ECM One

User’s manual and startup guide.

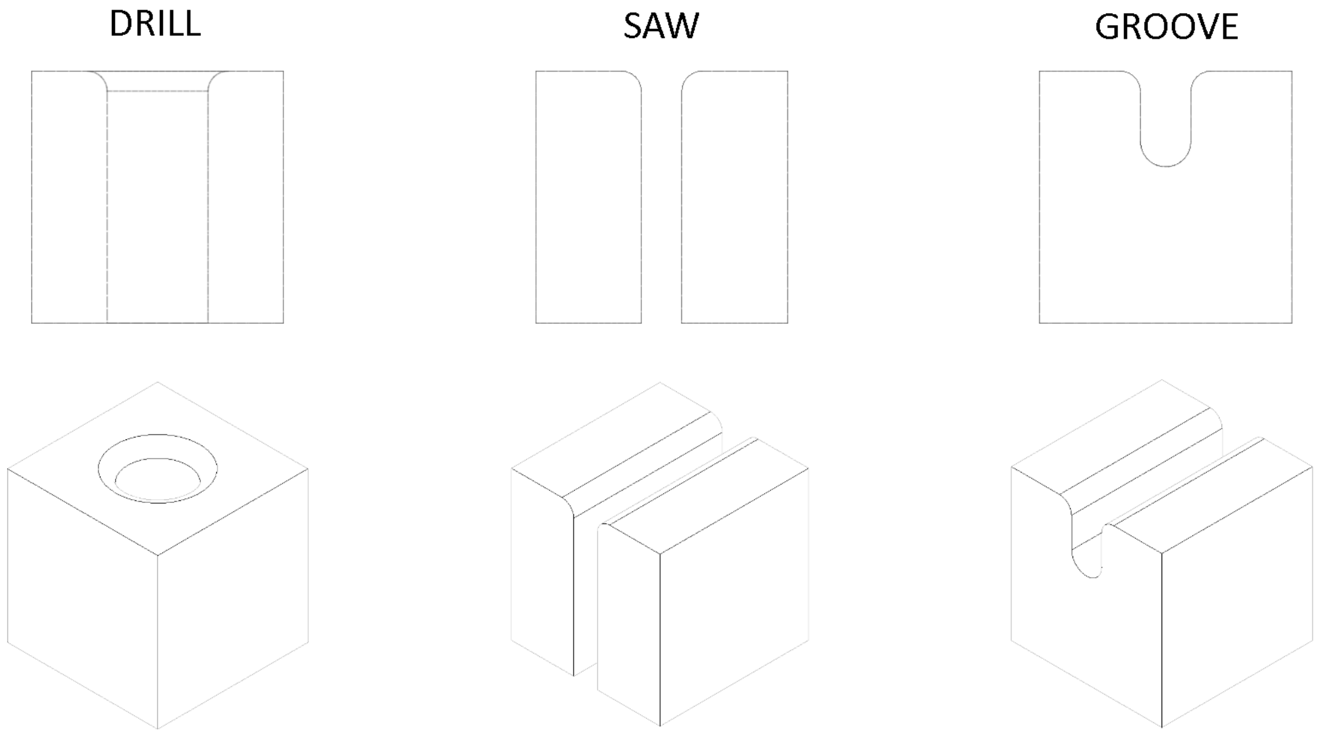
Contents

Introducing the ECM One

The ECM One is a machine that allows one to cut or shape metal using the electrochemical machining process.
The ECM One is primarily intended as a research platform to explore electrochemical machining. It has the necessary capabilities to do this very well. Using this machine, one can investigate the following:

- Effect of addition effect of varying concentrations of salt in the electrolyte solution
- Addition to electrolyte solution of other hydrogen donors (than plain H2O) such as weak or strong acids
- Effect of higher or lower electrode voltages
- Effect of pulsing the electrode voltage
- Effect of varying rates of electrode movement
- Electrode design and fabrication

The ECM One has confirmed the efficacy of basic electrodes which can perform hole drilling, grooving or through-cutting operations. Importantly, the machine's electrode mounting fixture is adaptable to custom 3D printed electrodes of the user's design, with different shapes and fluid flow patterns.



WARNINGS

The machine uses electrical voltage and current plus a saltwater electrolyte solution which is pumped under pressure through an electrode-nozzle to selectively remove metal material from a target workpiece of metal. As initially configured, the working voltage of the ECM One (i.e. the voltage used to remove metal) is typically in the 12V range but may be considerably higher with additional optional circuitry. The working current may range from a few milliamps to tens of amps, depending on the working voltage, the configuration of the electrode and the exact composition of the electrolyte. When the electrode is powered up, the current employed may be enough to cause serious burns if bare skin comes into contact with the electrode, the workpiece or the electrolyte. Even with no electrical current flowing, the electrolyte solution itself, particularly if the solution contains acid in addition to salt, will be harmful to bare skin, eyes, and mucous membranes.

In addition, the salt (NaCl) in the electrolyte is extremely and rapidly damaging to electronic devices including the machine’s onboard microcontroller and power supply, and also the connected computer (including keyboard, mouse and monitor).

Electrochemical machining produces small amounts of inflammable hydrogen gas. Under normal operating conditions, this should not accumulate but nonetheless, the machine should be operated in a well-ventilated area.

The by-products of the electrochemical machining process may be toxic or even deadly if ingested or contact with bare skin, eyes and mucous membranes. Using the ECM One to machine any workpiece metal which incorporates chromium or other heavy metals (e.g. hardened or stainless steel) will produce extremely toxic waste material. This toxic waste material will be especially concentrated in the solid waste captured in the machine’s filter but is also present in the electrolyte. The solid waste material which is captured in the machine’s electrolyte filter and the used electrolyte solution must be disposed of properly.

The fluid hoses used in pumping the electrolyte solution are made of latex and may irritate someone with a latex allergy.

PRECAUTIONS

Wear gloves, goggles, and smock while setting up the machine for a run, during use, and when cleaning the machine after a run. Check continuity and integrity of fluid pumping hoses and connections to pumps before operation. Make sure that the latex fluid hoses are securely connected with tie-wraps. If in doubt, fill the machine with plain water to test the pumping system for leaks. Position the computer and peripherals as far away from the machine as possible.

In addition:

- Provide proper ventilation of machine during operation
- Do not touch the electrode or workpiece while machine's electrode power is "ON"
- Do not operate machine without frontal splash plates in place
- Do not attempt to open-up and clean the filter after it has been used.
- Dispose of solid waste, used electrolyte solution, and used filter properly.

Online Resources:

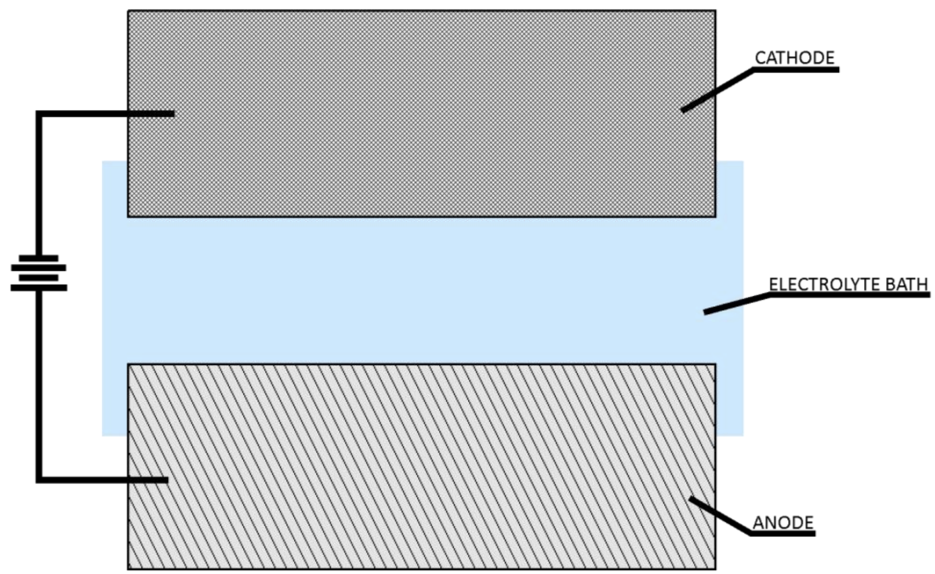
https://keybase.io/team/zurad_collab

Keybase is the home of our research and support community. Join us in sharing ideas and pushing forward the limits of home manufacturing. Share electrode files, configurations, and get support on machining issues. The integrated Git is one way to get official Zurad electrodes or replace this manual should you lose it.

https://github.com/CooperZurad/ECM-One

The GitHub is another place to get the user's manual and the latest firmware. If you are so inclined, fork our source and make the ECM One work better for everyone.

What is ECM?



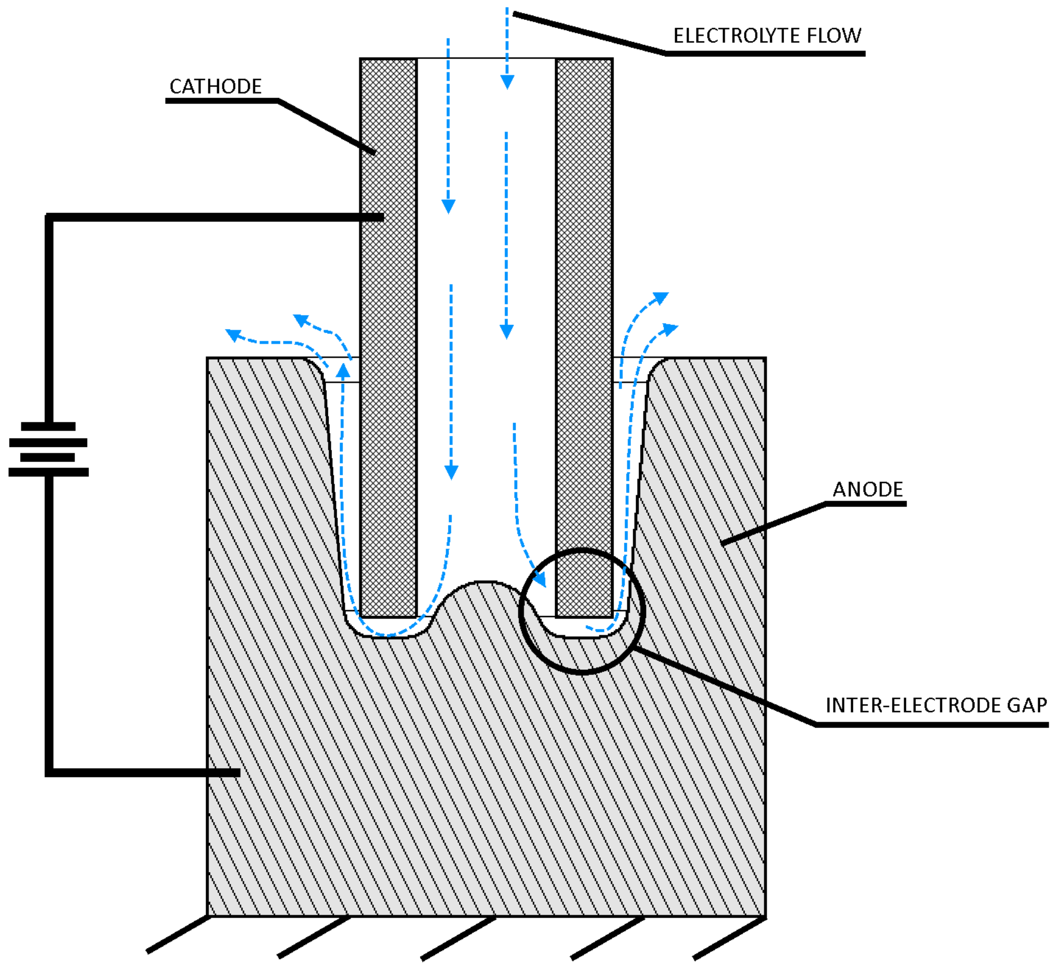
Electrochemical machining, or ECM, is the process of selectively removing metal from a metallic and electrically conductive workpiece through a redox chemical reaction. A redox reaction is one in which one substance is reduced and another one is oxidized. “Reduced” means that the substance acquires electrons. “Oxidized” means that electrons are removed. Reduction takes place at the cathode. Oxidation takes place at the anode. A Direct Current (DC) electrical voltage drives the exchange of electrons. The positive pole of the DC supply is connected to the anode. The negative pole is connected to the cathode. Also, the redox reaction typically takes place in a conductive solution, the electrolyte.

Consider an example of a redox reaction. The anode is a piece of aluminum, clean on its surface (i.e. does not have anything such as grease that would interfere with the exchange of electrons. The cathode can be anything that is electrically conductive, such as a copper wire. The cathode remains essentially unaltered during the redox reaction. Its purpose is to send electrons into the electrolyte where the electrons meet up with positive ions. If the electrolyte solution is simply water, the positive ion is H+. The H+ ion comes from the water (H2O). The H+ ions that receive electrons will combine to form gaseous H2, which bubbles away. This bubbling process may be observed.

At the anode, atoms of aluminum give up electrons, and enter the electrolyte as positively charged Al ions. The positive Al ion will quickly combine with OH- ions that were left behind when the H2 was formed. An insoluble precipitate of aluminum hydroxide will be formed.

In this example, the aluminum is simply immersed in a bath of the electrolyte solution. Hence, the atoms are removed indiscriminately from the aluminum and no particularly shaped results.

However, in the ECM One, we use a moving cathode (the "Electrode") which proceeds at a constant rate towards the anode (the "Workpiece"). The electrolyte is routed through the fluid nozzle, now part of the Electrode, to direct the flow of the electrolyte onto the Al, which is now held out of the bath in a chosen position. The fluid nozzle is positioned close to the Workpiece and maintains the small inter-electrode gap (IEG), the distance between anode and cathode, by constantly moving. The close proximity of the Electrode to the Workpiece results in much greater material removal at the point of fluid impact, than elsewhere on the Workpiece, though this removal still does occur (to a lesser extent) anywhere the fluid comes in contact with the Workpiece.



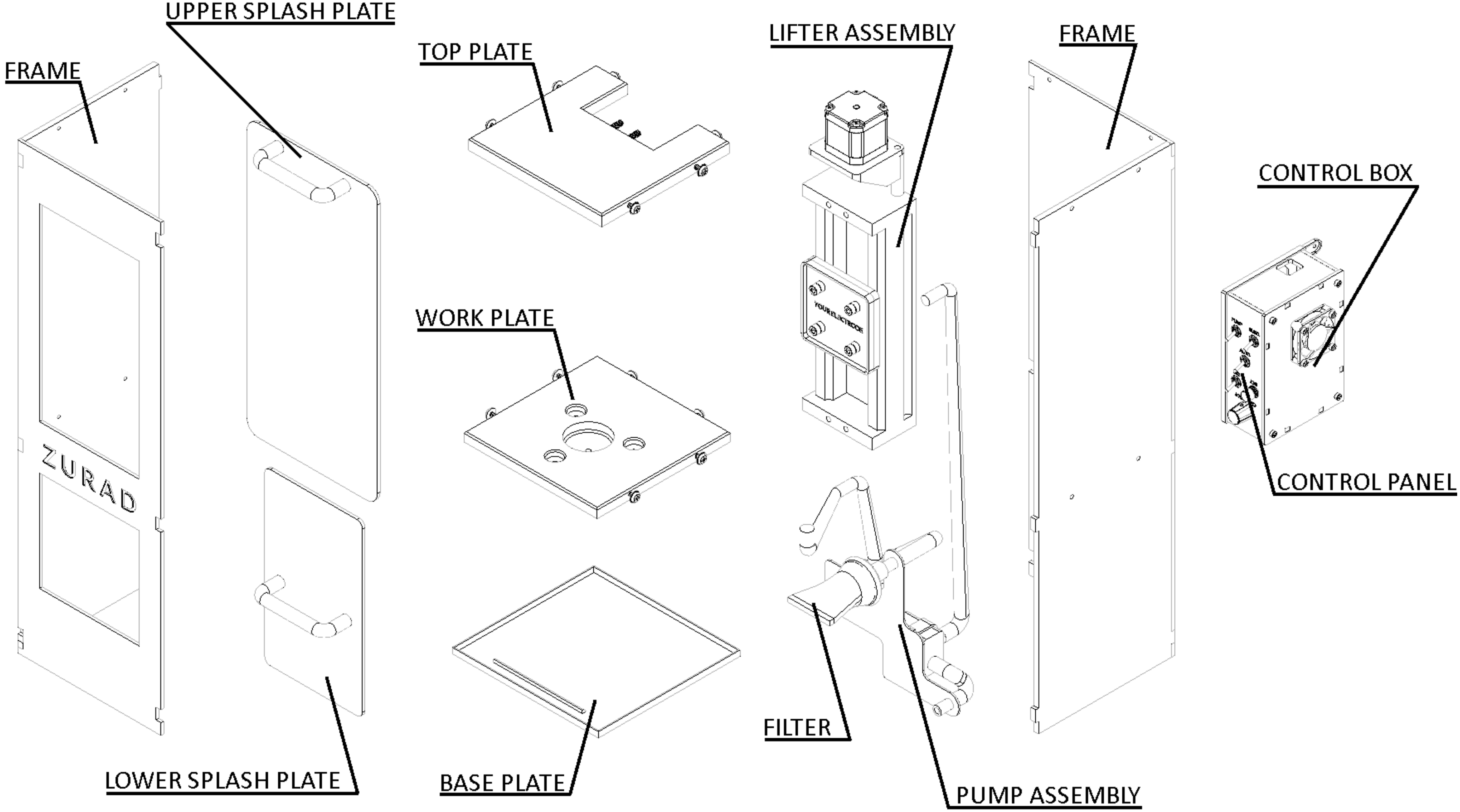
In this way, we can achieve moderately selective removal of Al material. This results in a specific shape being cut into the Workpiece, in this case a hole. The shape of cut is determined by the shape of the fluid flow formed by the nozzle, the shape of the Electrode, and by how fast or slowly the Electrode proceeds toward the Workpiece. Note that the Electrode need not be a simple tube but may be a more complicated shape such as a saw, a 2D profile, or even an array of such things.

In the ECM One, after the fluid from the Electrode impacts the Workpiece, it drips down into a collecting funnel and then is pumped through a filter to remove any solid waste material (such as aluminum hydroxide for an aluminum Workpiece). Then, the cleared fluid is pumped again through the Electrode.

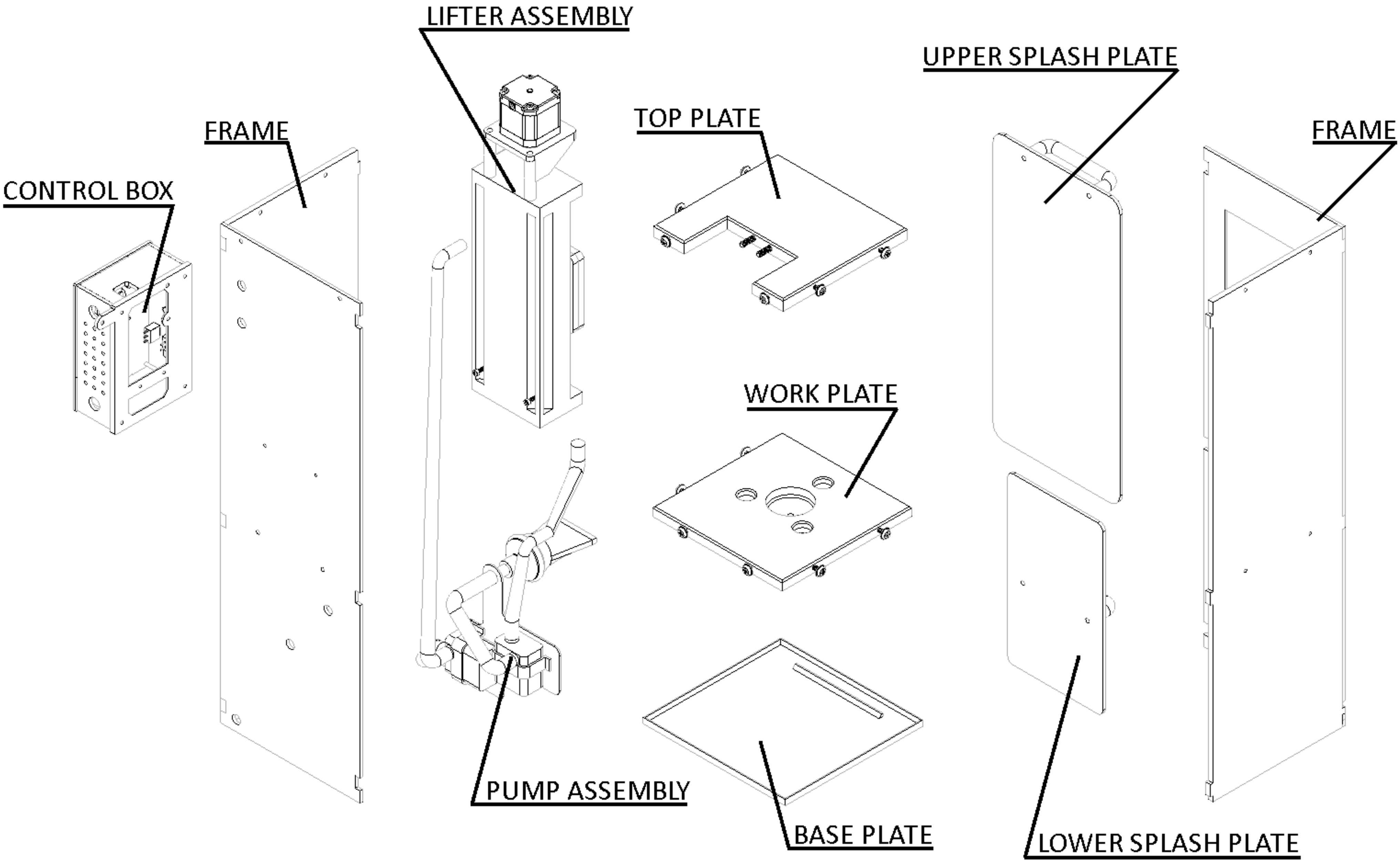
FRONT VIEW

Anatomy of the ECM ONE

The ECM ONE is comprised of the following subsystems:



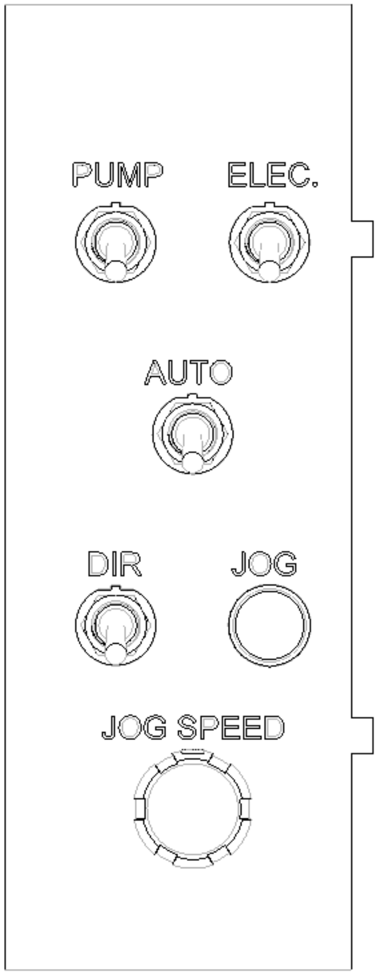
BACK VIEW


LIFTER ASSEMBLY
UPPER SPLASH PLATE
TOP PLATE
FRAME
FRAME
CONTROL BOX
WORK PLATE
PUMP ASSEMBLY
BASE PLATE
LOWER SPLASH PLATE

Control Panel

Inputs are labelled as follows:

- PUMP-------------------Toggle switch, Pumps On/Off
- ELEC--------------------Toggle switch, Electrode current On/Off
- AUTO-------------------Toggle switch, Manual or Automatic mode
- DIR----------------------Toggle switch, Lifter Stepper Motor Direction Up/Down
- JOG----------------------Momentary push button, Jog movement of Lifter in Manual mode.
- JOG SPEED------------Potentiometer, Jog Speed



Firmware

Firmware is operated via the Serial Monitor of the Arduino IDE: Numbers are entered as follows

0 ---------------------------------shows this Menu
1----------------------------------turns On Electrode current
2----------------------------------turns Off Electrode current
3----------------------------------enable stepper motor driver
4----------------------------------disable stepper motor driver
5----------------------------------turn On buzzer, to test it
6----------------------------------turn Off buzzer
7----------------------------------show version of firmware
8----------------------------------reports AutoDescentDelay, ElectrodeDutyCycle and Instant Current (ma)
9----------------------------------after a Current Limit exceeding event, re-turns on the Electrode and re-enables stepper motor
10---------------------------------start Probe
11---------------------------------stop Probe
12---------------------------------reset counter for AutoDownSteps to 0.

Entering a number greater than 100 sets AutoDescentDelay to that number.

Definitions:

“Electrode current” is the current in milliamps as measured by the INA260 current sensor on the shield. This is the working current that removes metal from the Workpiece. The current is measured very frequently, once every time through the main loop of the firmware program. This current may be sourced from either the 12V, 5V or 3.3V output of the ATX power supply or from a separate source with a voltage up to about 35V.

“Current Limit” is the upper limit for current allowed through the shield to the Electrode. This is intended as a safety limit to preserve the electronics in event of a serious malfunction. This limit is set in the firmware at 9000 milliamps. It can be changed by recompiling the firmware in the Arduino IDE and reloading it to the Arduino. The Current Sensor on the shield can handle a maximum of 15 A and 36 V.

“AutoDescentDelay” is the time in milliseconds between downward steps of the Lifter in AUTO mode. It is set at 5000 msec when the Arduino powers up or is reset.

“AutoDownSteps” keeps track of the number of downward steps taken by the Lifter. It can be reset to 0 by entering 12.

“ElectrodeDutyCycle is the duty cycle of the MOSFET which controls the current through the Electrode. The number can be from 1 to 255 referenced to 255. It is set at 255 (100% duty cycle) and can be changed by recompiling the firmware.

Electrolyte

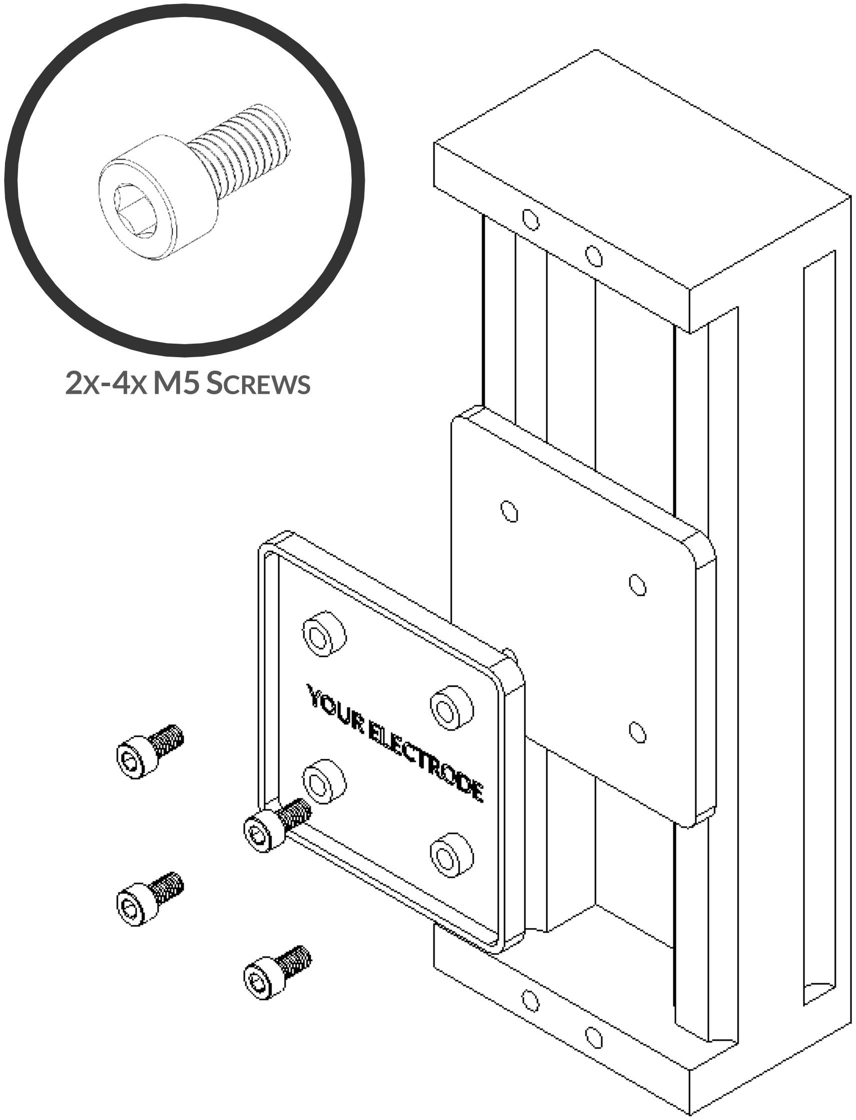
A Standard Electrolyte solution is comprised of water and 10% by weight NaCl (table salt).

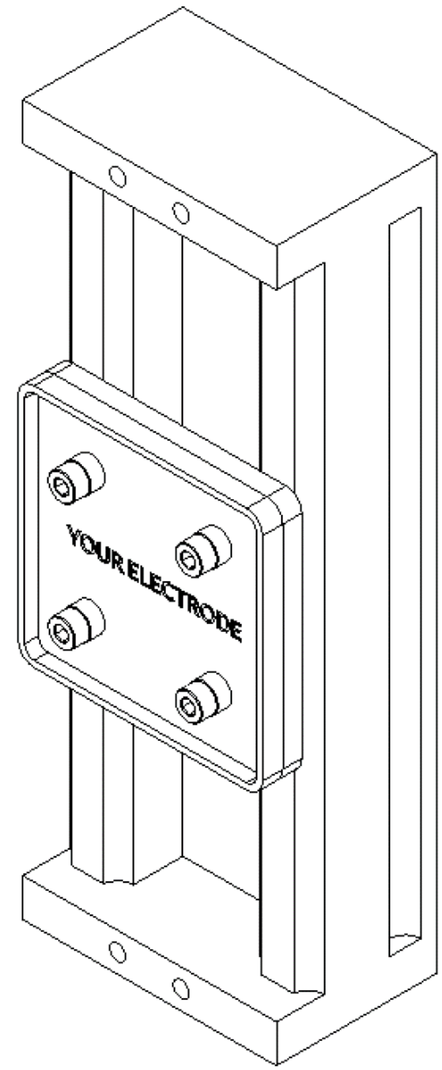
Recipe:
To a clean and dry container add 100 grams (3.5 oz by weight) of non-iodized salt. To the dry salt, add 900 ml (30.5 fluid oz) of clean water. Distilled water is preferred, but tap water is suitable for testing and most machining operations. Mix well until completely dissolved. Using warmer water can speed this process but is not necessary for function.

When completed, add enough electrolyte (approximately 500 ml) to the basin to cover the drain hole by about 12 mm or one-half inch. This prevents cavitation of the pumps as the fluid fills the system and tubing. If cavitation occurs, fluid flow to the reaction will be greatly lessened and waste clearing will be impeded. This cavitation will be noticed by an increase in the sound of the pump during operation and bubbles in the electrolyte flow even when machining current is turned off.

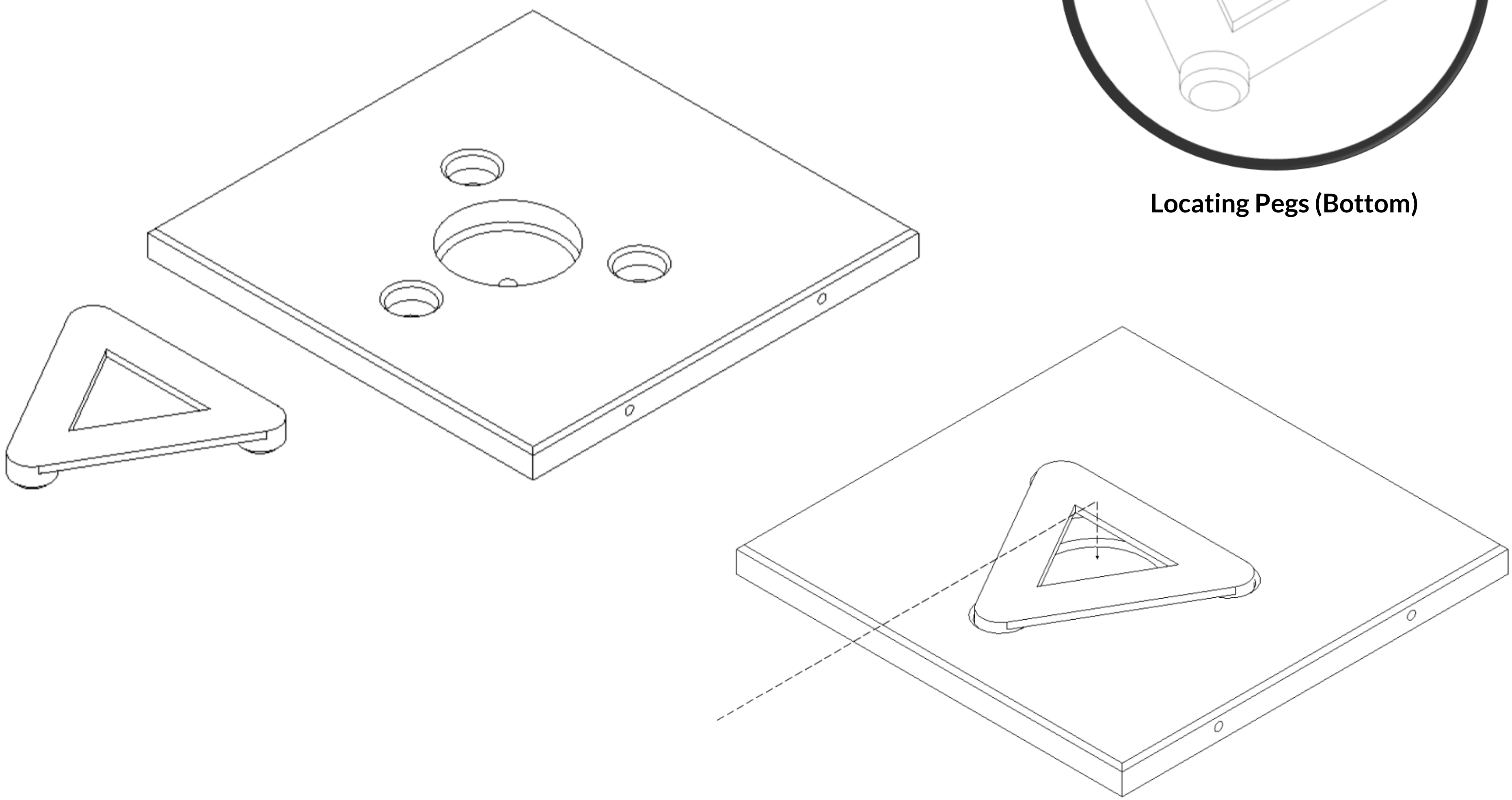
Operating Instructions

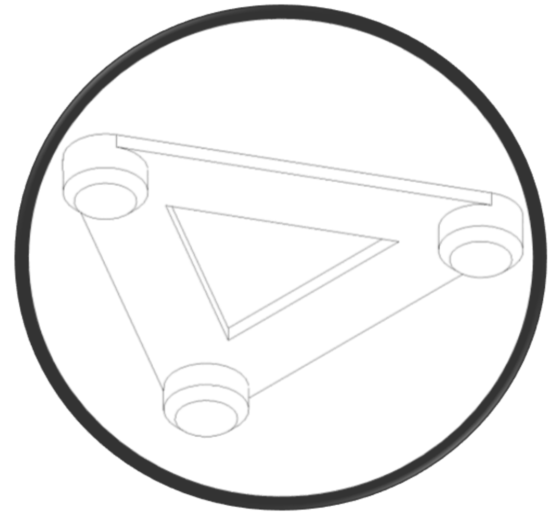
Attach Electrode





Attach Workpiece





Locating Pegs (Bottom)

Prime with Electrolyte

Double check all the fluid hoses and connections to pumps.
Add Electrolyte to the lower compartment.
Make sure Splash Plates are in place in upper and lower compartments.

Position Electrode

To position Electrode automatically, enter the Probe command (“10”) in the Serial Monitor of the Arduino IDE. The Electrode will advance down until it touches the Workpiece and then back off a few steps. The Probe command will be automatically turned off. The tool is now in a very close position to the Workpiece. During a Probe, the Probe can be turned off manually at any time (“11”).

Instead of using Probe, the Electrode can also be positioned by jogging in Manual mode. Using the Control Panel, set the AUTO switch to down position to place machine to Manual mode. Set DIR switch to down position to Jog downwards. By repeatedly pressing the JOG button, slowly jog the Electrode down-- close to but not touching the workpiece. Speed of jog is controlled by the JOG SPEED knob on the Panel.

Start the Cut

Enter a number greater than 100 for AutoDescentDelay (the time between downward steps of the Lifter). The default AutoDescentDelay is 5000 milliseconds. Enter “1” to turn on Electrode current in software.

On the Control Panel, turn On the PUMP switch and make sure both pumps are running and that fluid is flowing through the Electrode nozzle properly and that no leaks of fluid are occurring from the hoses or connections to both pumps. Turn on the ELEC switch, to turn on Electrode current in hardware. Set AUTO switch upward to On. The cut will now proceed downwards automatically at the rate determined by AutoDescentDelay.

Monitor the Cut

With the cut underway, the Electrode current can be monitored by periodically entering “8” into the Serial Monitor. Generally, the current should read a relatively stable number in milliamps which will be initially shown by entering “8” at the start of the cut. The current may increase gradually as the cut progresses, as the Electrode is being moved closer to the Workpiece as the Lifter descends. However, if the current jumps up unexpectedly, this usually indicates some degree of direct contact between the Electrode and the

Workpiece, without a gap for the fluid to flow. The software can be adjusted to a Current Limit that will automatically stop the cut as well as signal the buzzer alarm when limit is exceeded. The default Current Limit is rather large at 9000 milliamps but can be reprogrammed to a smaller value if desired. To prevent a Current Limit event from happening again, one should increase the value of the Auto Descent Delay. Conversely, if the current begins to drop, the descent delay may be too long. This will not cause a failure but will decrease accuracy of cuts.

Continue the cut until the desired result has been achieved.

Final Thoughts

Three Basic Facts About ECM

1. The *rate* at which metal is removed depends on the Electrode current. For a given Electrolyte solution and a given distance of the Electrode from the Workpiece, a higher voltage will push through more current, increasing the rate of the cut.
2. The *extent* to which the metal is removed depends on the voltage of the Electrode current. A higher voltage will extend the cutting action further away from the Electrode. This may be desirable or not, depending on the application.
3. The *time* which the Electrode spends in one spot will affect the depth and lateral extent of the cut. One should be able to achieve finer cuts by moving the Electrode more quickly, or wider cuts by moving it more slowly.

Higher salt concentration should increase the current carrying capability of the Electrolyte and so increase the speed of the cut. But up to what point?

Addition to electrolyte solution of hydrogen donors such as acids may improve the performance of the Electrolyte.
When the metal atoms are removed from the Workpiece, they go into the Electrolyte. If Electrolyte contains an anion that results in a soluble compound with the metal atoms, then the filter should not fill up as rapidly and more importantly flow through the Electrode may also be improved. Acetic acid is a simple acid to add. Stronger acids, such as HCl acid, may also be worth investigating (carefully!).

Higher voltages, greater than the 12V maximum of the ATX power supply, may also produce faster or deeper cuts. Note that the upper voltage limit of the Current Sensor is 36V. Pulsing, i.e. using an ElectrodeDutyCycle less than 100%, may allow for more precise cuts, particularly if lower voltages and electrolyte concentrations are used.

Electrode design is another and far reaching way in which home scale ECM can be improved. By combining the power of the 3D printer with the ECM One machine, it should be possible to invent and make novel and amazing Electrodes. These can be easily attached to the ECM One and performance characteristics can be measured. The Electrode shipped with the machine is an insulated brass tube. For more information about this Electrode, go to our Keybase team.

Home Scale ECM Is in Its Infancy.

While this process may take longer than classic physical machining, the avenues for development are many. Our aim is to open the doors of improvement. Hundreds of bright minds and engineers-to-be who might never have had access to this process can now participate in the Industrial Distribution like never before. Not only can makers of all stripes print high quality and dimensionally accurate models in engineering polymers, they will now have access to a standardized research and basic machining platform for working with aluminum and harder metals such as steel and other engineering grade alloys. As the community enlarges its library of electrodes and refines the home ECM process to gain better precision and speed, home-grown mass manufacture will become a reality. Complex injection molding and extrusion dies will be just another thing to make in your garage or dorm room. Extremely hard or complex, wear resistant components will be within reach. The barrier to entry to manufacturing anything from prototypes to thousands of units of an item will drop drastically. The world will continue its march forward through the Industrial Distribution.

Still, these things take time. The ECM One is just the first step on a long road and there is much room to grow. The only way this project will be able to meet the needs of the coming paradigm of manufacturing will be if there is a strong and dedicated community willing to support each other. This machine has taken quite some effort and is our contribution to the community thus far. We hope you like it, and we cannot wait to see what you will come up with.

Cooper Zurad　　　　Michael R. Treat