. 3/16" plate might do, but I used 1/4". All of the circular and semi-circular surfaces can be much thinner. I suggest ⅛" plate. The flanges of the units can also be of ⅛" steel plate, except unit #3, which presses on to the rubber seal against

unit #2. This flange should be made of 1/4" plate, as also the two plates on either side of the area that houses the screens.

My Notes:

I think that 1/8" plate is a little light for anywhere in this machine, especially if you are using mild steel. I used 1/4" plate throughout, and 1/4" by 8" well-casing for the barrel. Have the barrel segments cut on a large bandsaw or reciprocating hack-saw at a machine shop. ***Before*** having them cut, mark off the cuts and make permanent registration marks with a cold chisel and number-stamps or center-punch marks at the cuts between section #1 and #2 and between #2 and #3. Even the best machinist's hacksaw or bandsaw is not absolutely accurate, but as long as you have accurate registration marks for when you weld on the flanges, drill the bolt holes, and assemble the sections, you can put them together exactly as they were cut, and the barrel will be absolutely straight.

If it is within your resources, make the whole thing out of stainless steel. I didn't, and my mill can only be used for stoneware and terracotta. If you want a mill for porcelain and whiteware, it must be stainless. If not, the clay interacts with the mild steel, creating a rock hard bluish-gray deposit that breaks loose in lumps that clog the shredder screens and end up in your clay. This deposit will also eventually fill the space between the ends of the blades and the inside of the barrel, in which case the machine quits working altogether.

Another compelling reason for using stainless, at least for the barrel, shaft, helixes, and blades, is corrosion. The inside workings of my machine are getting pretty severely pitted with rust. I expect that I (or someone) will have to replace the barrel, blades, and half-helixes in another twenty-five years.

Harry Davis:

<u>Bevel of the Blades</u>

The lee side of the leading edge should be ground leaving a cutting edge of about 1/8" or less, and the leading edges of the helixes should be done in the same way. This becomes very important if it is decided to use say 1/4" plate, because the absence of a bevel will greatly increase the HP consumption. (I have used 3/16" plate on mine and this is quite adequate for the amount of running a potter would give the machine. A clay salesman would want to give it more continuous use.)

My Notes:

When the machine is working, clay necessarily remains partially stuck to the inside of the barrel, while the rotating blades and helixes are constantly cutting through the clay within the barrel, slowly moving the mass forward. As Harry Davis suggests, without this bevel, the motor must do much more work to accomplish the same end. By "lee side," he means the back side - the side facing the hopper end of the mill.

I used 1/4" steel for the blades, and recommend against anything thinner unless you are using stainless steel.

Harry Davis:
Blade Pitch
Note the differential pitch of 25 and 28 degrees, and the difference in the amount of shaft occupied by the two sets of helixes. The blades in the feed-opening and in the vacuum chamber should be given a tilt of 2 to 3 degrees in the direction of clay flow. This detail is not shown in the drawing, but it is a valuable feature that greatly helps to achieve the automatic intake of the clay. If the clay is fed on to the down-side of the feed-opening, and the forward tilt is provided, force feeding is quite unnecessary.

My Notes:
Do not neglect the differential blade pitch and the 2 to 3 degree forward tilt of the blades. When the blades and helixes are all properly set up in assembly, the machine rarely has to be force-fed with the plunger. When Harry Davis says to feed the clay on the down-side of the feed opening, he simply means to feed it on the side of the hopper closest to the shredding screens. I *throw* fist-size lumps of clay into this zone, and I do not have to use the plunger at all if the clay is the proper consistency. If the clay is too soft or if you are pugging a mixture of soft and stiff, you will have to use the plunger.

Harry Davis:
Bolts Holding Breather Valve to Casing
It is important to provide these with well-fitted flat washers, as this can be a leak point for the vacuum chamber. On no account use spring washers here.

My Notes:
You can get copper washers at any good auto-parts store, and they will give a perfect seal. By spring washers he means split lock washers, and he is saying that they should not be used as seal washers. Install the bolts with the heads and the copper washers on the inside of the vacuum chamber and the nuts and lock washers on the outside. Purchase a good anti-seize compound from an auto-parts store, and apply this to all bolt threads, to facilitate disassembly when you eventually have to replace the tool-steel cams. All bolts in the vacuum chamber and the hopper area should be installed as described - with the heads on the inside and the nuts on the outside, away from the clay.

Harry Davis:
Tool-Steel Pad on Cam Blade
It is very important that this pad is filled into a recess previously ground out of the edge of the blade, so that when finished the tool steel pad does not rise above the standard curve of the top edge of the blade. If this is disregarded, point #2 above under “Breather Valve Unit” will be interfered with.

My Notes:
This was covered earlier, but I am including everything from the original instructions.

Harry Davis:
<u>Painting the Interior of the Mill</u>
There is a good case for painting the blades and shaft with a high-gloss paint. The inside of the discharge-cone can also be thus painted. Apart from the obvious rust-proofing value, the passage of the clay is greatly helped by this. However, it is not a good idea to paint the inside face of the barrel of the machine where the blades and helixes rotate, as the clay will adhere much better to the unpainted steel, which is important for the proper functioning of the mill.

My Notes:
DON'T DO IT! Don't paint anything inside the barrel! I did as he indicated, and pretty soon I had sharp paint flakes appearing in my clay. I had to take the whole thing apart and have all the painted areas sandblasted.

Harry Davis:
<u>Method of Determining the Shape of a Helix</u>
Prepare a block of wood with the following measurements: A) height equal to the traverse of half a revolution of the intended helix, B) length equal to the diameter of the intended helix, C) width equal to the radius of the intended helix. Describe semi-circles on the top and bottom faces as shown in figure #1. The greater semi-circle will equal the outer diameter of the intended helix, and the smaller circle will equal the diameter of the shaft on which the helix is to be fitted. Then cut away the unwanted wood to produce the form shown in figure #2. Prepare paper triangles X and Y with measurements as follows: A1 - B1 and A2 - B2 equal to A - B in figure #1, C - B equal to the half circumference of the outer face of figure #2, and D - B2 equal to the half circumference of the inner face. Paste these two triangles on the inner and outer faces with the corners C and D coinciding with the points C and D on figure #2. The positions of hypotenuse X and hypotenuse Y will then correspond to the dotted lines in figure #3. The face of the desired helix will emerge when the surplus wood is cut along a plane linking the hypotenuse lines C - A1 and D - A2.

My Notes:
The heck with this. Every time I read it I get a headache. I know I damaged brain cells trying to figure this out. And even if we follow his instructions, Harry tells us nothing about how to actually form the half-helixes in steel plate. I scrapped this entire process. Instead, by trial and error, I cut the shape out of thin sheet-metal, and bent it into the appropriate half-helix shape, and kept doing this until I had a half helix of the right shape and size. I then flattened the sheet metal out again to give a pattern for cutting out the actual half-helix pieces from 1/4" steel plate.

To bend the cut pieces into half helixes is itself a rather complicated process. If you figure an easier way to do it, let me know. You will need to build some bending tools as mentioned below. It would be possible to do it with only the hand-held bending tool and a very heavy vise, if you could visualize the shape of the entire half helix, slowly moving it out of the vise a bit at a time, heating it up, and twisting it. I had no luck at that, so I fabricated a very sturdy stationary (when mounted in a heavy vise) jig with a slot capable of holding the half-helix anywhere along its length even after it is partially formed. That way, I could work outwards in both directions from the center of the half-helix, which made it much easier to get the appropriate shape.

To do as I did, you will need to build two holding/bending-jigs. Cut four 6"-long pieces of 1/4" by 2" flat bar, and four 1 1/2"-long pieces of 5/16 round stock. For the latter, just buy four 5/16" bolts 3" long, cut off the head and the threaded end, leaving a piece of 5/16" round stock 1 1/2" long. On a flat steel table or a piece of steel plate, clamp two pieces of the flat bar down face down side by side, with pieces of the 5/16" round stock spacing them apart at either end, leaving a 5/16" by 3" open slot down the center. Weld them together, unclamp them and flip them over, and weld the other side. Repeat with the other pieces to make the second jig. An alternative is to use 6"-long pieces of 1/4" by 4" flat bar and cut a 5/16" by 3" slot cut down the center of each one with a cutting torch, but that will involve considerable skill with the cutting torch to get a nice even slot. The one fabricated from multiple pieces is much easier in the long run.

One jig will be stationary, and must be welded vertically to a mount that can be clamped in a very heavy bench vise or bolted to a very sturdy workbench or to the floor. The other jig is welded to the end of either a five-foot piece of 1" solid shafting, or a 5" piece of steel pipe at least 1 1/2" diameter, forming a very large “wrench” to twist the heated steel piece while it is held in the first jig.

Before you start forming your half-helixes, cut a piece of poster board or aluminum flashing to the pattern shape. Hold this piece by opposite ends, and twist the ends in opposite directions, holding the piece against the main shaft for your pugmill. In doing so, you will be able to visualize the shape you need to form, and you will be able to tell which direction to twist the blades to get the half-helixes to move the clay properly. Just like screw threads, these helixes are either left hand or right hand, and they must be correct for this machine. By examine the ones in the plan, and by trying the cardboard or flashing mock-up against the main shaft, you can make sure that you twist your half-helixes in the right direction. DO NOT NEGLECT THIS. It would be a real shame to finish the mill and discover that your half-helixes are backwards.

Cut four pieces of steel to the pattern shape. Just rough-grind the edges at this point. In final bending and fitting you will grind and fit two half-helixes to traverse a 3"-length on the shaft, and two of them to traverse a 3 3/4" length, as indicated on the plan. After welding the half-helixes to the shaft you will grind the outer edges and the leading and trailing edges to the appropriate form.

Clamp the stationary jig in a large vise or bolt it to a heavy bench, and place one of the rough-cut pieces through the slot in the stationary holder so that an equal portion sticks out of either side, with the ends pointing upwards. Have a helper hold one end of the helix piece with a pair of heavy pliers (large vise-grips work well) or blacksmith's tongs during this stage of the process. On the other side of the jig and directly adjacent to the jig, heat the piece along a radius line with a rosebud tip or the cutting-tip on your oxy-acetylene torch, and when it is cherry-red all the way across the width of the piece, take the "wrench", and with the handle extending up in the air, slip it over the piece and twist it slightly towards you at the heated zone. Remove the "wrench", and slip the previously twisted area about 1/2" into the stationary jig, so that a smaller portion sticks out on the side where you doing the heating and twisting. Have your helper hold the piece firmly in the jig with pliers or tongs on the opposite end of the piece. Heat up again, slip the "wrench" over the helix, and twist again in the same direction. Continue this process until you get to the end of that half of the helix piece. Next, remove the piece, turn it around, and reinsert it in the stationary jig to the half-way point, still with the ends pointing upwards. Have your helper hold the now-twisted end securely. Start the same process on the un-twisted half of the helix, again pulling the "wrench" towards you with each twist, and moving the piece 1/2" further into the stationary jig with each twist. When you are done, and you hold the half helix with the mid point completely level, half of the half-helix will twist upwards, and half of it will twist downwards. Hold it against the shaft, and see if it does what you want. When snug against the shaft, if it does not traverse approximately 3" linear distance along the shaft, then you twisted too much. If this is the case, you can untwist it a bit with sledge and anvil without even heating it up. If it fits too loosely against the shaft and covers more than 3 3/4" linear distance on the shaft, then you twisted too little, and you will have to twist it a bit more. MAKE SURE that the twist is in the right direction for the rotation of the pugmill and the movement of the clay. When you are certain that this is correct, make three more half-helixes.

NOTE: When making the half-helixes by this method, don't expect the outcome to be perfectly streamlined like the ones commercially made in an industrial forming machine. They might come out a little lumpy, but as long as they are pretty even overall and traverse the correct distance on the main shaft, they will work great, as mine have proven.

As mentioned above, the final step involves grinding the inside curve of each half-helix to fit the main shaft, with two of them ground to traverse 3" along the main shaft, and two ground to span 3 3/4" along the shaft, as indicated on the plan. When this is done, set the pieces aside until you are ready to weld the half-helixes and blades onto the main shaft. After the half-helixes are welded onto the shaft you can grind the outside face and the leading and trailing edges. The trailing edge only has to be ground to a smooth cosmetic edge, while the leading edge needs to be ground to a bevel as describes earlier.

<u>My Supplemental Notes and Recommendations</u>

The following is a collection of additional information I came up with in adapting the Harry Davis design, building the mill, and using it over the last twenty-five years.

<u>WARNING!! WARNING!! WARNING!! WARNING!! WARNING!! WARNING!!</u>

This pugmill is virtually unstoppable, and if anything other than clay goes into the hopper opening, the motor and drivetrain won't even notice. They will either chew up the foreign object or start breaking screens and blades. You can throw or drop clay into the hopper, but never under any circumstances should your hands enter the hopper opening when the mill is running. Do not ever push clay into the hopper with your hands, or with anything except the plunger. Even when the machine is turned off do not ever put your hands in the hopper or disassemble the machine unless the main switch AND breaker switch are in the off position. Check this and double-check it. If the machine happened to start while you were cleaning the auger, with your hands or clothing entangled in the blades, the outcome could be truly horrible. Make sure this pugmill cannot be started by children or other unauthorized users. In such situations, always install a key switch and keep the key secure. Such switches are available from any good industrial electric supplier.

When properly used, pugmills are very safe and benign. Improperly used, they are EXTREMELY DANGEROUS.

<u>Selection and Location of Switch</u>

When you install and wire the machine, make sure that the main pugmill switch and the vacuum-pump switch are very accessible and easily operated, but make sure they are not where you will lean against them accidentally, or where they are within the reach of children. A good solution is to mount them on the wall above and slightly to the right of the hopper, or to fabricate a bracket attached to the machine itself with the switches mounted in the same location. If you are using a five HP motor for the pugmill, as I did, you will need a relay switch, such is used on most heavy power equipment. This is normally located in a metal box mounted on the wall, with the push-button on-off switch that operates the relay mounted as described above.

CAUTION: *If children are around, or anyone else who might use this pugmill without authorization, always install a key switch and keep the key secure. Such switches are available from any good industrial electric supplier*.

<u>Blade/Helix-Clearance within the Barrel</u>

It is critically important that there be approximately 1/4" clearance between the outer surface of the blades and helixes, and the inner bore of the barrel, as specified in the plans. The blades push the clay against the inside surface of the barrel, and the clearance allows some clay to stick to the barrel, causing the blending action essential for proper operation. The friction against the barrel tries to hold the clay back, while the blades and helixes move it forward. This action is critical for proper operation. If the pugmill is constructed with inadequate blade-clearance, then the entire slug of clay inside the mill will simply rotate with the main shaft, accomplishing nothing.

<u>Further Notes on the Breather Valve Assembly</u>

The drawing on Harry Davis's plan is close enough for you to get the idea. As mentioned earlier, I placed the breather-valve door in the center-top of the vacuum zone, so that the door was spaced evenly between the front and back walls of the vacuum chamber. DO NOT build and mount the breather valve as shown in the plan, as the door would simply hit against the back wall of the vacuum chamber. Harry Davis's plan indicates an arm with an adjustable nut to control the downward movement of the door when it closes, but with the bevel system I indicate earlier, this is not necessary, because the door simply closes against this bevel. For the door spring, I used an automotive valve spring, which has worked fine. When installing or removing the breather valve, it is necessary to hold the door in the partially raised position. To accomplish this, weld a 3/8" nut to the door top center, and drill a 3/8" hole through the spring bracket directly above the nut. To compress the spring and lift the door, insert an appropriate length bolt (with washers if necessary) through the hole and screw it into the nut, so that it holds the door in a slightly raised position. After making necessary adjustments or repairs, and after bolting the breather-valve assembly back in place, remove this temporary bolt, lowering the valve-door. Apply a dab of thick grease into the threads of the nut welded to the door, to prevent corrosion of the threads. Save the appropriate bolt and washer(s), so that you can use them to raise the door when you need to remove the breather-valve assembly to do maintenance on the tool-steel cams.

The Main Shaft

As mentioned earlier, I used 1 15/16" shafting, a very common size in machine shops and industrial applications, because the Falk shaft-mounted gear-reducer I obtained was already equipped with an internal sleeve adapter for this size. You might want to scavenge scrap yards and used machinery dealers to try to find a shaft-mounted gearbox, and if you find one you can use the shaft size it is already set up for, as long as it is at least 1 1/2" and not more than 2" in diameter. If you find a shaft-mounted gear-reducer that is slightly larger than this, contact the manufacturer and see if you can get an internal sleeve adapter to reduce the internal bore to the desired shaft size, or have a machinist make one. If you can get the gearbox for a good price, it will be worth the additional expense.

Whatever drive system you use, an enormous amount of torque is applied to the main shaft, and you will need to take it to a machine shop and have them cut a keyway, and then purchase an appropriate length of keystock to fit the shaft and bore of the gearbox, coupler, or sprocket that delivers the power to the main shaft. Have the keyway cut as soon as you purchase the shafting, before you start welding on blades and half-helixes. The keyway in the shaft should be only long enough to accommodate the key, and should be in exactly the correct location on the shaft to correspond to the location of the coupling, sprocket, or gearbox in the final assembly.

Note in the plans that the output end of the shaft is rounded. I actually ground mine to a dull point, which simply streamlines the travel of the clay a little more, making the pugmill do slightly less work. Every little bit helps.

Barrel Design and Connections

When I built my mill, I designed and built the barrel with sleeve connections and large O-rings, rather than flange-connections with flat gaskets (only the connection between unit #2 and unit #3 needs a gasket), along with a system of quick-disconnects to facilitate disassembly and cleaning. At the time, I was unaware that this mill would not work for porcelain and whiteware. After I discovered that, disassembly became a far less frequent chore. I recommend just using flange connections as pictured in Harry's plans. It is much easier to build, and the flange connections really are no inconvenience at all on the rare occasions that you have to do a thorough clean-out.

I did away with the connection between unit #3 and unit #4, making the cone part of unit #3, which has worked just fine. I did incorporate a flange on the small end of the cone (the 4" extrusion), so that I can use extrusion dies if I wish. I made a small flanged attachment with a short length of 4" I.D. pipe mounted on the extrusion end for normal pugging operation.

The Vacuum-Chamber Lid and Screen-Chamber Covers

It is essential that the removable lids and mating flanges on the vacuum chamber and screen chamber fit perfectly with flat mating surfaces, so that they seal tightly with rubber gaskets. Even a tiny leak will cause the vacuum to drop excessively. When you fabricate unit #2, complete with screen chamber and vacuum chamber, you will weld strips of flat bar onto the top of the vacuum chamber and onto the screen openings to form flanges to bolt the lid or covers on. In each case, make the lid (1/4" steel plate) or screen-chamber covers (1/4" steel flat-bar) before welding the strips of flat-bar in place, and drill all the appropriate holes through the lid or covers and the mating flat-bar pieces, and bolt all the pieces together (without the gaskets, of course), and then tack-weld the corners of the flanges together, and tack-weld the flanges thoroughly to the vacuum chamber casing and the screen-chamber, while they are still bolted to the lid or covers. This will insure that all the pieces are perfectly in place and that the mating surfaces are perfectly flat. After you tack weld them in place, remove the bolts and set the lid or covers aside, and then complete the welding and grinding of the flanges.

The Extrusion Cone

When scrounging scrap yards you may be so fortunate as to find an appropriate cone-shaped steel form to adapt as the extrusion cone on your machine. If not, you will have to form one. I made mine from 1/4" plate, but it would be much easier to form it with 3/16" or even 1/8" plate. By trial and error (or, if you are one of those math-whizzes, with clever calculations and layout) make a pattern from card-stock which when bent and taped together forms exactly the cone you wish to have. Use this template to transfer the shape on to steel plate and cut it out with a torch.

On a large and sturdy bench vise, open the jaws several inches, have a helper hold the steel piece across the vise-opening, heat along a radius line to cherry-red, and holding this line directly over the vise opening, beat along the line with a straight-peen hammer to begin the bend. If you do this carefully on closely spaced radius lines all along the piece, you can form a perfect cone. When the ends meet, clamp them together and butt-weld them. If the cone is at all irregular, you can easily heat it and work it on anvil and vise to finish forming it.

On the small end of the cone you can fabricate a bolt flange to accommodate extrusion dies, and make a bolt-on 4" extrusion die for regular pugmill operation as explained above, or else just weld on a 4"-long piece of 4" pipe. Keep in mind that this mill should only be used for fairly large extrusions, like tiles, tubes, or solid shapes. If you restrict the opening too much, it will overwork the motor, and the mill will overwork the clay.

The Hopper and the Plunger

Harry Davis's plan does not specify a plunger for the hopper, but you need one. See the image on the website to clarify the design of the hopper and plunger. First, I added a flared funnel-like mouth at the top of the hopper, constructed from four pieces of 1/4" by 2" flat bar. This really helps in feeding the machine. Build a steel bracket for the plunger-handle pivot. After you finish constructing the entire bracket/handle/plunger assembly, the bracket will be welded to the vertical back wall of the hopper below the flare. The pivot point should be at least four inches out from the back wall of the hopper, and at least an inch above the level of the hopper opening. For the handle, I used a 30" length of one-inch black iron pipe with a rubber bicycle-handlebar-grip over one end, and with a 3/8" hole drilled through it 1/2" from the other end for the pivot. Use a 3/8" bolt with a Nylock-nut for the pivot pin. Put the pin in place, and hold the bracket against the back of the hopper. Mark a point on the handle exactly centered over the hopper, and drill a horizontal 3/8" through the handle at this point. Cut two 6"-pieces of 1/4" by 1" flat bar, and drill a 3/8" hole on center 1/2" from the end of each one. The plunger itself is just the piece you cut out of the barrel to make the hopper opening. Grind the edges, and weld the two pieces of flat-bar vertically in the center of the back-side of the curve, spaced far enough apart so that they slip easily over the handle, with another 3/8" bolt slipped through the holes.

When the bracket/hinge, handle, and plunger are all completed and assembled, hold the plunger in place in the hopper, and hold the bracket in place against the outside back of the hopper. Slide the bracket up and down until you find the spot where the lowered plunger handle hits the front edge of the hopper while the plunger is still at least one inch away from the blades. Mark that spot on the back of the hopper, and weld the bracket in place.

When the bracket is welded in place and the plunger and handle are assembled and working properly, locate and weld a small stop on the handle to keep the plunger from pivoting downwards all the way when you lift the lever and pull the plunger out of the hopper. With this stop installed, the plunger will be in place to enter the hopper every time you lower the handle. Without this, you will have to manually swing the plunger upwards to align it with the hopper opening every time you lower the handle.

The Drive System

Unfortunately, Harry Davis gives no information to guide us in the selection of a proper drive system other than suggesting a homemade chain-drive reduction using off-the-shelf industrial components. I used a five horse-power single-phase motor with a Falk shaft-mounted gear-reduction box. Use a capacitor-start or an induction-repulsion motor for high starting torque. The shaft-mounted gear-reduction box design has a bore passing through the center of the casing and the main drive-gear, and it actually mounts on the main shaft of the pugmill, between two flange-mount ball-bearing units, to the left of the hopper. As you can see from the plan or from the image of my pugmill, the main shaft is entirely supported from this end by two bearings. If you can come up with a shaft-mounted gear reducer, it is by far the easiest way to go, and they are very heavy-duty units. My Falk unit was made to fit 1 15/16" shaft, a very common size in heavy mill machinery, so that is the size of shaft I used. Harry Davis specifies a 1 1/2" shaft, which should be plenty adequate, and will allow you to use a slightly smaller gear-reduction unit. Even if you get one that is oversize, you can contact the manufacturer and purchase a sleeve reducer, or if necessary you can have a machinist make an insert to bring it down to the shaft size you wish to use.

I like the shaft-mounted reducer for several reasons. It is independent of the motor, so if you have trouble with the motor, you can use any other scrounged motor that has adequate power, regardless of the design or size. Also, the shaft-mounted box makes it very easy to adjust the tension on the V-belt drive from the motor. On many motor-driven units, the motor must be mounted on a complex adjustable sliding base, to allow tightening of the drive-belt or chain, but that is not necessary here. Since the gear reducer is mounted on the main shaft, it needs a heavy stay rod attached to the pugmill frame to keep it from rotating on the main shaft. At the upper end, the stay rod is bolted to one of the main bolts on the rim of the gearbox, as far as possible from the main shaft (for maximum leverage in holding the gearbox stationary). The other end is bolted to the base of the pugmill frame. I used 1 1/2" by 1 1/2" by 1/4" angle iron for the stay, and on the end attached to the pugmill frame, I drilled a series of bolt holes overlapping one another and filed away the remaining metal to make an elongated slot. The input shaft on the gear reducer is located off to one side of the main shaft, so when the gear reducer housing is pivoted on the main shaft, it moves the input shaft closer to or farther from the motor. This allows tightening of the drive belts from the motor, by pivoting the gearbox up or down within the limits of the elongated bolt-slot in the stay-rod, and then tightening the bolt.

Use good quality industrial double-belt V-belt pulleys, and measure for the belts with the gearbox pivoted so that the input shaft pulley and motor pulley are as close together as the slotted bolt-hole will allow it. Install the belts, and using a pry-bar, swing the gear-reducer housing to move the input-shaft upwards away from the motor, thereby tightening the belts. Holding the gear-reducer in this position, tighten the bolt in the slotted hole. Use a flat-washer and split lock washer on this bolt, and tighten it very securely. The stay-rod and belts on my mill have never slipped, and have never been re-adjusted since I set the mill up the first time thirty-five years ago.

As mentioned above, for the belt-drive from motor to gearbox, use twin-belt pulleys. Use a 3" or 4" diameter pulley on the motor, and a larger pulley on the input shaft of the gear-reducer. You will have to determine the size of that pulley based on the reduction ratio of your gear reducer. Harry Davis specifies a speed of 30 RPM on the main shaft. My mill runs about twice that speed, but as mentioned, I have a five-HP motor. But my machine also pugs and de-airs just fine, and processes as much as 2000 lbs. per hour. You will have to decide on the ratio and the shaft speed depending on your needs and on the size of motor you use. If necessary, get your local math whiz to help you out with these ratios.

If you are unable to obtain a used shaft-mounted gear reducer, the next best thing is an integral gearmotor, which is a motor and gearbox combined. Again, they are very expensive new, but as with the shaft-mounted gearbox, you can often find them in scrap-yards, used equipment dealers, or electric motor repair shops. In 1979 I bought my Falk unit at a junkyard in perfect condition for $45, and at that time it retailed new for $1800.00. You can expect a similar situation with heavy gearmotors. But I have seen many of them for sale cheap in the above-mentioned locations. If you use this kind of gearmotor, make sure it is single-phase, unless you have access to three-phase power in your studio. And for this kind of unit you will need to construct a sliding gearmotor-mount with slotted bolt holes for adjustment. The drive from the output shaft of the gear-reducer to the main shaft must be a heavy chain-drive as is used on the Bluebird pugmills, with a small sprocket on the reducer output shaft, and a larger one on the main shaft, with a keyway in the main shaft to correspond to the keyway in the larger chain sprocket. Again, you will have to decide the ratio of the two sprockets based on the reduction ratio of the gearmotor. The slotted bolt-holes on the motor-mount will allow you to take the slack out of the chain, but remember that with a chain-drive you only remove the slack, as compared to the way you tension a belt-drive. Make sure that the two chain sprockets are perfectly aligned, or the chain will wear out very quickly.

If you find an integral gearmotor that produces exactly the main shaft speed you want, you can mount it with a direct drive to the main shaft of the pugmill, eliminating the chain drive. In this case, you would design the frame members that support the two main bearings and the main shaft so that they are closer together, but they should remain at least a foot apart to give good support for the main shaft. The gearmotor would be mounted on the outboard side of the left-hand bearing, mated onto the end of the shaft with a heavy duty power-transmission coupling (make sure you get one capable of handling a great deal of torque). This will require some additional shaft length, so be sure you have this figured out before you purchase your shafting. When you purchase the coupling, you will have to order the two members separately so that one part fits the output shaft of the gearmotor, and the other fits the main shaft of the pugmill. Once again, you will need to have a keyway cut in the main shaft to correspond to the keyway in the coupling.

If none of the above solutions work out, another alternative is to build your own gear-reducer. The one indicated on Harry Davis's plans is very vague. It involves several jackshafts to bring the speed down to the requisite 30 RPM. You can use a double-belt drive from a small pulley on the motor to a large pulley on the first jackshaft, but after that you must use chain drives to handle the torque. A good supplier of industrial power-transmission equipment can help you with the specifics to get the reduction ratio you need. If you go this route, this part of the mill must be enclosed in sheet-metal covers front, back, and top for safety and to prevent clay contamination on the exposed drive chains. Make the covers easy to remove, so that you can grease the chains and the bearings frequently. I would guess that unless you can scrounge some of the shafting and sprockets, the cumulative cost of this homemade gear-reducer will be considerable, and with all the labor involved you may decide to look harder for a shaft-mounted gearbox or an integral gearmotor.

The Main Bearings and Bearing-Mounts

Whichever gear-drive system you use, the main shaft must be mounted on two very heavy ball-bearing units. Harry Davis specifies a system with a pillow block bearing and a thrust bearing, which is extremely impractical, as I have indicated above. Instead, you can simply use two heavy-duty flange-mount bearings, which can easily handle an extreme amount of thrust load. Make sure they have grease fittings. The right-hand bearing (on the left-hand wall of the hopper), requires a special mount, to avoid clay contamination. Cut a square bearing mount plate out of 1/4" plate, slightly larger than the base of the flange-mount bearing. Cut a center hole for the main shaft, and drill the bolt-holes to mount the bearing flange. Cut two pieces of 1/4" by 1" flat bar as long as one edge of the bearing mount plate. Weld these two pieces of flat bar along opposite edges of the bearing mount plate at 90 degrees to the surface, so that they will space the bearing mount plate out one inch from the hopper surface. With the main shaft holes perfectly lined up, weld this assembly to the left wall of the hopper, with the spacer bars vertical, so that the 1" space behind the bearing mount plate is open at the top and bottom. Mount the bearing to this plate. The inevitable clay that works out around the main shaft will fall free in this space, instead of working into the bearing. Without this kind of mount, this bearing will fail very quickly. With this mount and proper lubrication, the bearings will last the life of the pugmill.

General Operation and Maintenance

As mentioned, this machine will self-feed if the clay is of an appropriate consistency, and if you throw fist-size balls of clay into the blades on the barrel-end of the hopper. Forgive me for stating the obvious, but no vacuum will register on the gauge until the barrel is full of clay, so when you first charge the machine, or after cleaning it, don't bother to turn on the vacuum pump until clay starts extruding from the end of the pugmill.

This machine is incredibly trouble-free. Grease the bearings often. If you are doing a lot of clay recycling, especially in a school situation, you will have to clean the screens frequently, at least once or twice per month. Do not neglect to make the raking tool described above, and rake the clay face within the barrel on the hopper side of the screen to remove any residue that sticks to the clay face inside the barrel instead of coming out with the screens. As long as you are using clay of an even consistency, if the machine seems to be pugging clay decidedly slower, the screens need to be cleaned. If you are pugging stiffer clay, you can of course expect the machine to pug slower.

If you accidentally put in too much very stiff clay it will jam the screens, and the machine will quit pugging completely. If this happens, turn off the main switch and the breaker panel switch, dig out as much clay as possible from the hopper opening, and fill the hopper with water and leave it overnight. The next day, with the main switch and the breaker still turned off, remove all the water with sponges, turn on the breaker switch, start the mill, and feed in soft plastic clay. Use the plunger to help force the clay through the screen until the machine starts working normally. You can easily process fairly stiff clay, but you must feed lumps of stiff clay and soft clay alternately. If you do not have any soft clay, you can feed a little stiff slurry with each handful of stiff clay, but you will have to use the plunger a lot in this case. If the clay is only slightly stiff, just dip each lump of clay in water before tossing it in the hopper.

Whenever the machine is not in use, cover the hopper and the extrusion end tightly with plastic. You can keep clay in the machine indefinitely if you seal the openings tightly. If you do not need to process clay for an extended period of time, turn the machine on once every few weeks, break off pieces of the extrusion, dip them in water, and feed them back into the hopper. This will help keep clay from stiffening up inside the mill. If you are going to be gone for a few months, pour some water into the hopper before you leave. If you are going to be gone for a longer period of time, clean out the mill and leave it empty.

This machine never needs cleaning except in rare circumstances. Even when changing clay bodies, unless the change is extremely radical I usually just run the new body through, expelling most of the old body. I either bag up that other body and save it, or feed it into the new one a little at a time. Obviously it will make a big difference sometimes, as when you are changing from a gritty stoneware body to a grit-free one or from a white stoneware to a red or brown one. I still do not clean out the machine, because the amount of grit or color ending up in the new body is minimal. I bag and save the first eight or ten feet of extrusion as the former clay body, and I set aside the next ten feet and feed it in a bit at a time as I process the new claybody. This works well even when changing from a stoneware to a terracotta. If I am changing from a brown stoneware to a white stoneware, I would save the intermediate claybody that is pugged during the changeover, hand-wedge, and use it for some one-of-a-kind pieces.

For some years immediately after building this machine I used it daily in Railroad Stoneware, my production studio in Blue Lake, California. It has received less extreme use since then, but has never failed me. As mentioned above, aside from greasing bearings and cleaning the vacuum breather-valve chamber, the only maintenance has been replacement of the shredder screens. In my production studio I purchased commercially-made moist Rod's Bod and Danish White with sand from Westwood (now absorbed into Laguna) in 10,000# quantities, so the clay had often been sitting for months or even years when I used it, and pugging remobilized the clay and made it as plastic as is possible, and I never, ever had to hand wedge my clay. That may partially explain why I have never experienced any of the wrist or hand problems so many potters encounter.

It is impossible to overstress the importance of sticking very close to all the critical measurements and tolerances. I improvised in some areas, as explained above, but never in regards to the critical measurements or tolerances specified by Harry Davis, such as the spacing, tilt, and travel of the blades and helixes, and the clearances from the outer ends of blades and helixes and the inside surface of the barrel. When I completed my mill, the only problems with operation resulted from the inadequate initial vacuum pump. When I adapted and installed the milking-machine centrifugal vacuum pump, the machine worked perfectly, and it has ever since aside from the infrequent replacement of the screens. I hate to pat myself on the back, but I have never used any commercially-made pugmill that worked better than the one I built. Since I do mostly handbuilding these days and not nearly as much of that as I would like due to teaching and administrative responsibilities, the mill doesn't get much use. I will retire in a few years and when I move the mill away from my university studio and into the private studio I set up at that time, it will likely get the kind of use it deserves.

If you build this machine, let me know how it goes, and please tell me of any changes you decide to make. Frequently refer to the picture of my pugmill on the website, and feel free to contact me with any questions. **GOOD LUCK**!