Chapter 6

MAKING THE FIRST INTERMEDIATE MODEL

The original plan for the Rice Husk Energy Project workshop was to have a modest range of tools and equipment for fitting and assembly and to rely on the main Kumudini Welfare Trust workshop to carry out most of the machining operations. We reasoned that this work would be done in the periods that the main workshop was not preoccupied repairing a broken-down jute press or overhauling a tugboat. Not long after the project started we could see that this arrangement would not be practical and decided to fully equip the RHEP workshop. A large Indian lathe and later a medium-sized Chinese all-geared lathe were procured. Kumudini shifted a large radial-arm drill from their dock and a universal milling machine from the central workshop to our project. Both of these British-made machine tools turned out to be invaluable for our work, and it was very convenient to have them close at hand.

In re-designing the engine we capitalized on the availability of skilled patternmakers (Fig. 6.1) and several different foundries. Most of the iron casting was done in a small foundry, (Fig. 6.2) where melts


Figure 6.1

🡐 Pattern makers working on the pattern for the unsuccessful first design for the engine body


Figure 6.2

🡑 In a small foundry, molten cast iron is poured into a series of moulds. The crucible has been heated in a small gas-fired furnace.

Figure 6.3

↑ *The project review team in May 1983: from left to right, Mary Fontaine (TAF), Craig Kinzelman (Sunpower), Bob Barnes (USAID), Eldon Beagle (TAF), Bruce Chagnot (Sunpower), Mrs. Joya Pati (KWT), Mr. Callahan (USAID), Sherry Plunkett (USAID).*

Figure 6.4

← *The cast iron crankcase for our first intermediate model*

Figure 6.5

→ *After turning its flange on a lathe, the crankcase was mounted on the milling machine, where it remained unmoved for most of the remaining machining operations. Here the near side is being faced.*

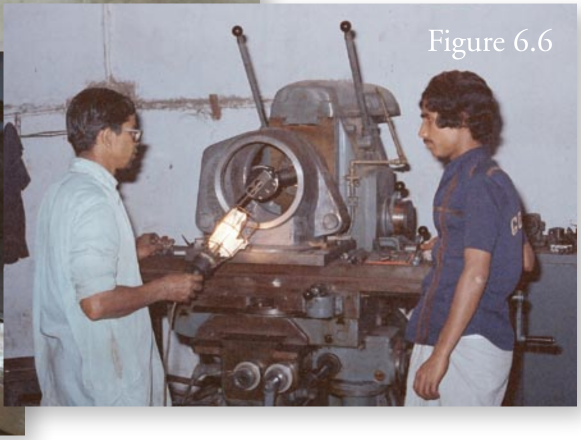


Figure 6.6

↓ *Fly-cutting the face of the far side of the crankcase with the boring head mounted on a long arbor*

were done in a crucible heated by natural gas with an electric blower supplying the combustion air. Several melts were done each day, so if a pattern was given in the morning we could usually pick up the casting in the afternoon. Sometimes the casting was not long out of the mould when we picked it up, and was still too hot to handle. The problem was easily solved with a loop of heavy twine that formed a carrying handle. The charge for iron castings was about one dollar a kilogram. Large iron castings like the crankcase and body were done in a large foundry with a cupola furnace that was fired once every week or two. Non-ferrous castings were done in another small foundry that specialized in aluminum and gun metal (bronze) casting.

From Phase 2 onwards there were half-yearly reviews held in Bangladesh, usually in May and November. In Fig. 6.3 the May 1983 review team was meeting in Mrs. Pati's office at Kumudini Welfare Trust with representatives from the Asia Foundation, Sunpower, and USAID.

Crankcase

The design of the crankcase incorporated two large symmetrical side ports that accommodated the bearing case on one side and an inspection port on the opposite side (Fig. 6.4). Machining the flange that bolted to the body proved to be a problem as there was no easy way to hold the casting in a lathe. This was solved by casting and machining two angle plates that enabled us to mount the crankcase on the faceplate of the large lathe. The remaining operations were carried out on the milling machine, which was still in the KWT workshop at this point. Figure 6.5 shows the near side of the casting being fly cut. Using a long arbor, the far side of the crankcase was similarly faced and then bored to size (Fig. 6.6). Without moving the casting, the holes for the swing link and bell crank pivots were drilled, reamed, and then faced with a fly cutter (Fig. 6.7). By completing this machining sequence in one setting on the milling machine we could be sure that the pivots and crankshaft would be accurately aligned and perpendicular to the axis of the cylinder.

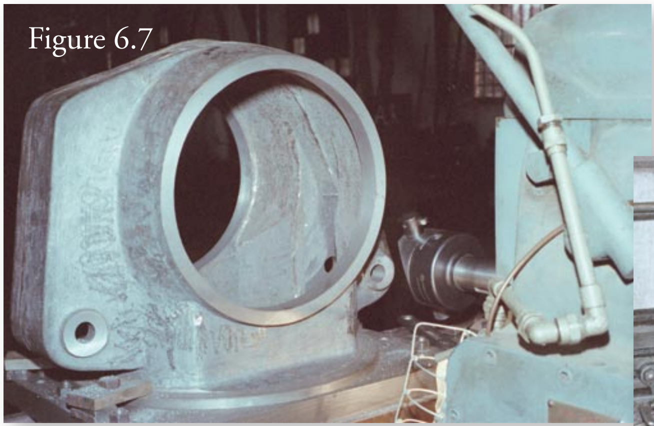
Bearing case

Having the bearing case and crankcase as separate castings simplified the design and machining operations. But, as with other castings, this added to the weight of the engine. Figure 6.8 shows the bearing case casting, core box, and pattern. The crankshaft of the IM-1 engine was mounted in the bearing case with standard deep-groove ball-bearing races. The pressure seal was a custom-made leather cup seal packed with grease.

Body

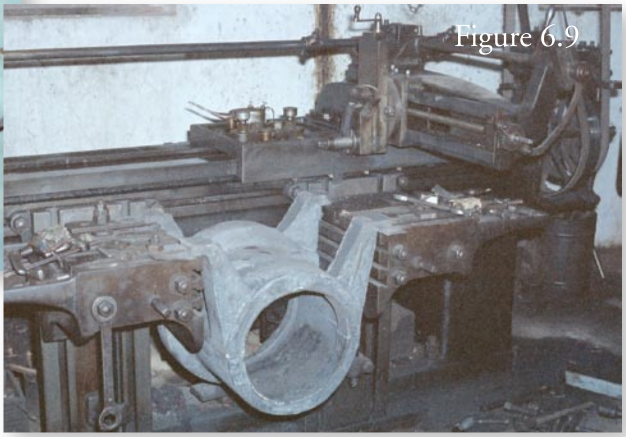
In some of my early designs for castings I made the mistake of trying to integrate several features in one casting. This was easy to do on the drawing board, problematic for the patternmaker, difficult to cast, and sometimes impossible to machine. So it was with my first body design that I happily incorporated cast feet. This involved complicated pattern-making and resulted in a huge casting. Figure 6.9 shows the feet of this casting being faced on an old but wonderful metal-planing machine driven through a flat belt from an overhead line shaft in the Kumudini workshop. In the end there was no way to mount the casting

Figure 6.7



← *After the crankcase was bored to size, the seats for the bell crank and swing link pivots were drilled and reamed. Here the pivot seats are being faced.*

Figure 6.9



↑ *The abortive first design for the engine body mounted on the planning machine to have the feet faced*

Figure 6.8

← *The pattern (right), core box (top), and casting (left) for the bearing case* on our milling machine, and the design was scrapped. The second version of the body omitted the feet and could easily be machined. In the first intermediate model the body was anchored to the foundation with the hot end bolted to one end and the crankcase to the other end (Fig. 6.10).

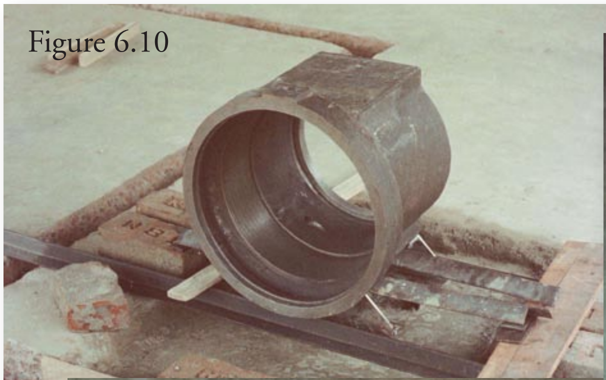
Finned aluminum cooler

One of the most problematic components of the engine was its cooler. In the prototype the aluminum cooler also formed the structural connection between the hot end and the crankcase, so the casting was large. In our engines a cast-iron body physically connected the hot end and crankcase and also formed the outer jacket of the cooler. This greatly reduced the size of the aluminum cooler casting. After machining the cooler on a lathe, we took it to an industrial assistance organization equipped with a large vertical slotting machine to have the internal slots cut (Fig. 6.11). The leading edges of the internal fins were filed to provide streamlining, (Fig. 6.12) and finally the external grooves for cooling water were milled (Fig. 6.13).

As an alternative for the aluminum cooler I designed one that would make use of copper tubes. The body of this first model, the copper tube cooler, was a large iron casting that also served as the body and the cylinder of the engine. It was drilled to receive a large number of copper

↓ *The foundation for the second version of the engine body nearing completion*

Figure 6.10



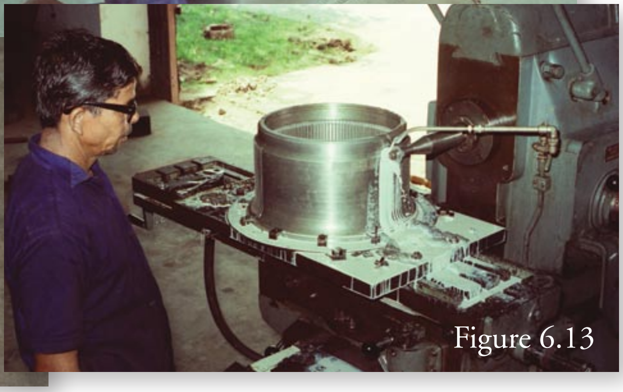
↓ *Filing the leading edges of the internal fins to reduce air flow friction. At this time we didn't realize that the spots on the casting by Fazul's knee represented a porous spot and would pose a serious problem for us.*

Figure 6.12

Figure 6.11

↑ *After we machined the aluminum cooler sleeve on one of our lathes, it was taken to a specialty shop, where the internal fins were cut on a vertical slotting machine.*

Figure 6.13



↑ *Radha milling the external cooling-water grooves on the aluminum cooler*


Figure 6.14

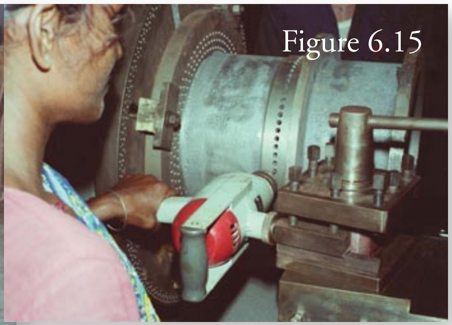


Figure 6.15

← Drilling holes for the copper tubes in the cast iron cooler body

← Fitting the aluminum cooler and cast iron cylinder in the engine body. The castings for the first copper tube cooler are in front of the packing crate.

tubes through which air would move from the hot end to the cold end of the engine. Cooling water would be confined by a cast-iron jacket. The castings for the cooler body and the water jacket can be seen in front of the empty packing crate in Figure 6.14. In this picture Fazul has fitted the aluminum cooler and cylinder in the body of the engine. A second crankcase, in front of the work table, is about to be mounted on a lathe faceplate with two cast-iron angle plates. In Figure 6.15 Momotaz is drilling holes for the copper tubes in the cast-iron cooler body. The problem we ran into was that because of the mass of the cooler casting, we couldn't achieve the necessary temperatures for brazing the copper tubes to the body, and this design was abandoned.

Cylinder liner

The thin steel cylinder of the prototype had become oval to the point that there was significant leakage past the piston ring. We made our cylinder from cast iron as a sliding fit in the cooler with a wall thickness of 5 mm. The Xylan that was never used as an antifriction coating for the piston and displacer was put to good use as an anti-corrosive coating for the outside of the cylinder (Fig. 6.16).

Crankshaft assembly

The crankshaft was built up from a mild steel shaft with a cast-iron counterweight/web. In Figure 6.17 a key-way is being milled for the crankshaft to flywheel key. Figure 6.18 shows two crankshafts with different sizes of

↓ The cast iron cylinder with milled ports

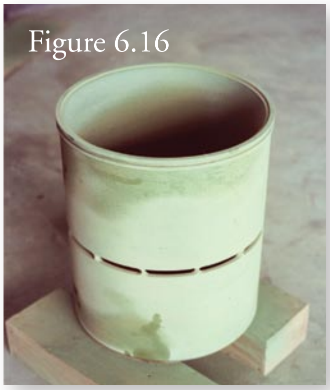


Figure 6.16

↓ Milling the keyway in the crankshaft for the flywheel


Figure 6.17


Figure 6.18

↑ Our first crankshaft (right) and a later model with more counterweight. The crank throw is about to be fitted in the new crankshaft assembly (left).

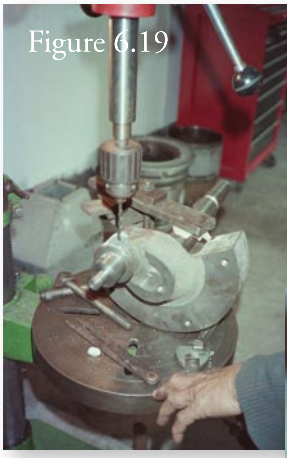


Figure 6.19

🡑 *The crank throw is fixed in place by drilling and fitting a spring pin.*

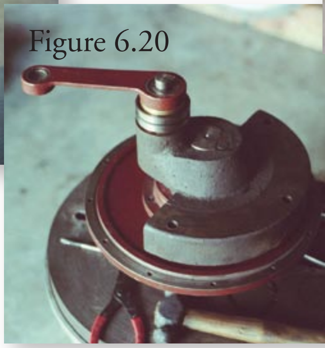


Figure 6.20

🡓 *The finished crankshaft assembly fitted in the bearing case. The inner sleeve of the main con rod bearing and the displacer con rod have been fitted.*


Figure 6.21

🡐 *The main con rod casting (left) with its pattern and core box.*

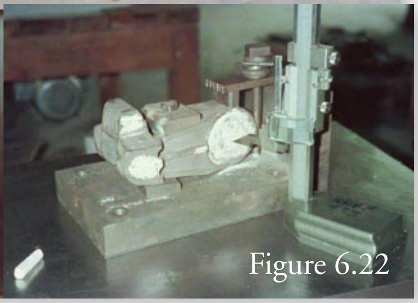


Figure 6.22

🡐 *The main con rod mounted on a purpose-made angle plate being marked out for machining*

counterweights. The throw of one has yet to be installed. This is done by drilling and fixing with a spring pin (Fig. 6.19). In Figure 6.20 the crankshaft has been assembled with the bearing case, and the cast-iron bell crank connecting rod is in place.

Piston linkage

In the prototype the main connecting rod was made from a steel casting. As this option was not available in Bangladesh the design was made heavier with an integral web and cast in iron. Figure 6.21 shows the finished casting, pattern, and core box for the main connecting rod. The main connecting rod casting was mounted on an angle plate and the positions for pins and bearings marked out (Fig. 6.22, 6.23). The con rod remained on the jig for the boring operations. The completed main connecting rod with bearing and pins installed is shown in Figure 6.24.

Our first piston links were cast in aluminum

🡓 *After it has been marked out, the main con rod casting, still on the angle plate, is mounted on the milling machine for boring and facing.*

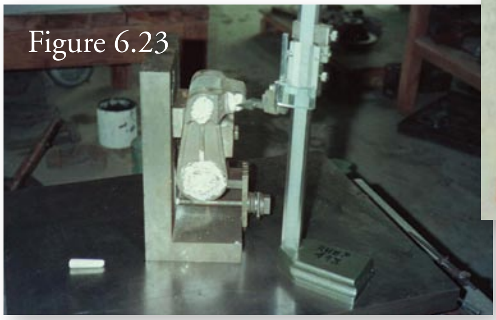


Figure 6.23


Figure 6.24

🡑 *The finished main con rod*

🡓 *The pattern and aluminum casting used to make the piston links*


Figure 6.25

(Fig. 6.25). After facing on the lathe they were bored to be fitted with oil-impregnated sintered bronze bushes (Fig. 6.26).

Piston

The initial piston design made use of a single aluminum casting similar to that of the prototype but with a longer skirt and two piston rings. Having two rings eliminated a problem with the piston tilting in the cylinder. The crown was cast with extra material for the lathe chuck to grip; in Figure 6.27 this sacrificial material is being turned to provide a grip for the lathe chuck. Figure 6.28 shows the piston itself being turned. Drilling and reaming the piston to receive the piston pins was possible, but it was difficult to maintain accurate alignment. A later two-part design for the piston simplified this operation.

Displacer linkage

The displacer is driven through a bell crank so that its movement is out of phase with the movement of the piston. In the IM-1 and the IM-2 engines, as with the prototype, the displacer top dead center occurs about 69 degrees before piston top dead center. One arm of the bell crank is connected to the main crankshaft throw by the displacer con rod. The other arm of the bell crank drives the displacer by means of a flexible displacer rod (Fig. 8.20), which is fitted inside the displacer tube. Using a flexible link eliminated the need for the separate link used in the prototype to connect the bell crank to the displacer rod.

By this time it was clear that an aluminum bell crank would not be strong enough. The prototype bell crank machined from tough alloy stock had


Figure 6.26

↑ *Boring the piston link for bronze bushings*

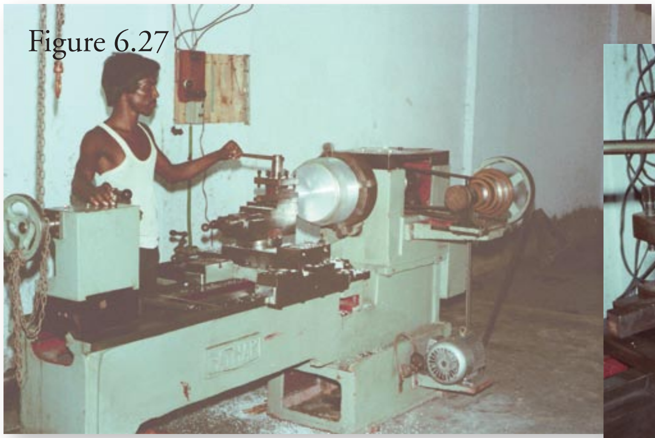


Figure 6.27

↑ *Turning the crown of the Model-A piston casting*

↓ *Turning the skirt of the one-piece piston*

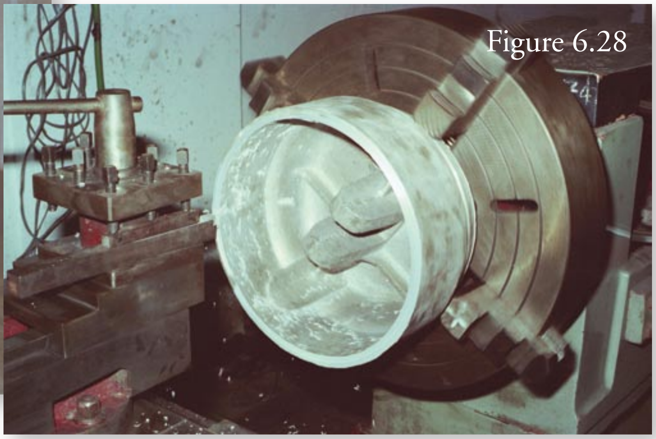


Figure 6.28

cracked, and by comparison locally cast aluminum material would have considerably less strength. As an alternative, a bell crank was designed that was built up from mild steel plate by welding and riveting (Fig. 6.29). In Figure 6.30 the seats for the bearing pins are being bored on the lathe. In this design the arms of the bell crank were offset, a feature that eventually proved to be a problem.

In the prototype the displacer rod was not supported at its end, and this had led to some misalignment and drag. To avoid this problem in our engine I designed a spider that was fitted at the base of the cylinder. The spider was fitted with a PTFE bush through which the displacer tube slid back and forth, thus maintaining accurate alignment. The prototype's displacer rod was connected to the bell crank with a short link. This was replaced by a tube with a long flexible link inside that could be connected directly to the arm of the bell crank.

Displacer

The displacer can of the Sunpower prototype was made by forming 0.7 mm stainless-steel sheet into a cylinder and TIG-welding the seam. The dome was made by clamping a stainless-steel blank to a heavy steel plate with a steel ring sealed with O-rings. Hydraulic fluid pumped into the space between the base plate and blank caused it to bulge. This bulged dome was trimmed and TIG-welded to a stainless steel ring, which in turn was welded to the displacer can. Radiation baffles were formed from stainless steel sheet that was cut and spot welded to form a shallow cone. Tabs along the edge of these cones allowed several of them to be spot welded inside the displacer can along its length. These effectively blocked radiation but did not provide much support for the walls of the displacer. The finished displacer can was attached to the aluminum displacer body with small machine screws and sealed with epoxy.

Explosive forming (part 1)

Having read a bit about explosive forming, I decided to give this approach a try. For one thing, it promised to be a lot more exciting than hydraulically bulging a dome, rather like reliving childhood adventures. Early work on explosive forming had made use of shotgun shells with the shot removed, so my first stop


Figure 6.29

↑ *The bell crank being assembled*

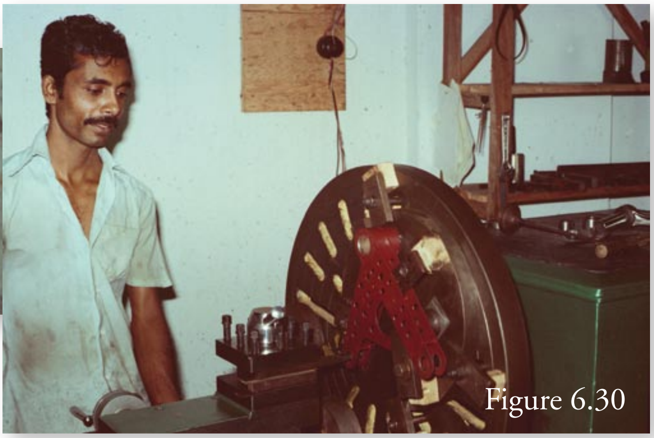


Figure 6.30

→ *Boring the seats for the bell crank bearing pins* was at a gun shop in Dhaka. It soon became apparent that there was no way that I could get shotgun shells as I was not a licensed gun owner. As this was being explained to me my eyes fell on a big glass jar on the counter filled with about 4 liters of gunpowder and pellets. The shopkeeper explained to me that after repairing the firing mechanism of a shotgun they would put a shell, emptied of powder and shot, in the gun and fire it to see if the cap went off properly.

"Can I get some of this surplus powder?" I asked.

"Please come back tomorrow."

The next day when I returned, I got a firm negative. I suppose my explanation of what I wanted the powder for was so farfetched as to arouse all sorts of suspicions.

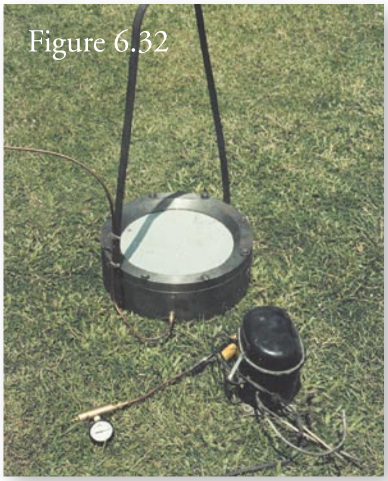
My next stop was at a small shop selling fireworks in Narayanganj, not far from our workshop. Here I hit pay dirt, for Tk5, Tk10 and Tk15 each (US$0.18-$0.50) I could get firecrackers that were more like little bombs. They were made by winding jute string around a paper packet of powder with a small bamboo tube leading the fuse out. Popular sizes ranged from that of a hard ball up to soft-ball size. Even the smallest would blow an empty gallon paint can to shreds. Since explosive forming is done with the die immersed in water, I removed the bamboo fuses and replaced them with lamp-cord wire leading to a short length of a single strand of copper wire (from the lamp cord) as a fuse. The firecracker was then repeatedly dipped in wax to render it quite waterproof.

A big advantage of explosive forming is that only a female die is required, so there is no need for accurate machining of male and female dies to match each other. Another advantage is that cast iron is quite satisfactory as a material for the dies. After machining the outer dimensions of the die, the trick was to cut the inside curve. A hole of one inch or more was drilled at the center of the die to nearly the final depth. The first cylindrical portion of the die was machined, and then I used a Lotus 1-2-3 spreadsheet that did a simple geometric calculation for the two curves (radius of the shoulder and radius of the dome) which gave how many divisions less on the cross feed to cut for each division on the longitudinal feed. A somewhat tedious process, but one that yielded good results. And with a bit of emery paper the fine ridges resulting from this technique were soon removed, leaving a reasonably smooth surface. To complete the die I turned an O-ring groove, and it was drilled and tapped for a vacuum fitting. Figure 6.31 shows the completed die before the clamping ring and blank have been fitted. The O-ring seal and the vacuum fitting allow the air to be removed

Figure 6.31

↑ *The die used in explosive forming of the displacer dome. The stainless steel blank will be clamped to the die with an O-ring seal to make it airtight.*

Figure 6.32

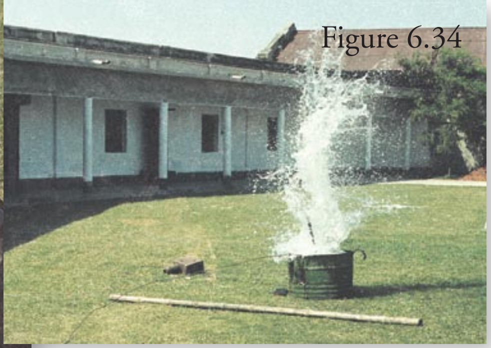


↑ *A refrigerator compressor is used to evacuate the space inside the die.*

Figure 6.33

← *In the first test, the die was immersed in a half drum of water.*

Figure 6.34



↑ *The charge is detonated*

before the metal is formed. A mild-steel flat bar handle facilitates moving and positioning the heavy die. In Figure 6.32 the clamping ring and blank have been fixed in position and the vacuum pump (a small refrigerator compressor and vacuum gauge) connected to the die by a long copper tube.

In the first trials the die was placed in one of the parboiling drums (half an oil drum) filled with water (Fig. 6.33). The explosive had been suspended at about the center of the radius of the dome. After running the refrigerator compressor till the gauge showed a half-decent vacuum the two leads from the wire fuse in the explosive were touched (at a safe distance) to the terminals of a 12-volt car battery. The explosion was most satisfying (Fig. 6.34), but the blank was not fully formed (Fig. 6.35). It was a good start though.

To provide more water pressure, a full oil drum was half buried in the ground, and we stepped up one size in the firecracker range. In Figure 6.36 the die, blank, and attached explosive are ready to be placed in the tank. The explosion (Fig. 6.37) was bigger and the resulting dome (Fig. 6.38)

↓ *This stainless steel blank was not fully formed.*

Figure 6.35

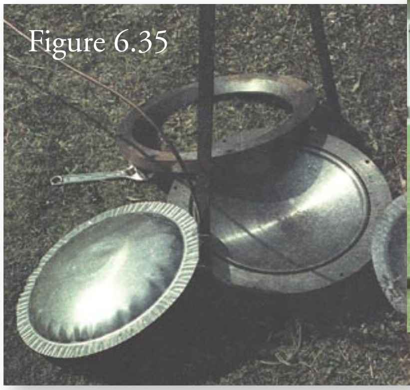
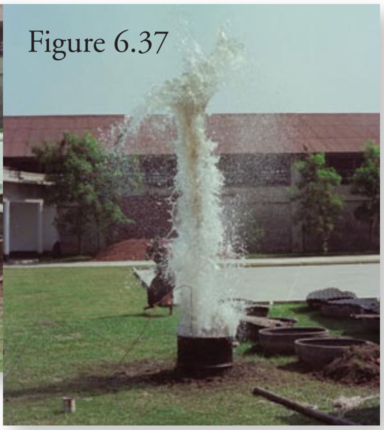


Figure 6.36

↑ *Ready for another test using a full drum of water, which is half buried in the ground. The explosive is positioned above the blank.*

Figure 6.37



↑ *A bigger explosion*

Figure 6.38

← *A fully formed dome. With more experience we eliminated most of the creases and irregularities seen here.*

Figure 6.39

↑ *After parting on the lathe, this dome is ready to use as a baffle in the displacer.*

almost fully formed with vertical edges suited for the spot welding to come. With deeper tanks we were later able to fully form the displacer domes and baffles without creases. In Figure 6.39 the displacer dome has been parted from the formed piece and is ready to assemble with the rest of the displacer can.

Spot welding the displacer

In the prototype we had made extensive use of Tungsten Inert Gas (TIG) welding, which is well suited for stainless-steel, particularly thin sheet. At this time in Bangladesh it was not possible to get the argon gas needed for TIG welding. For the thicker (3 mm) stainless steel in the heater we were able to use conventional arc welding with flux-covered stainless steel electrodes. The displacer, however, was made from 0.7 mm stainless steel sheet, and this was too thin to be arc welded. After some experimenting (Figure 6.40) we decided to use closely spaced spot welds to assemble the displacer. The first attempts at spot welding the seam of the displacer produced a warped cylinder that was not improved when we tried to slide in the baffles. To solve this problem a fairly elaborate jig was developed. The jig consisted of a cast-iron sleeve with a longitudinal thickening inside. After machining the outer dimensions on a lathe the sleeve was mounted on the antique metal plane (Fig. 6.41) and grooved to accept the lower electrode of the spot welder. The completed jig

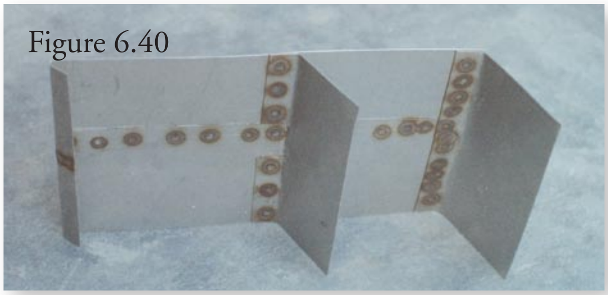


Figure 6.40

↑ *This test sample demonstrated the proposed method of using spot welding to make the displacer.*

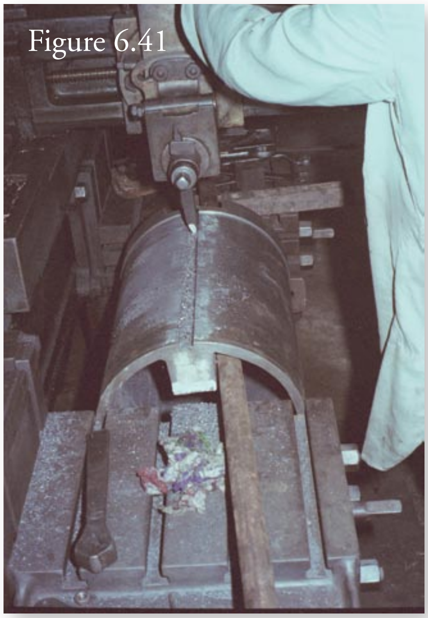
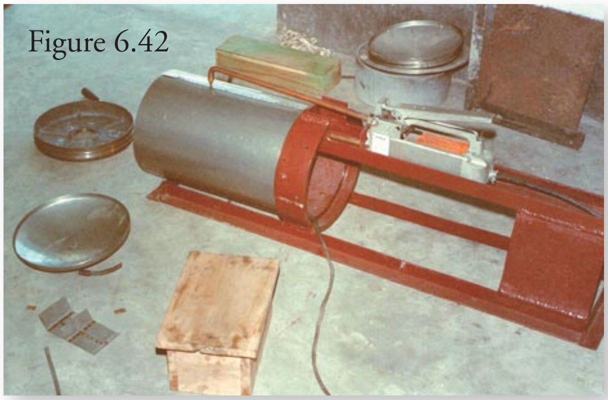


Figure 6.41

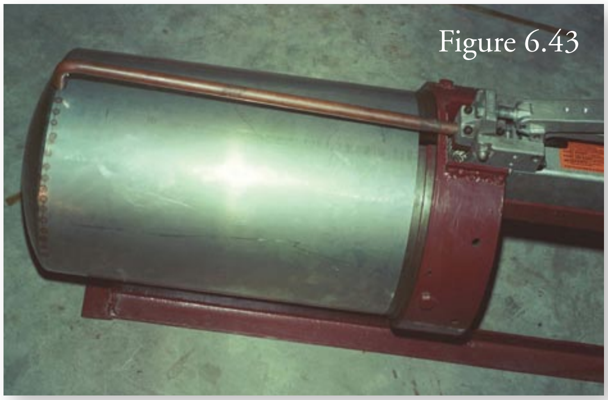
← *Part of the welding jig for making displacers. A groove is being cut in the casting where the lower electrode of the spot welder will be positioned.*

Figure 6.42



🡑 *The seam of the displacer can being spot-welded*

Figure 6.43



🡑 *The dome of the displacer being spot-welded in place*

consisted of the cast-iron sleeve mounted in a mild steel frame that also supported and guided the spot welder, allowing the electrodes to be positioned anywhere along the seam.

There were several advantages from using this jig. The sheet for the displacer can was first rolled and then tied onto the jig, which ensured that it remained accurately cylindrical. The seam was welded by randomly positioning weld spots, leaving plenty of time for the can to cool and slowly filling the entire seam with weld spots (Fig. 6.42). A packing strip between the can and the jig provided clearance so that, when it was removed, the can was a close but sliding fit on the jig and could easily be removed.

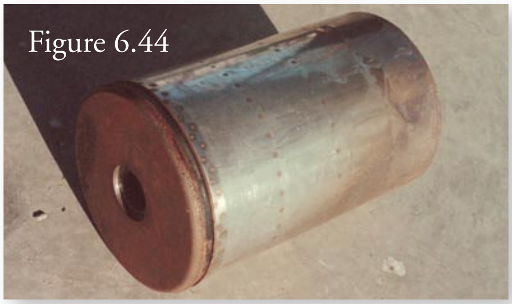
The jig also allowed the dome of the displacer to be accurately positioned and then spot welded in place (Fig. 6.43). Finally the baffles were positioned one at a time and fixed in place with a quite a few weld spots to provide good support for the displacer can. Figure 6.44 shows our first displacer can, which was attached to the cast-iron base with spot welds. Later we used small machine screws sealed with epoxy.

Hot end

The first intermediate model was operated with the hot end from the prototype. During this period we explored a number of avenues in respect to making both the hot end and the material for the regenerator.

Searching for big presses, I discovered the Dhaka Drum Factory next to the old airport not far from the center of Dhaka. In contrast with the rest of Dhaka, which was becoming increasingly congested, the Drum Factory was surrounded by 10 acres of grass and trees. The factory was equipped with large American-made presses, power shears, and equipment to seam-weld the drums. It turned out that the facility had been set up during World War II, when Dhaka was a staging point for flights over the hump into Burma. I was impressed that all the equipment was still working smoothly. Although I never made use of their presses I regularly had them shear the 3-mm stainless sheet that we worked with.

Figure 6.44



🡐 *The finished displacer*