Prototyping and Low Volume Production-Part 1

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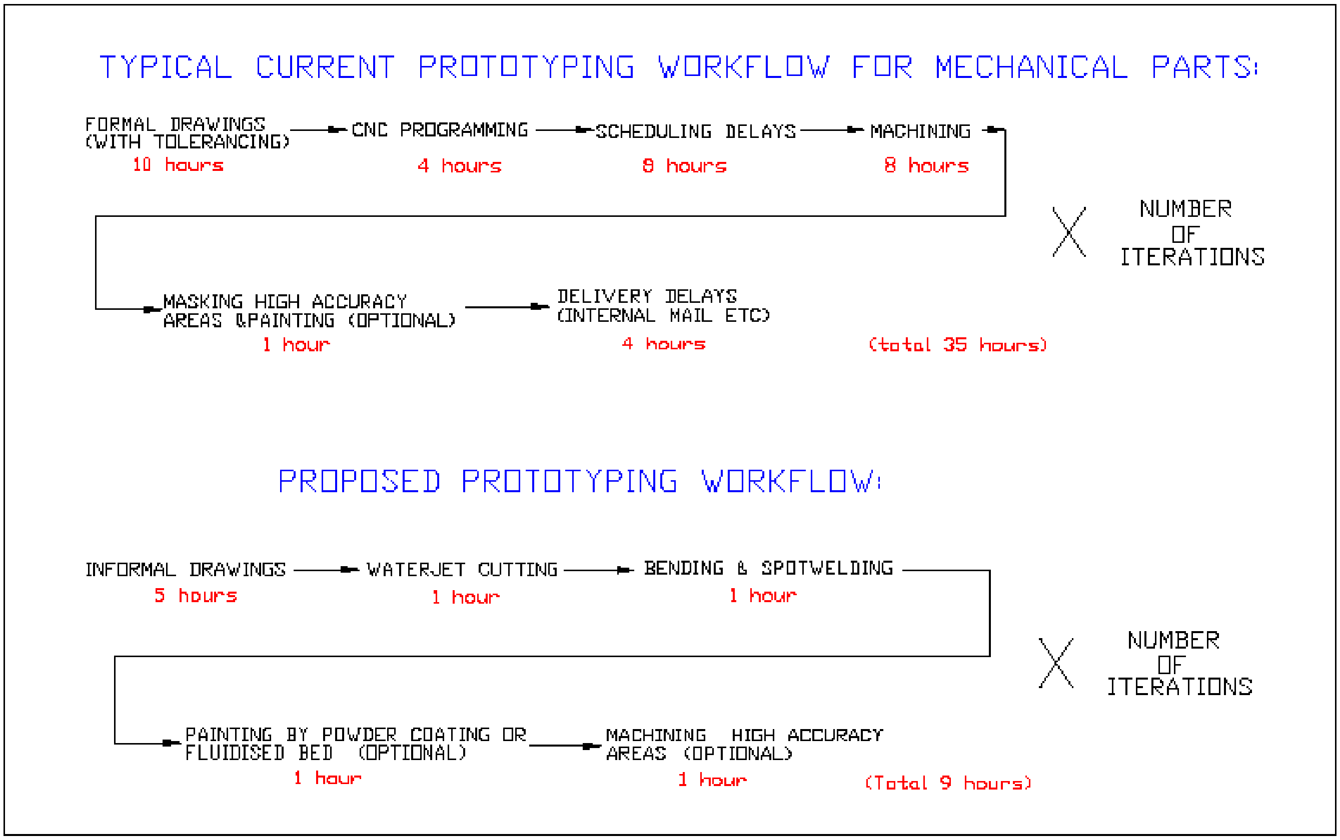
Introduction

1. As traditional manufacturing moves to Asia, the jobs thriving in the west will be mainly based on more R&D and prototyping (example: hi-tech, medical, energy, new concepts).
2. When an engineer or researcher can build his/her own prototypes quickly, the pace of R&D is greatly accelerated, mainly because no formal documentation is needed. In many cases the designs can be changed on the fly to accommodate materials on hand or fabrication errors. This is not possible if designs are sent to the shop for fabrication.
2. The traditional way of building prototypes (typically everything is milled out of aluminum on a CNC mill) has three disadvantages:
- Too slow (requires careful CNC programming).
-Expensive. Aluminum is relatively expensive, steel machines too slow.
-A student/engineer with no machining background can not be taught to become a machinist in a short time.
3. The turnaround time for even simple prototypes today is many days, even in well run places. Any changes require a new iteration and delays.
4. The great majority of prototypes can be built in a few hours by the designers, without formal drawings or CNC programming, by making them of formed sheet metal instead of machining from solid blocks.
5. The key "enabling technology" for this approach is waterjet cutting. A waterjet cutter can cut practically any material up at least 50mm thickness. The waterjet cutter is self programming, and is as easy to operate as an x-y plotter. No machining experience required. Training time is typically 1 day. It is also inherently safe for machine and user.
6. The other equipment needed is a brake (with automatic back-gage), spot welder, sand blaster and powder coating unit. These are all simple, low cost machines. A stock of weldable hardware (nuts, studs, hinges, latches etc) is also required.
7. Prototyped this way produces designs which are a lot closer to finished products, since most products are made by forming sheet metal.
8. The more innovative the project is, the more likely it is that many rounds of prototyping will be needed. Cutting each cycle from days to hours has a major impact.

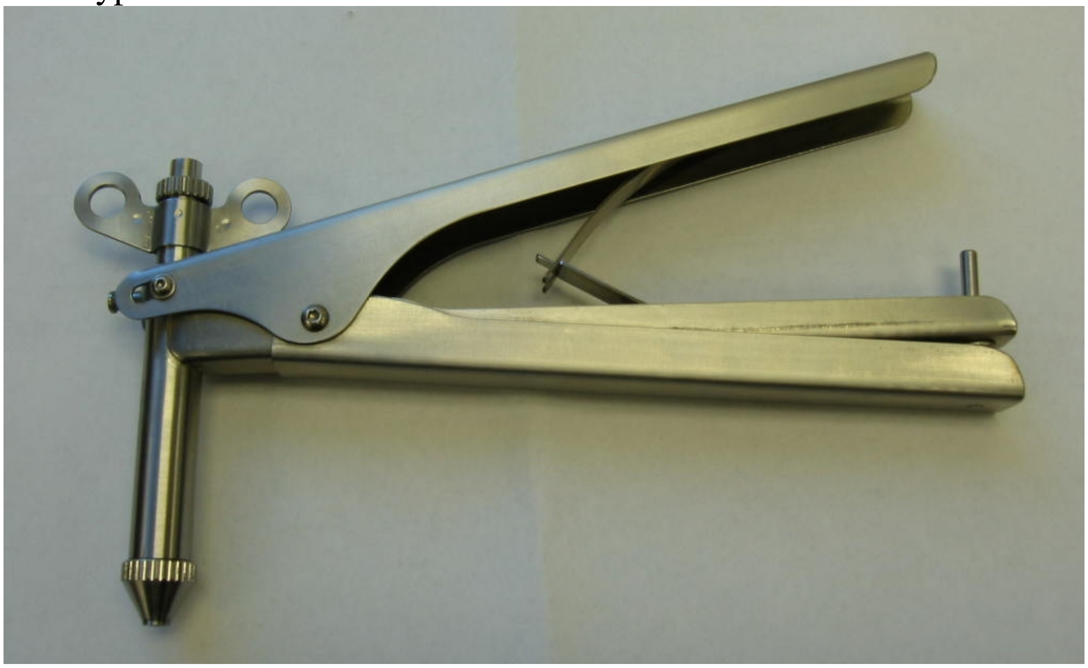
The workflow of traditional prototyping and the proposed method are shown on the next page. Please note that the "scheduling delay" is inevitable unless machine shop has a capacity many times the actual workload, which is not economical. In the most efficiently run organizations the scheduling delay is approximately equal the actual time the job requires,
The times shown in the workflow examples are for a given part or assembly and obviously will change with the part; however the ratio between the two methods will stay about the same. Some specific examples of projects with fabrication times are shown.



Another factor to keep in mind is that for simple parts the programming can be done in minutes right on the waterjet cutter, and the overall time from idea to part can be as fast as 10 minutes, for example a simple box or bracket. With traditional methods the time does not drop as dramatically as the CNC programming is rarely done on the machine and requites more care to avoid damaging the machine.

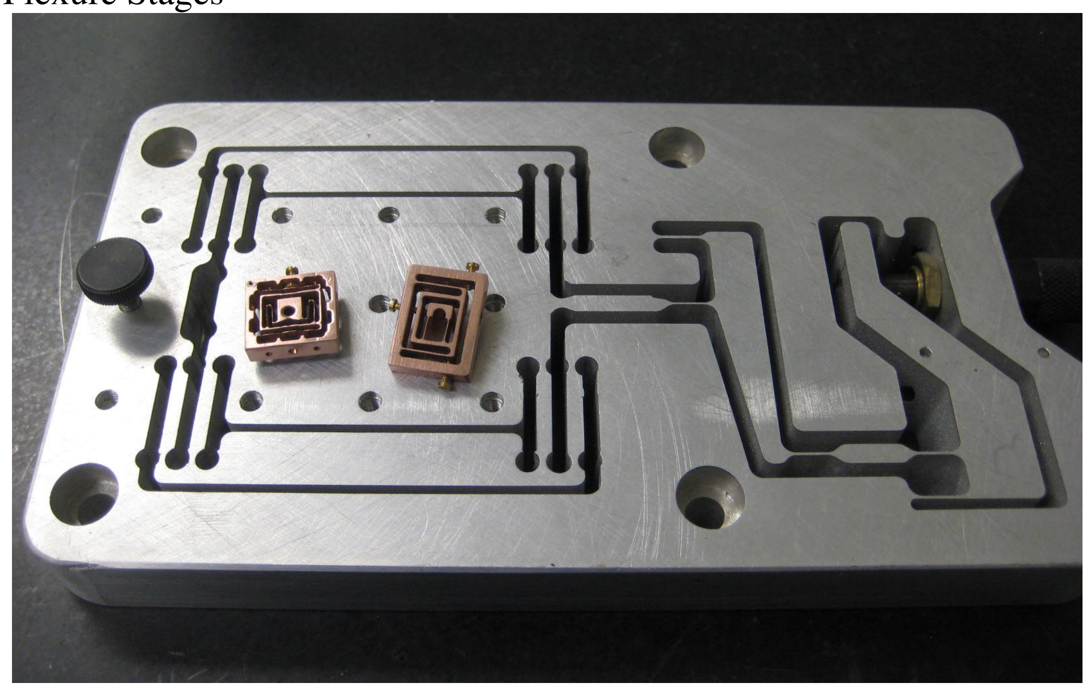
Examples:

Prototype medical tool



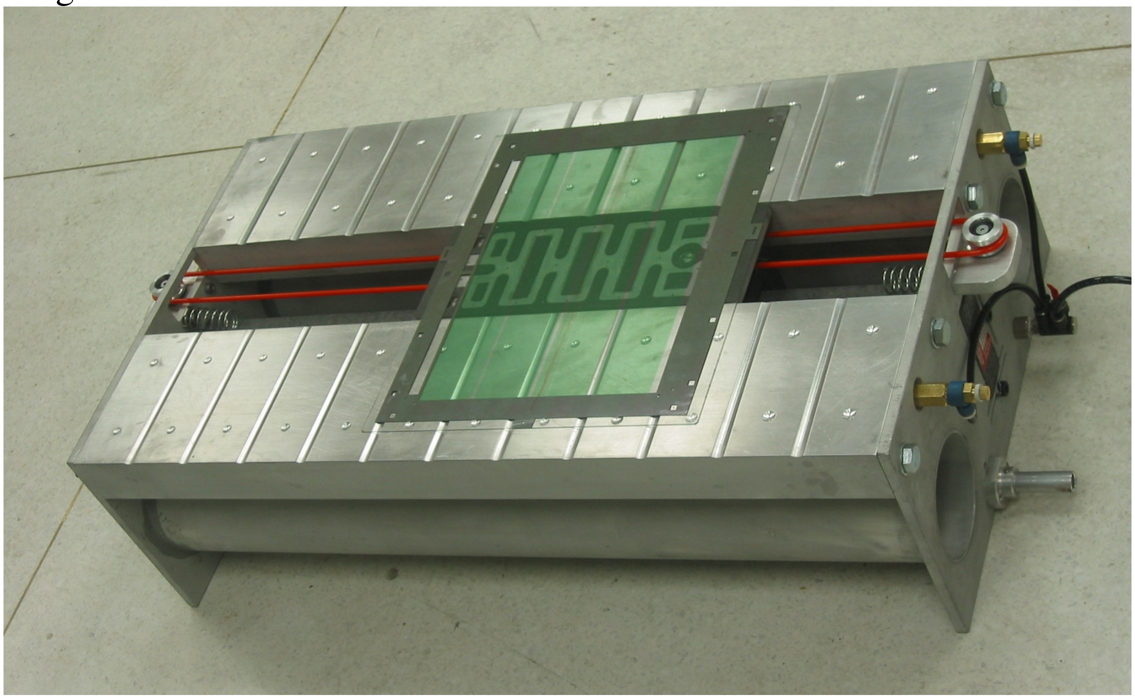
All parts except for the turned parts were done by WJ cutting, bending and spot welding. Total fabrication time (not including design) is about 8 hours.

Flexure Stages



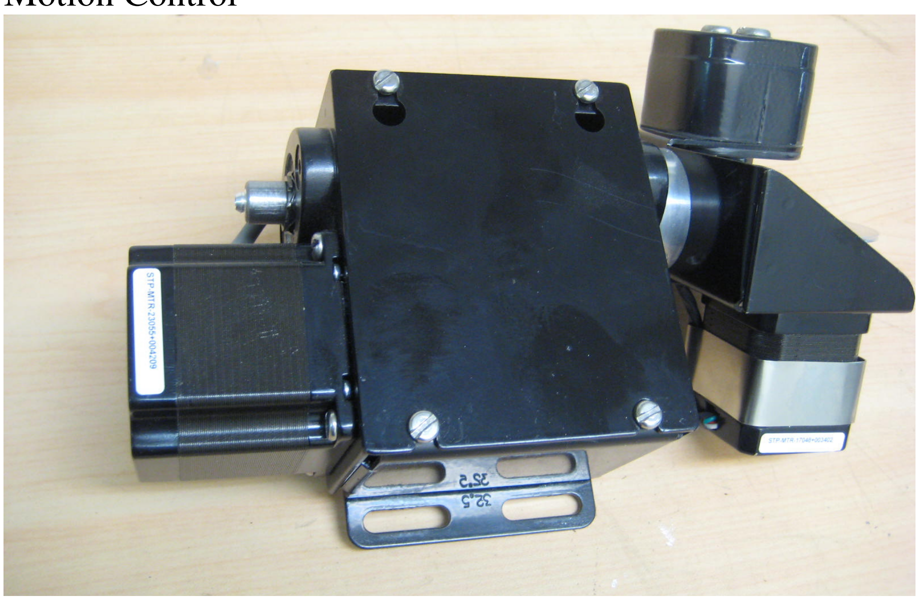
The two small x-y stages are flexure-based positioners for optical fibers (made of BeCu); the large stage is a linear stage with nm adjustability over 1mm range. Total fabrication time (not including design) for all three stages is about 1 hour.

Larger Structures



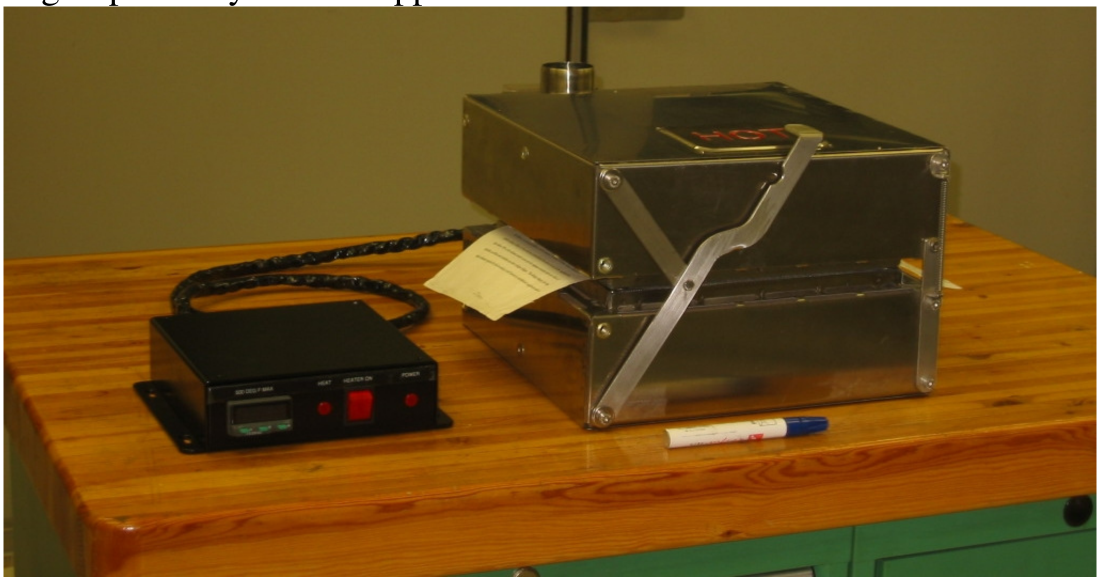
Proof-of-concept pressure/vacuum air bearing scanning table for a machine to manufacture LCD displays. Parts cut by WJ and assembled by adhesive bonding using a granite surface plate for alignment. Total fabrication time (including many parts not visible in photo) is about 12 hours.

Motion Control



Assembly of stepper motors and gearbox based on timing belts. Shaft holes finish bored after painting.

High Speed Dryer for 600ppm IJ Printer

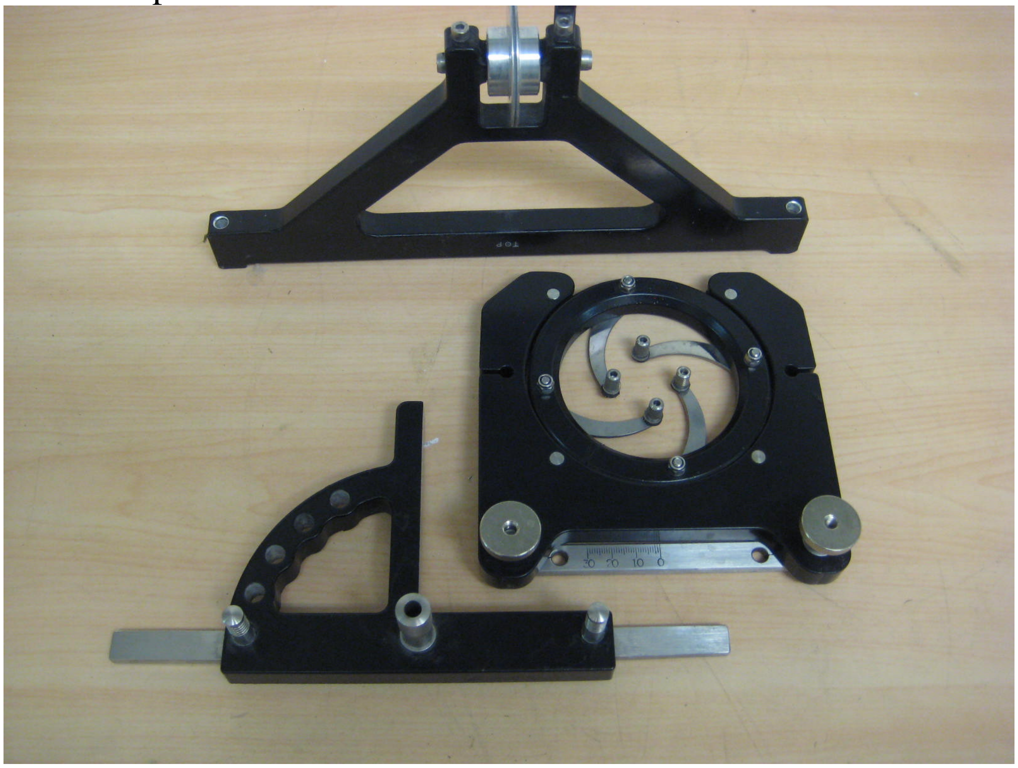


All parts of both dryer and control unit are WJ cut, bent and welded. No other machining used. Dryer is doubled walled with dual air bearing heat transfer.

Linkage

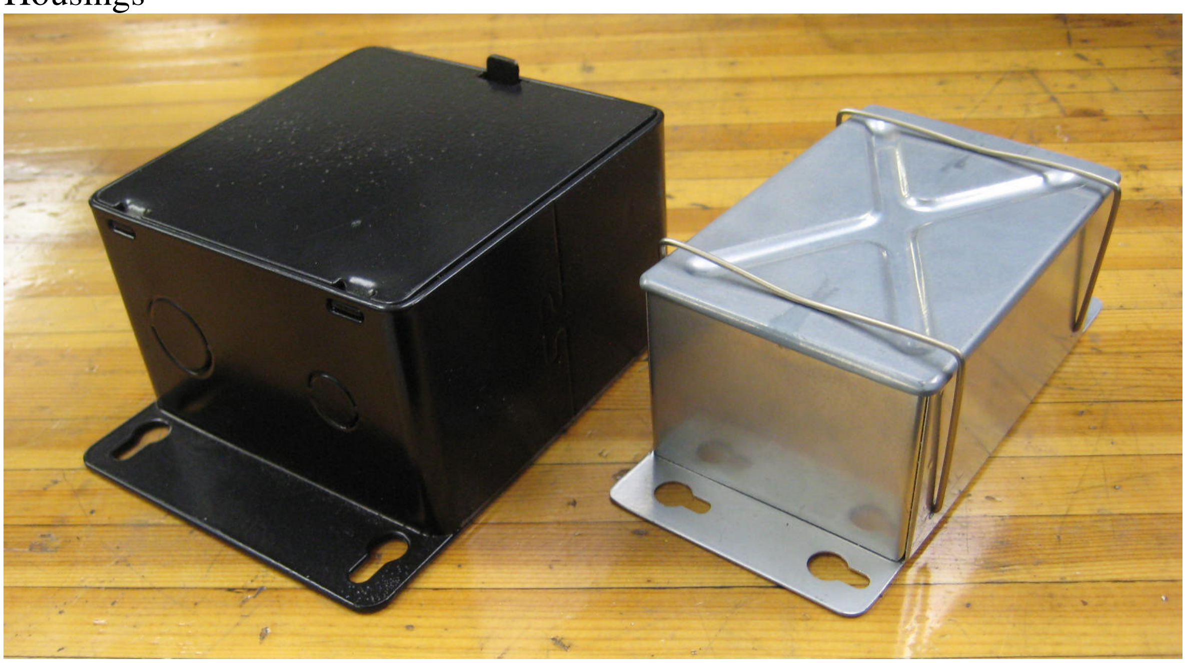
Simple linkage, 8 identical arms and two end pieces. Total fabrication time, including painting, is about 1 hour. Paint is fluidized bed Rilsan (acts as a bearing surface).

Precision parts



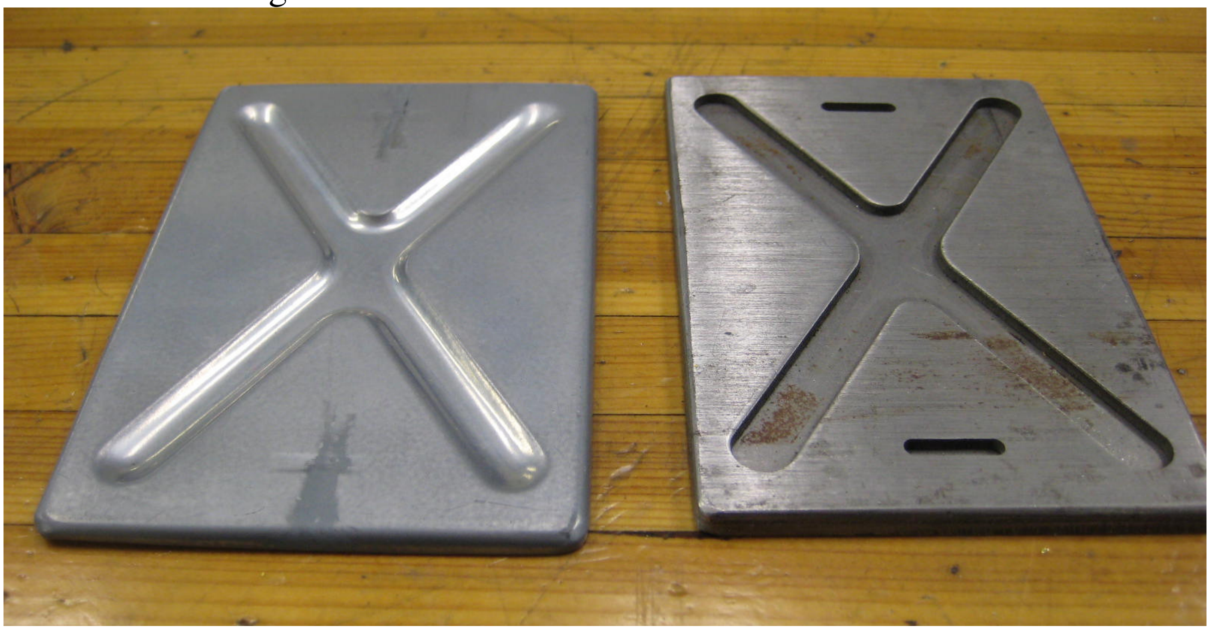
Cut from 12.7mm aluminum plate, painted, then machines at the critical areas. Total fabrication time 2-3 hours per part.

Housings



General purpose housings for prototypes. Total fabrication time (not including design) is about 25 minutes per box.

Presswork Tooling



The tool to press the cover on the left is made of two layers, spot welded together. Total fabrication time for the tool and the cover is about 10 minutes. Pressed into hard polyurethane.

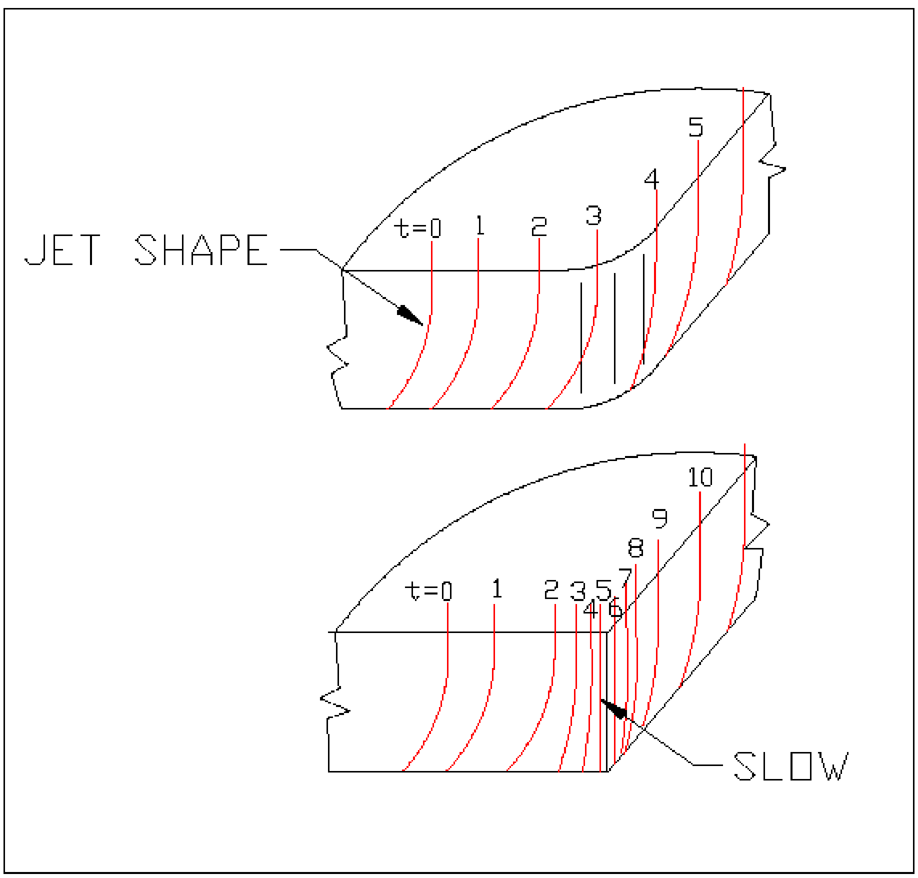
Part 1- Making enclosures

1. Materials used

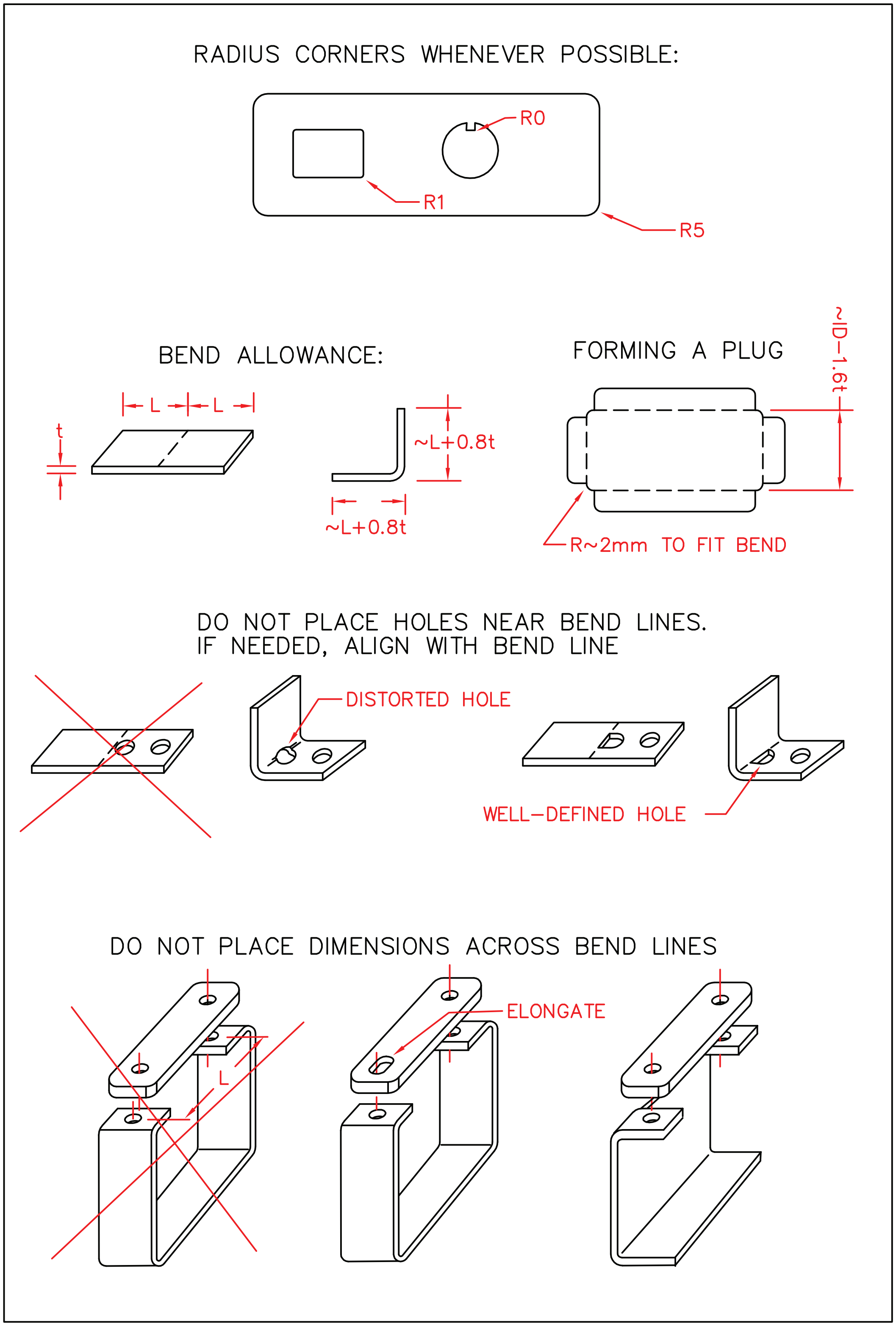
The best material to use is regular mild steel sheet (known as CR, for “Cold Rolled”). For medical devices, harsh environment or long duration (>1yr) outdoor application use stainless steel. For all enclosures #20 (0.9mm), #18 (1.2mm) or #16 (1.5mm) steel is sufficient. For heavily loaded structural parts use #12 (2.7mm) sheets. For most critical applications, where strength to weight ratio is critical, the best materials to use are type 301 Stainless in “half-hard” condition or type 17-7 stainless in the annealed state. The latter requires a two-step heat treatment.

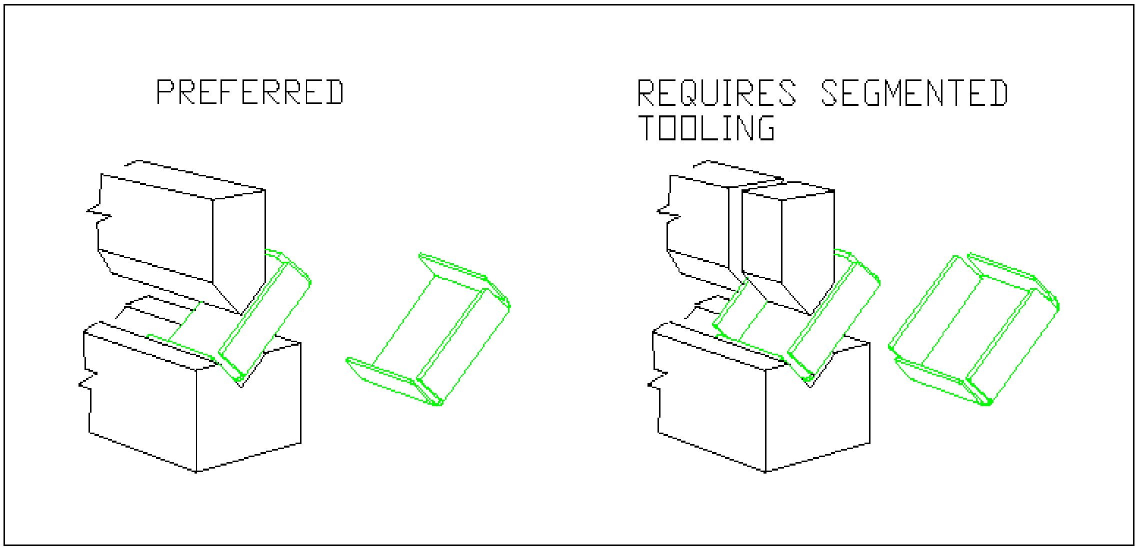
2. Waterjet cutting tips

When cutting thick materials (anything over a couple of mm) the jet is bent as shown below. In order to cut a sharp corner the machine has to slow down to allow the jet to straighten out. For this reason it is important to always use the largest fillet radius that is practical.

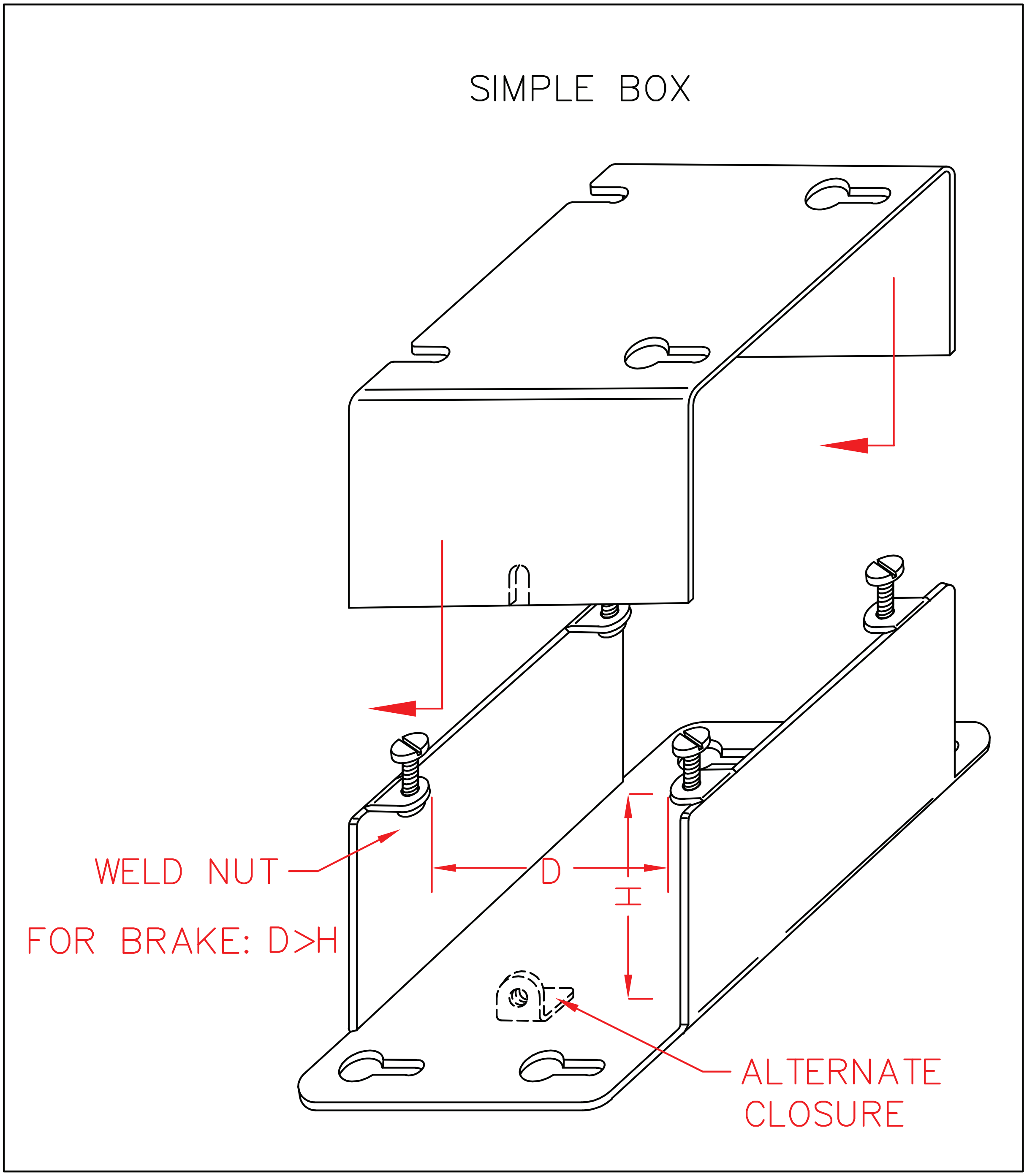


3. Bending

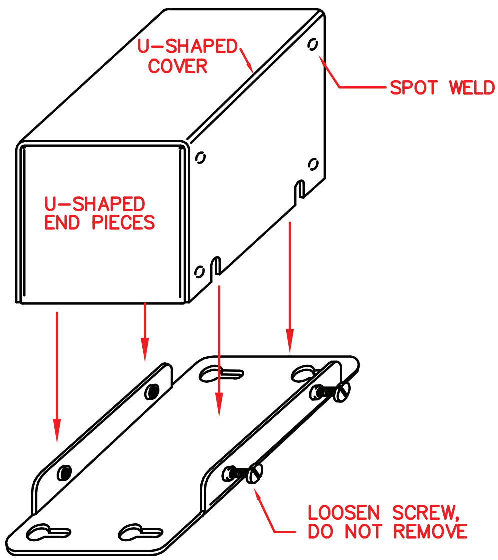

RADIUS CORNERS WHENEVER POSSIBLE:
R0
R1
R5
BEND ALLOWANCE:
L
L
t
~L+0.8t
~L+0.8t
FORMING A PLUG
~ID−1.6t
R~2mm TO FIT BEND
DO NOT PLACE HOLES NEAR BEND LINES.
IF NEEDED, ALIGN WITH BEND LINE
DISTORTED HOLE
WELL−DEFINED HOLE
DO NOT PLACE DIMENSIONS ACROSS BEND LINES
L
ELONGATE



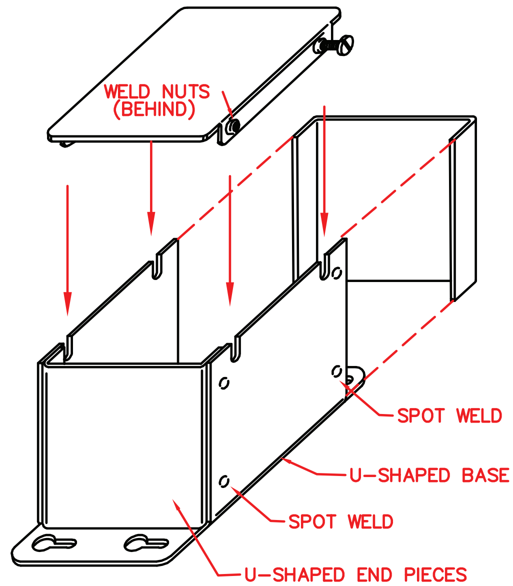
One of the simplest box designs is shown below. It can be made of aluminum as well as steel (aluminum is used only if base has to serve as a heat sink). For aluminum, use heavy gage (typ #12) and tap screw holes instead of using weld nuts. Nut inserts such as Nutserts or Helicoils can be used as well. For prototypes it is important to use quick-release systems and captive fasteners, since they are taken apart frequently. Note the use of keyholes and slots in all the designs, requiring only loosening of the screws to remove cover. A locknut can be placed on the screw end beyond the nut, in order to make screw captive. Captive screws prevent one of the most common disasters in electrical engineering: a screw falling into live equipment and shorting the line to some signal running to all electronic boards. The probability it will happen to you in your lifetime is very near100%. Another way to look at it, think of the time you save over your lifetime by not having to remove screws completely.


SIMPLE BOX
WELD NUT
FOR BRAKE: D>H
D
H
ALTERNATE
CLOSURE

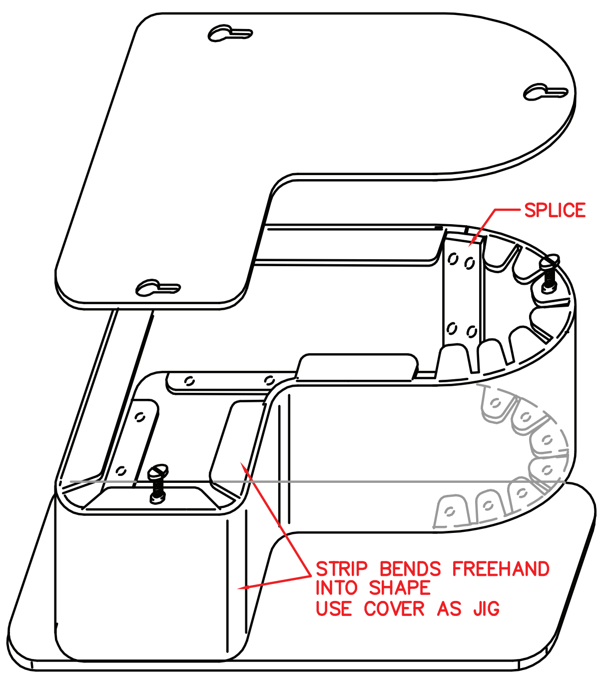
SHALLOW BOX



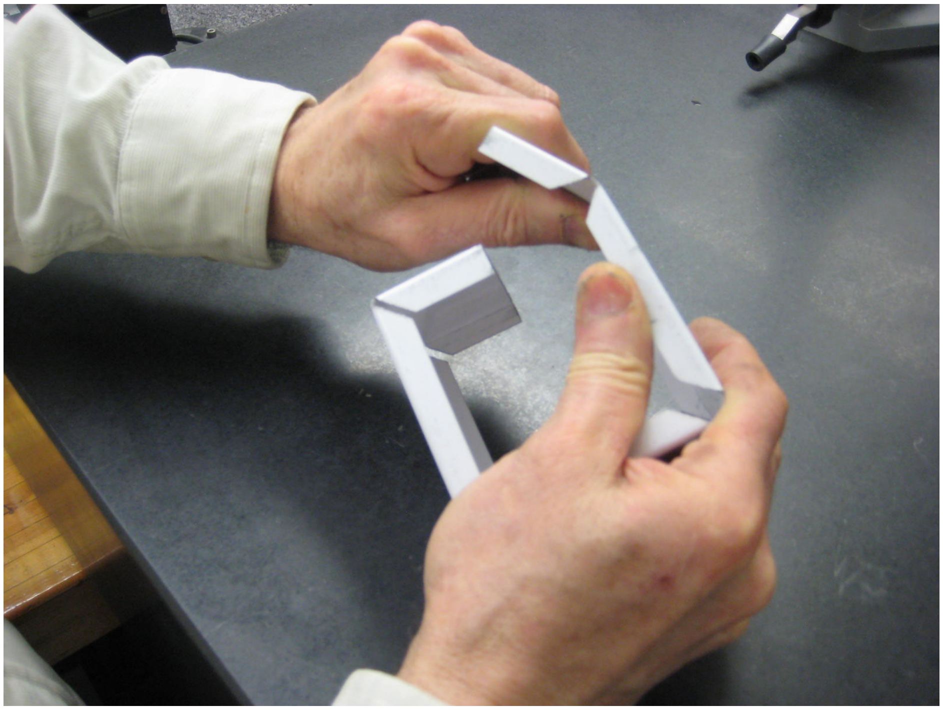
DEEP BOX



ARBITRARY SHAPED BOX



When making arbitrary shaped enclosures it is sufficient to bend the “wrap around” part in the form of a channel, all other bends can be done freehand as the channel will only bend where it is notched out. The radius of the bend id determined by the width of the notch, as can be seen below.



4. Spot Welding

Spot welding should be used to join sheet metal, weld nut and studs, attach hinges and latches, and build structures from wire or rods (similar to supermarket shelving). It should be the first choice for any permanent fastening (no wonder that cars are held together by this method). You can only spot weld steel and stainless steel. Dirty or galvanized steel should not be spot welded. Other tips:

A. If not sure, use a temporary weld first. It can be broken by twisting the parts using the weld as a pivot point. If OK, go over the weld with a permanent weld setting. To remove a permanent well drill it out.

B. On critical work do a “tear test” on a test piece (see photo below). Metal has to tear/break without breaking the weld.

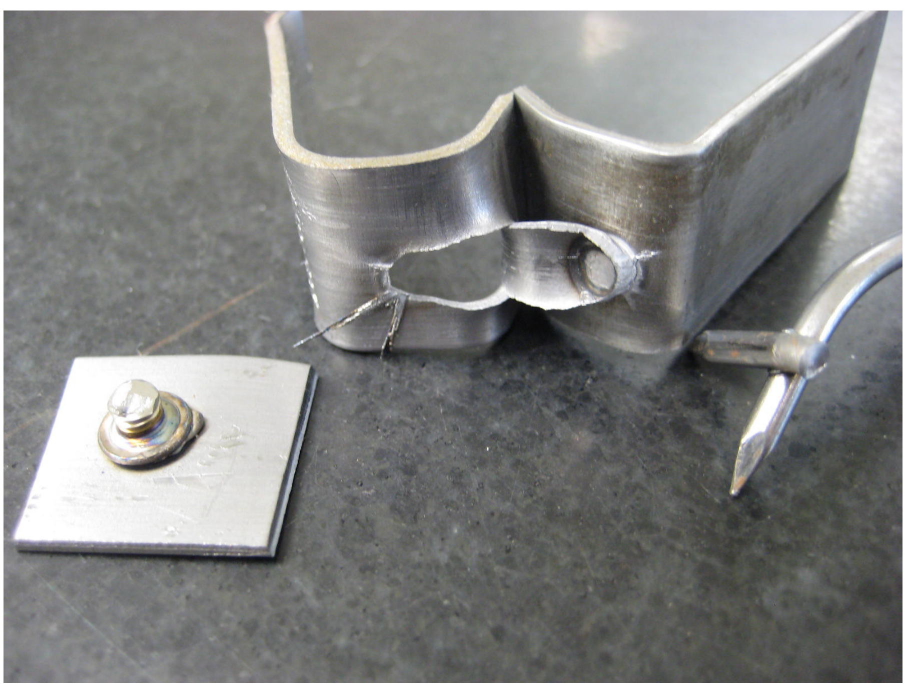
C. If electrode tips appear dirty or corroded, clean with rubberized abrasive stick or sand paper.

D. Electrodes are locked in place by a tapered end. To release, tap with hammer on top of electrode holder. Make sure water is shut-off before removing electrodes.

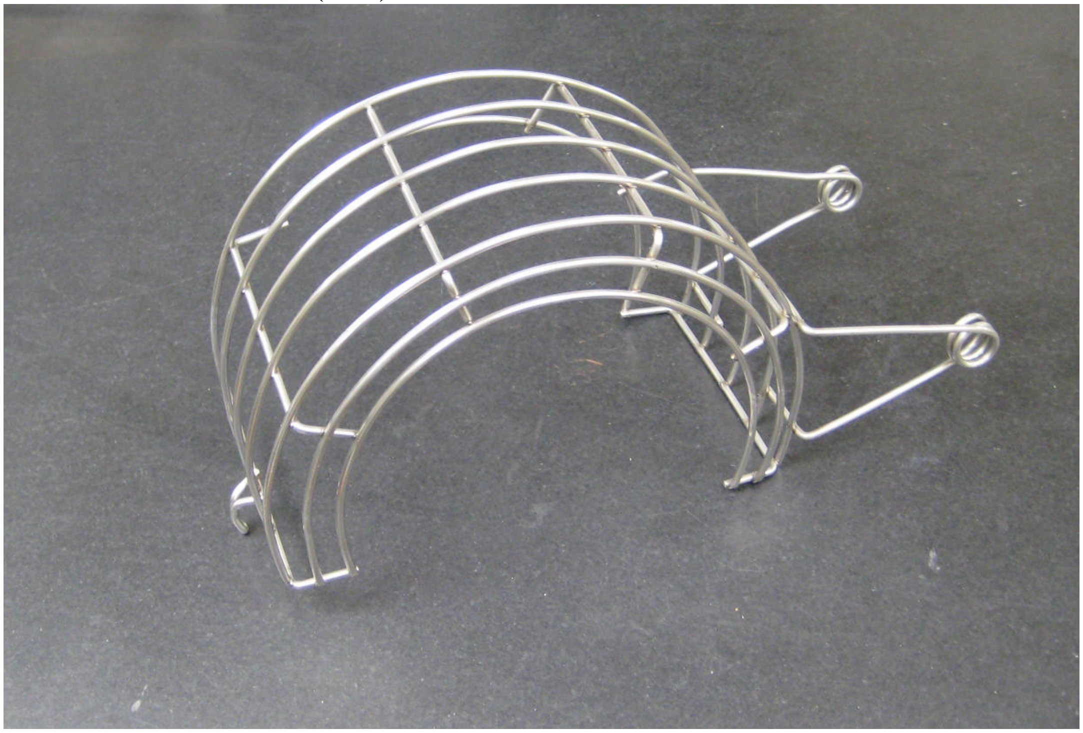
E. For welding sheet to sheet, use pointed electrodes. On light gages it is OK to use one pointed and one flat electrode. Use the flat electrode on the more visible side of object. For nuts and rods use flat electrodes. For studs use the correct size hollow electrode against a flat electrode.

F. To check alignment of electrode tips without welding, place an insulating sheet such as cardboard or plastic between electrodes and activate weld cycle.

G. Spot welding works particularly well on rods (see “twist-off” test on a nail in second photo below). Rods up to 13mm (1/2”) can be welded. Making parts from wire or rod should always be the first choice.



Guard made from 3mm (1/8”) stainless wire:

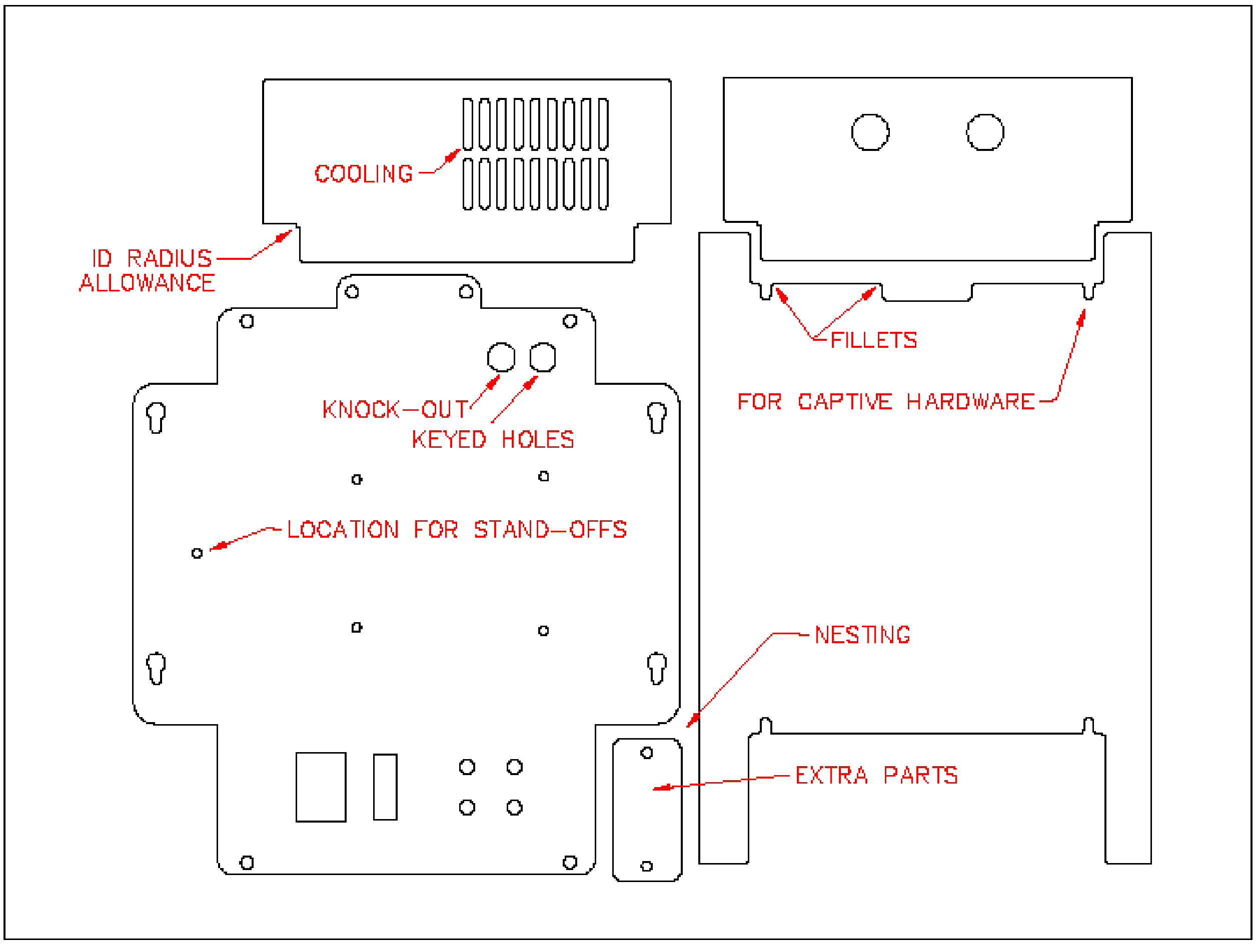


5. Painting

The best over-all method is electrostatic powder coating. There are methods producing better coating, such as fluidized bed coating, but the equipment is hard to find for a small scale.
Best preparation before painting is sand blasting. **If sand blasting is not possible, heat item to 300 deg C for about an hour and cool down.** For very large objects scrubbing abrasive cleaner such as Ajax or Comet can be used. Areas to be masked have to be covered with a material capable of withstanding 235 deg C. Use aluminum foil, metal shims, Kapton or silicone tape etc.
One disadvantage of electrostatic coating is that it does not reach into corners or deep cavities. Reducing the voltage from 100Kv to 25Kv helps. Restore voltage to 100KV after inside corners are done.

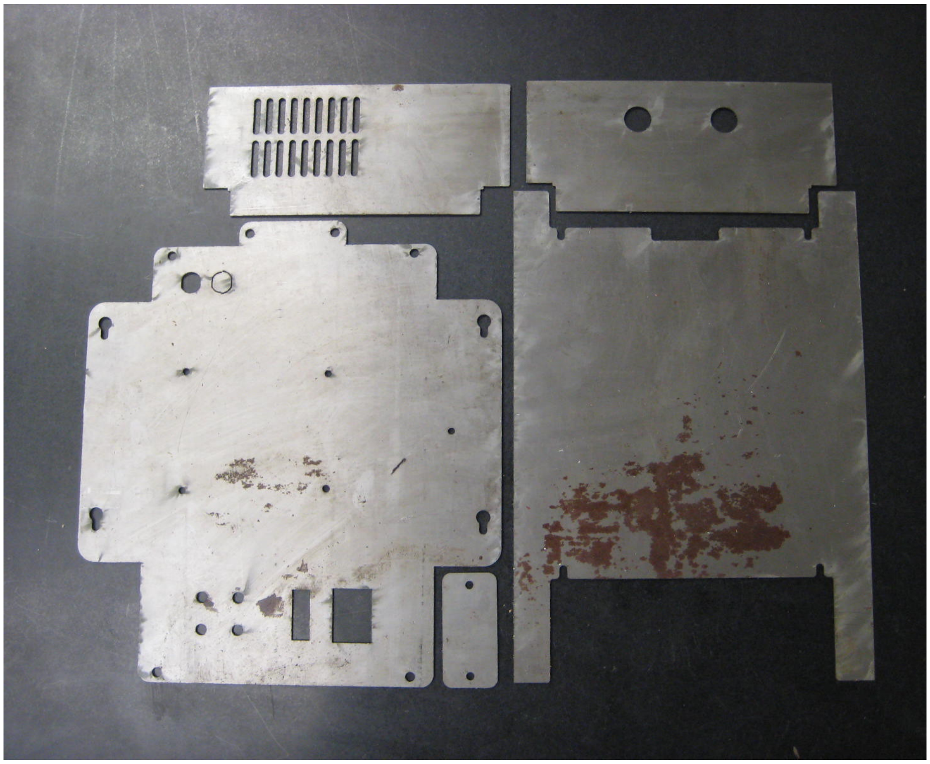
Step-by-Step Example

Step 1: CAD layout.
Note nesting of parts (to save material), rounding corners and use of "knock out" where holes may be needed in the future. For knock-outs leave about 1-1.5mm uncut gap at two places. The stand-offs are made from regular M4 round-head stainless screw (slotted, Allen or Philips). The locating hole, about 4mm diameter, allows accurate positioning of the screw head by tactile feel. Any extra parts needed, such as clamps, brackets etc. can be cut out at the same time. Most round electrical components, such as switches, connectors, strain-reliefs etc, are designed to fit into keyed holes. Take advantage of the ability to cut keyed holes.

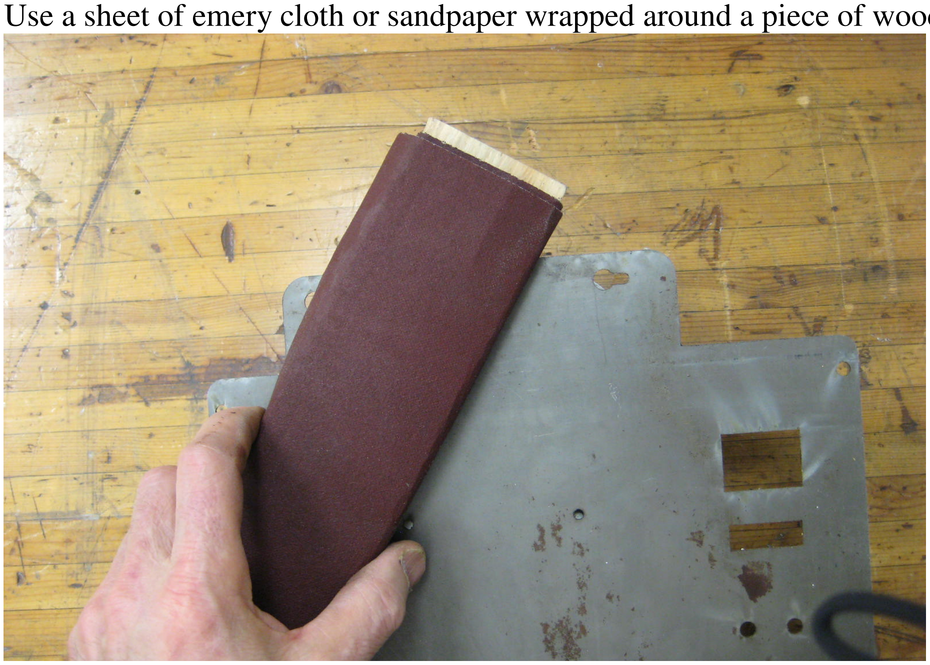


Step 2: Water Jet Cutting and Deburring

Parts “as cut”:

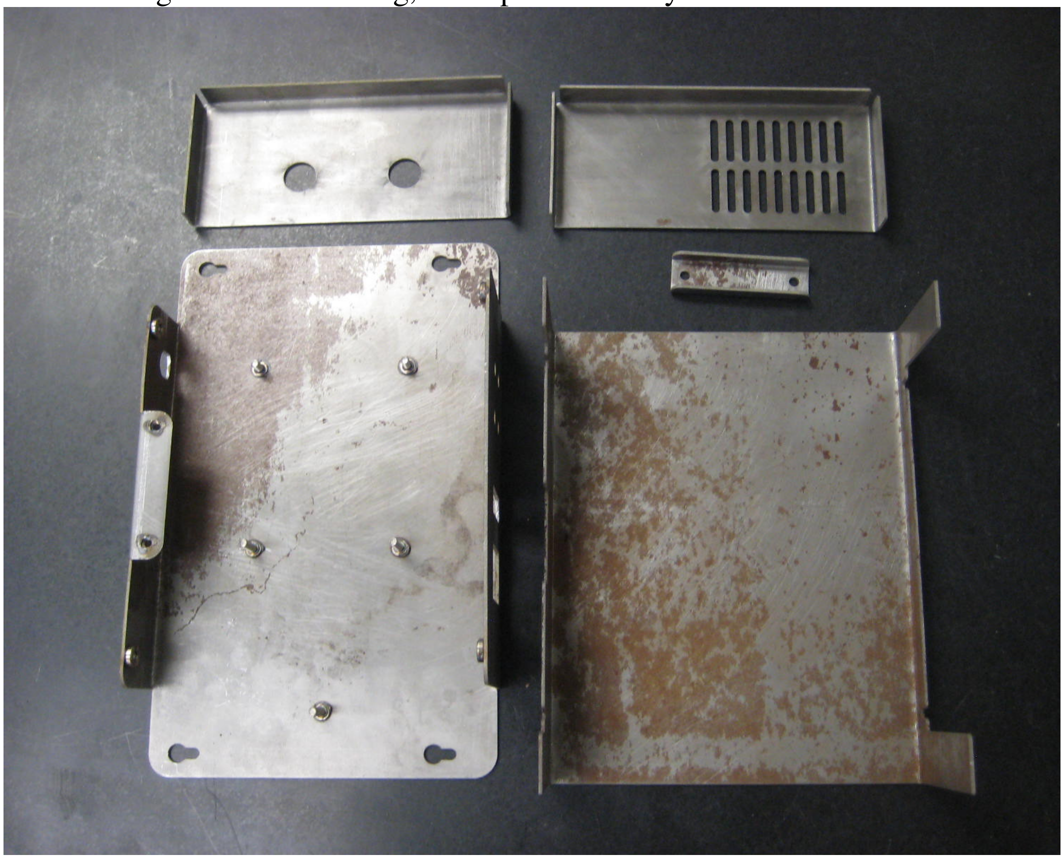


Use a sheet of emery cloth or sandpaper wrapped around a piece of wood.



Step 3: Bending

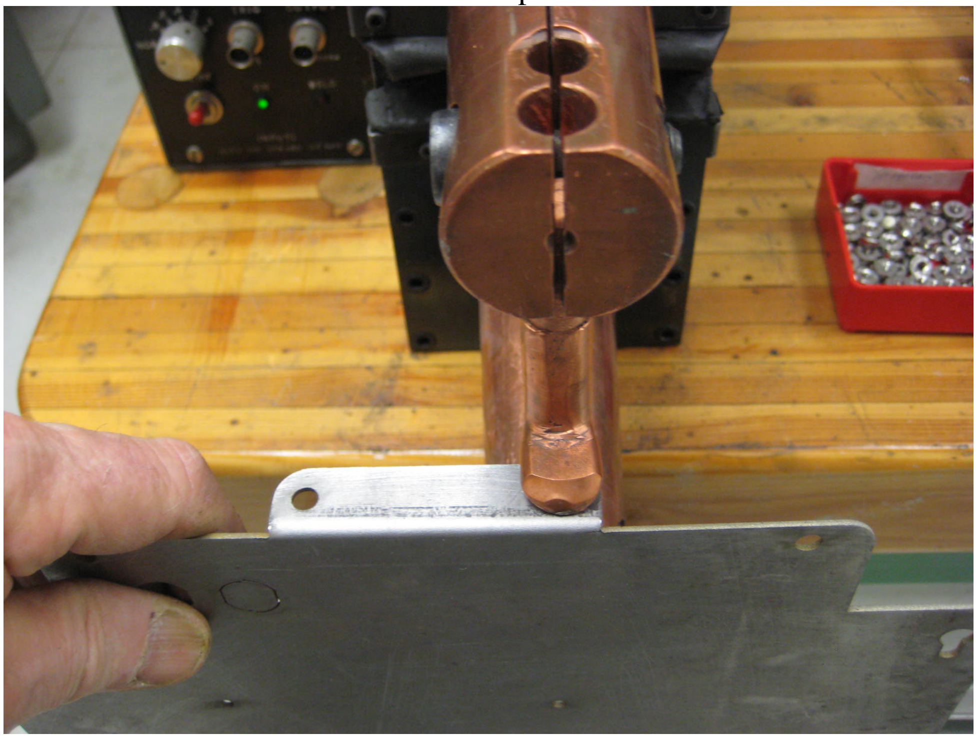
Think through order of bending, some parts can only be bent at a certain order.

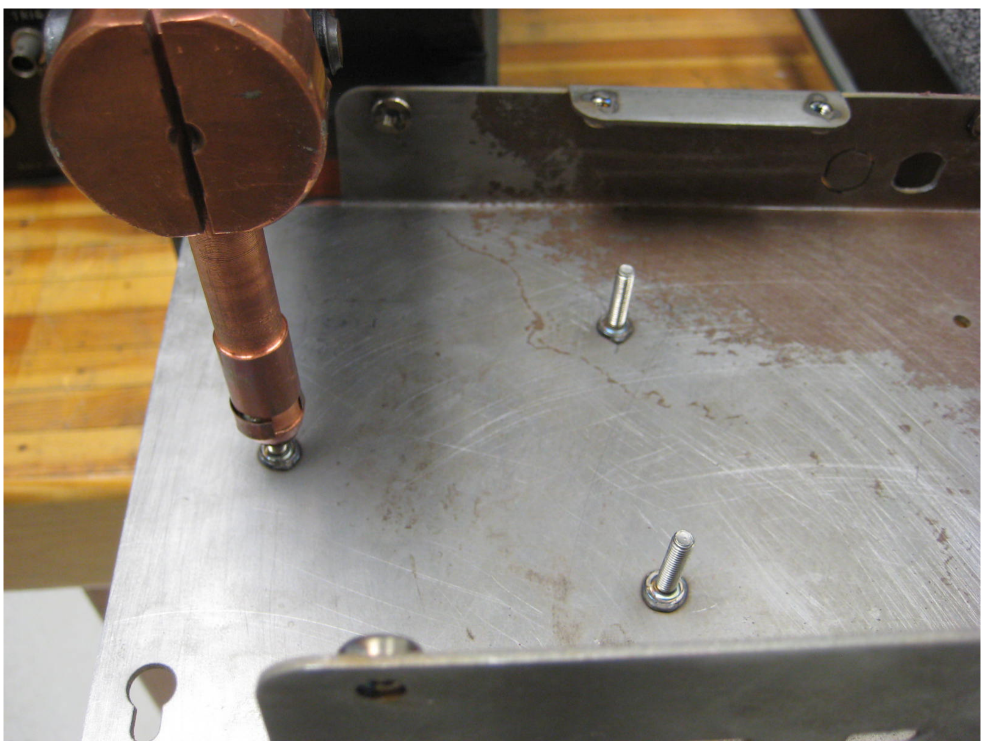


Before bending cover bend a test strip having the same length to check fit.

Step 4: Nut/ Stud Welding and Spot Welding

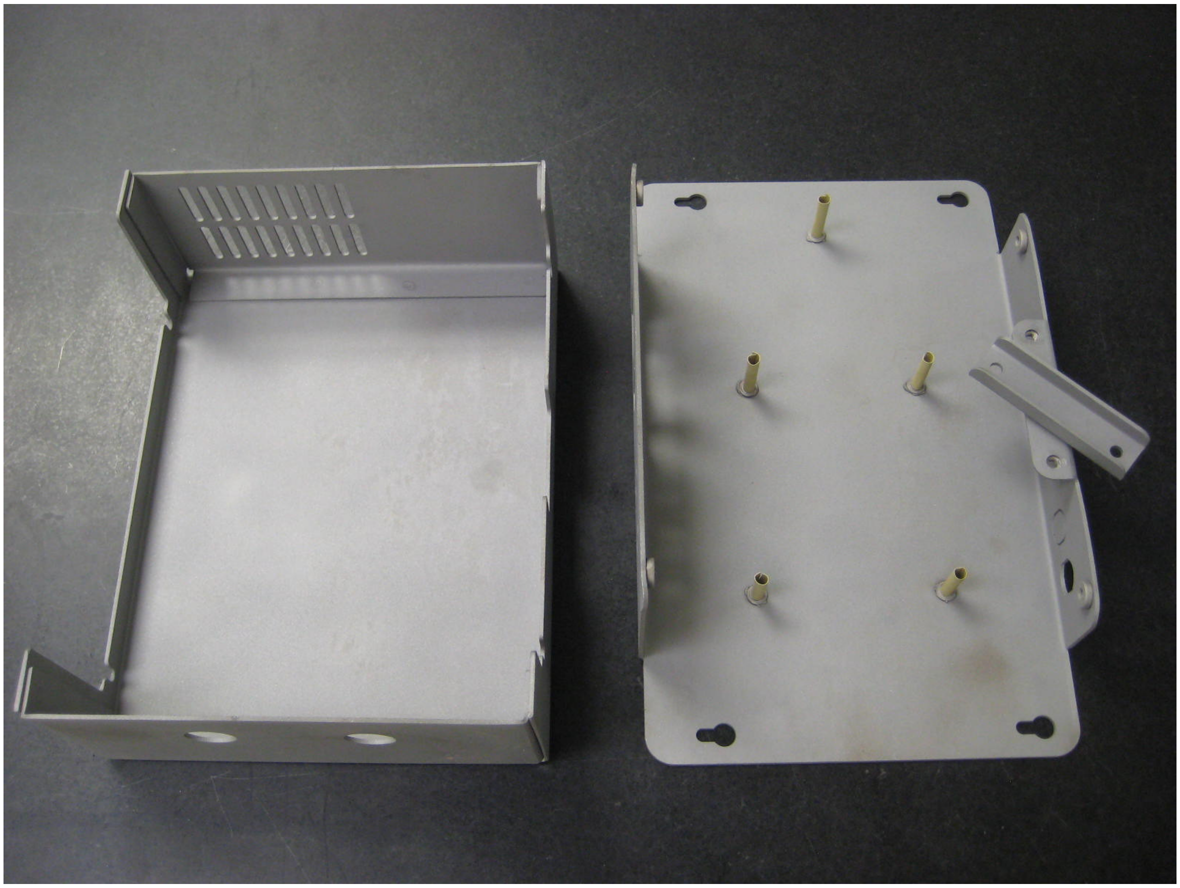
Note bent electrode for access under a lip.





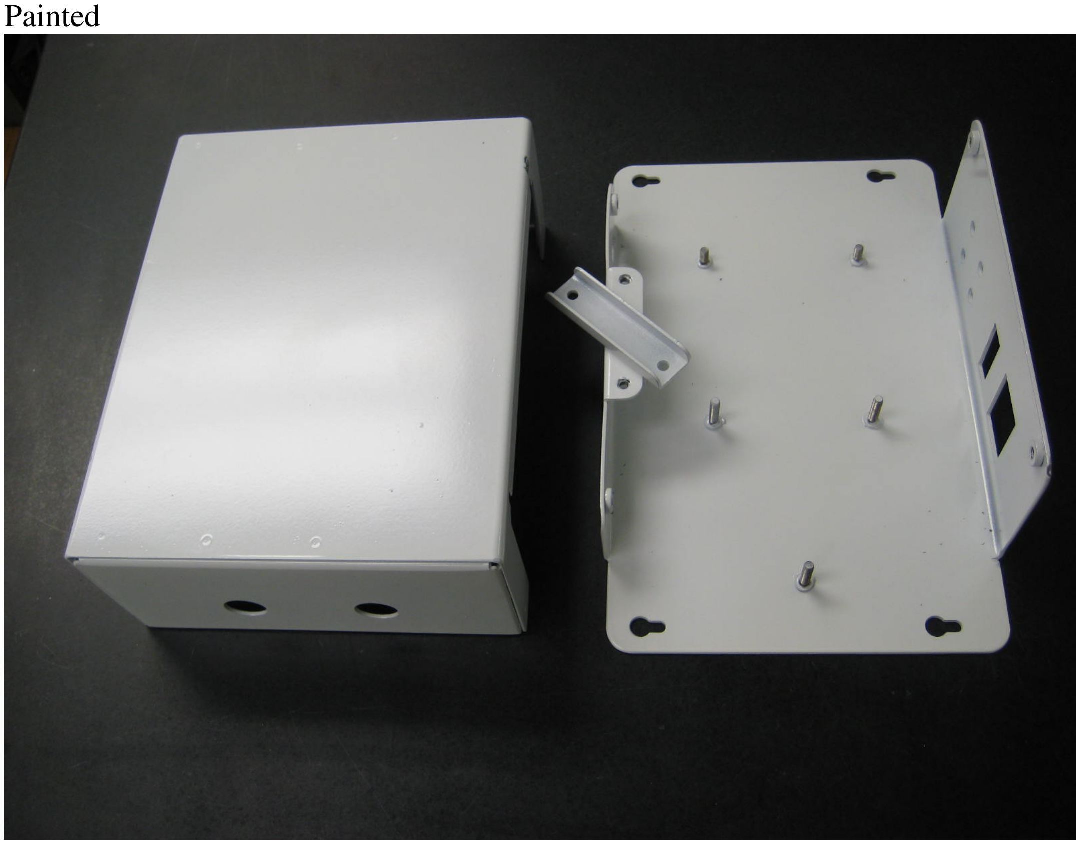
Step 5: Sand-blasting

Make sure no shinny area remain. Note studs are masked by a rolled-up piece of shim stock. A few layers of aluminum foil can be used as well. Masking has to withstand 235 deg C, as it is used during powder coating. Internal threads normally do not require masking. Note small bar on the right, to be used as clamp and strain relief for flat cables.



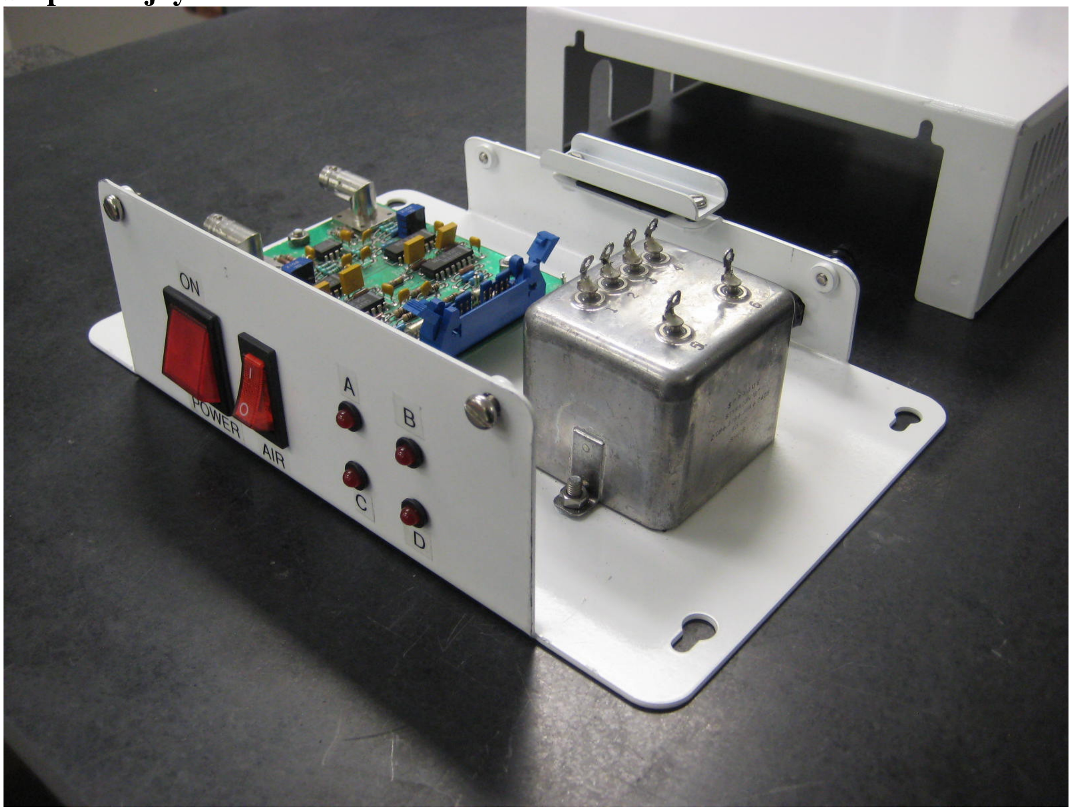
Step 7: Powder Coating

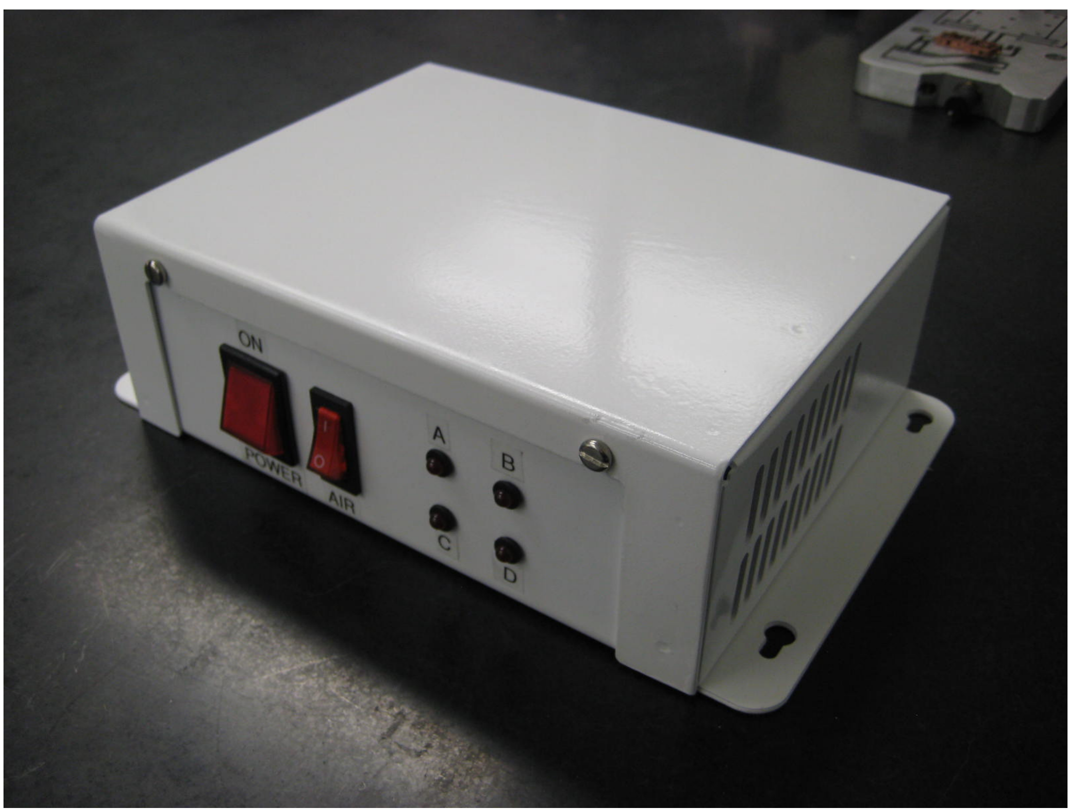
Painted



Clean the internal treads by running a tap through them. Use reversible hand drill.

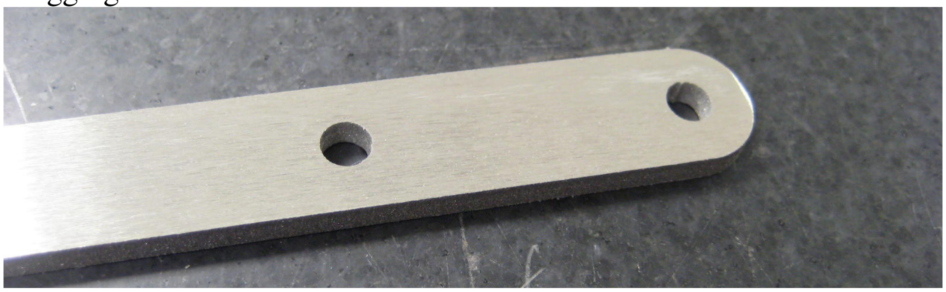
Step 8: Enjoy



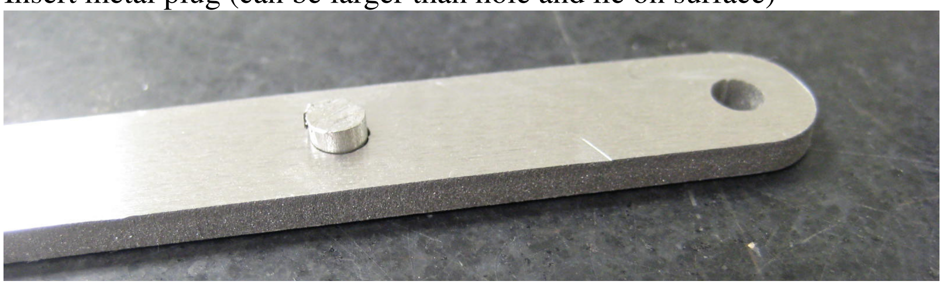


Repair Techniques

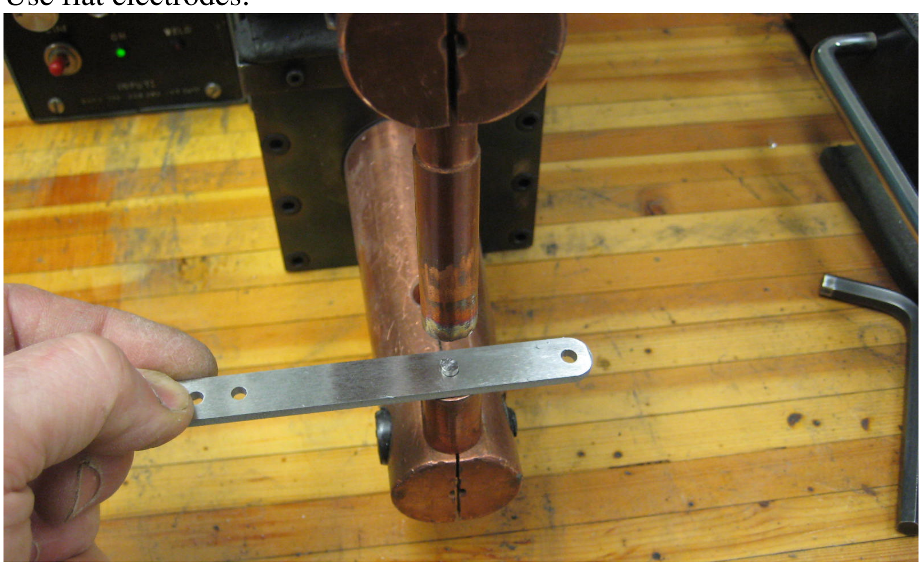
Plugging holes:



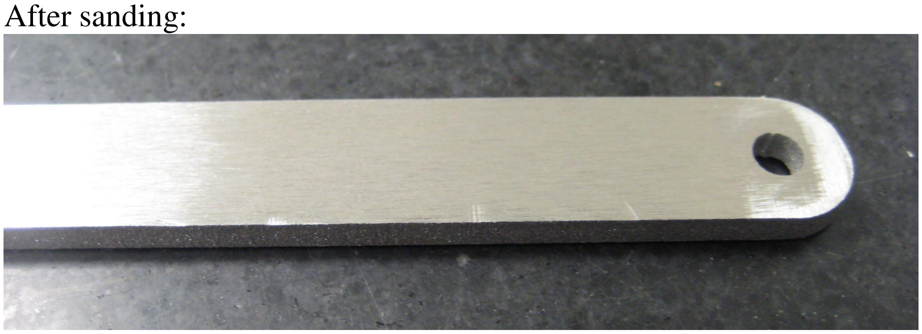
Insert metal plug (can be larger than hole and lie on surface)



Use flat electrodes:



After sanding:



Correcting bending errors: