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Please see the section titled "Safety Protocol".

S-EDM Version 1.0 by B.J. Rao
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To Handan, for being so technical

Introduction

Spark Erosion, or more commonly known as Electrical Discharge Machining (EDM), is a special type of machining technique. It's essentially based on repetitive electrical spark discharges, which lead to localized erosion of a work piece. The tool, which delivers the discharges, erodes into the work piece. It sinks itself in, and its reciprocal profile is thereby formed into the material. Hence, the term Sink EDM.

EDM has gone through an extensive amount of development. It has proved to be a very useful machining technique and its presence in the modern workshop has become more or less mandatory.

The EDM process is not a high speed machining process. Yet it carries other attributes like high precision and the ability to work materials that are too hard or brittle to form using conventional mechanical techniques. It allows the machinist to create highly complex intricate precision parts, which could sometimes not be produced efficiently by other means or not at all.

This manual describes the building of a DeskTop Sized Sink EDM unit. It's a simplified version of its SEDM industrial counterpart. The unit is a single axis 300-watt computer controlled system, which uses the PC's parallel port as the communications channel. It can cut through just about any electrically conductive material irrespective of material hardness. Its use may be for simply removing broken taps out of a work piece but it can also create small profiles like square shaped holes or even more intricate designs.

The unit has been designed in such a way that lathe/mill work is not required. Anybody with basic home shop machinery and tools, and naturally some electrical/mechanical know-how, can create their own home made Sink EDM setup. Provided that certain materials can be purchased pre-sawed, to the required dimensions, the main manufacturing task is drilling holes. A good drill press is the only real machine needed to complete the unit.

Software code is also included in this publication. It's "test" software or testware. This will control the unit and allow it to perform all the necessary basic functions. Explanations are provided, which permit a basic insight into the workings of computer controlled machinery.

The chosen design concept is based on various criteria. Every aspect possible from the design to the assembly has been stepped down to the most basic and cost effective level. This while allowing the unit to still incorporate the precision and durability to create a well performing and useful system. Naturally some builders may, for their own reasons, choose other ways to build the unit or make modifications to the design and workings for their own purpose. Yet the unit described here has proved its design in practice. Hopefully builders will construct it first before attempting any major modifications of their own. Every effort has been taken to choose a design plan that incorporates common and available components. However this may not be the case everywhere. Modifications may therefore still be necessary. Use the design (then) as a guideline. Yet try and keep the modifications as limited as possible. The explanations of the operation of the process and the unit will hopefully allow the builder to understand what is and what is not possible.

The building of the unit requires some skill. Yet those who are acquainted with basic machining should have no problem here. Naturally, time, attention and patience to manufacture and assemble the unit are required. The explanations and drawings should first be looked over thoroughly before starting. Working precisely and systematically will ensure that unnecessary obstacles and errors are avoided. A properly working unit will then become the result of the labor invested.

An important aspect, that demands attention, is safety. Every attempt has been carried out to integrate this in the manual explanations. EDMing can be very dangerous and even fatal when used incorrectly. Liquids, electricity, flammable substances and sparking can be a lethal combination. Be alert!

CNC machining is becoming more and more wide spread for the home shop as information and components become more accessible and less expensive. This allows the home machinist to adapt new technology into his or her workshop. More easily can ideas now be translated into tangible, functional products or even artwork. Hence, the recent introduction of PC controlled EDM into the home shop is not that surprising. Yet there are several other machining processes, some known and some less known, that the home machinist can incorporate. Hopefully this publication will serve as the stepping stone as the first of many more Proved by Practice Publications. Your purchase of this manual, and the building of this unit, will invite the incentive to carry on and provide more publications. Publications that regard relatively inexpensive and easy to build yet versatile machining units for your home shop.

If you have any questions, suggestions or comments regarding this publication please write to:

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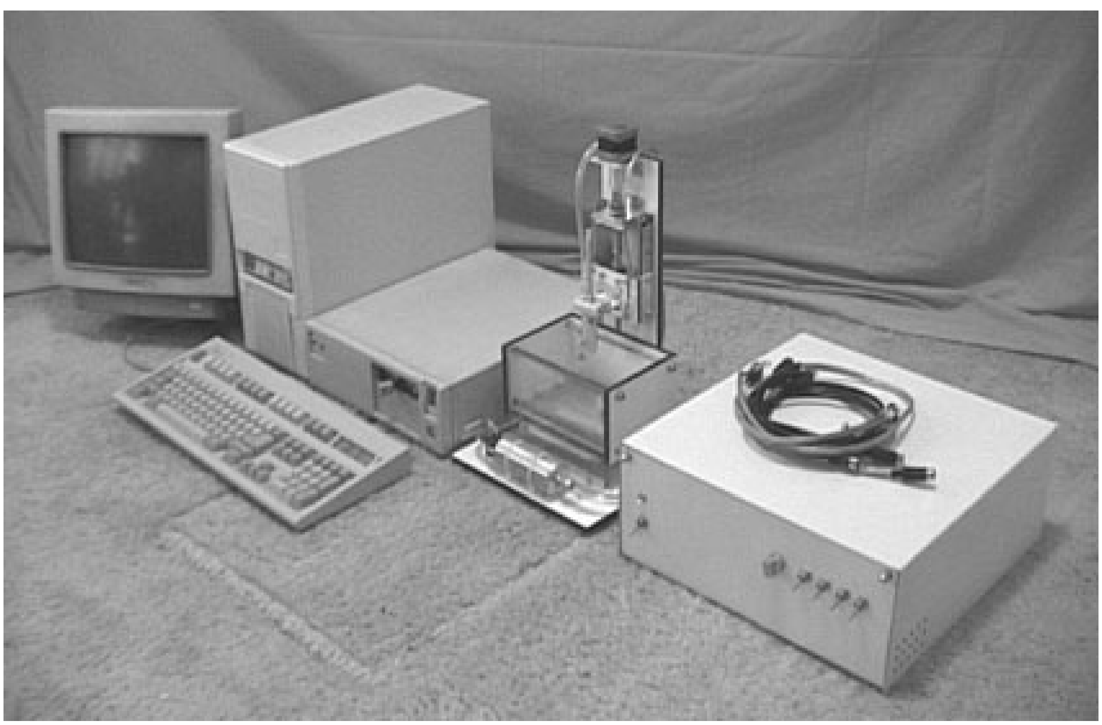
Your feedback will provide you and future builders of a better publication package.

B.J.Rao Amsterdam 2000

Acknowledgment

This manual was created with the assistance of several contributors. A special thanks goes out to the following people and companies:

Mr. Fred Buijs, RNC Vrije Universiteit
Mr. Wolter Kragt, ICN
Mr. H. Bakker, MTS Amsterdam
Dan Mauch at Camtronics Inc.
Carken Co.
Hakan
Vijay Rao
Lazlo Kleczewski



The complete S-EDM setup

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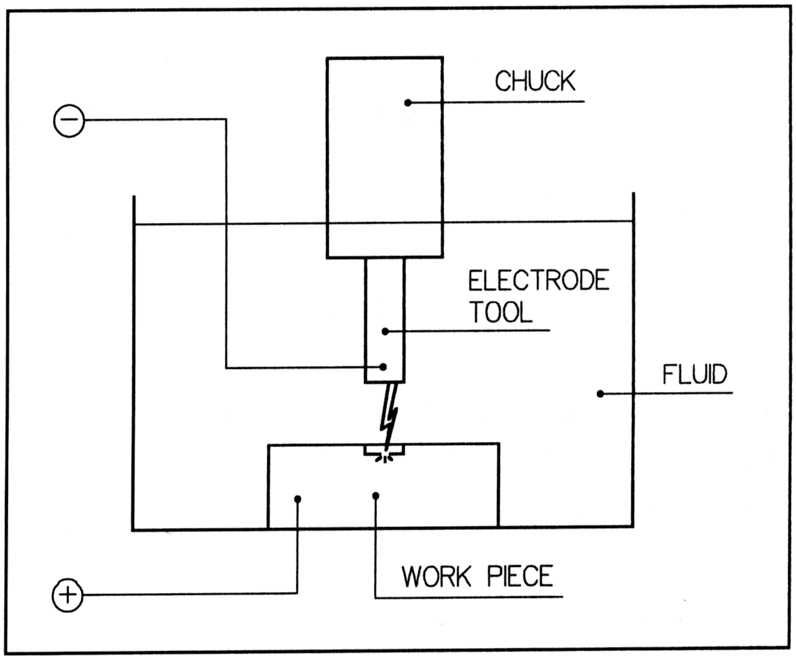


Fig.1. The S-EDM setup

1. The EDM Process

The EDM process is based on the repetitive sparking between two electrically conducting surfaces namely the tool and the work piece. The sparking erodes the work piece. It, in a manner of speaking, chips pieces away in very specific areas thereby machining it electrically into a new form

1.1 The Machining Basics

Short circuiting an electrical power source, by connecting its terminals together, via wires, will at the point of contact cause a spark to jump the gap. An inspection of the surface of the sparked points will reveal that some of the material has been melted away. The spark has eroded a minute fragment of the material and left a small cavity.

Instead of wires, a metal plate (work piece) and a small diameter metal rod (electrode tool) can be used. The two are positioned closely adjacent to one another and placed in an electrical circuit. Bringing them closer together in a controlled fashion will at a certain distance cause a spark to jump the gap. This will result in the electrically induced erosion of the materials. Repeating the sparking over and over will cause the rod to slowly erode itself into the metal plate. The rod surface may be many times greater than the diameter of the spark. Yet evenly distributed spark erosion will occur over the work piece. This is due to the fact that only the areas closest, between the electrode and the work piece, will more or less induce spark over. Hence, the reciprocal profile of the rod will be eroded into the work piece. This is the basis of the EDM process.

A closer inspection of sparked surfaces may sometimes reveal that the cathode end (negatively charged part) displays less erosion than the anode (positive) end. For this reason the cathode is generally chosen as the tool (which is usually referred to as the electrode) in the EDM process.

A more detailed illustration of the EDM process can be explained as follows: The electrical tension between the adjacent electrode and work piece is at a maximum value before the spark exists. When these two surfaces are brought sufficiently close together the electrical tension will cause the substance in between, for instance air, to breakdown, electrically. The air becomes ionized creating an electrical path for the current from the EDM power supply circuit to flow through. The effect is displayed as a spark, which jumps the gap. The current is made up of mobile charged

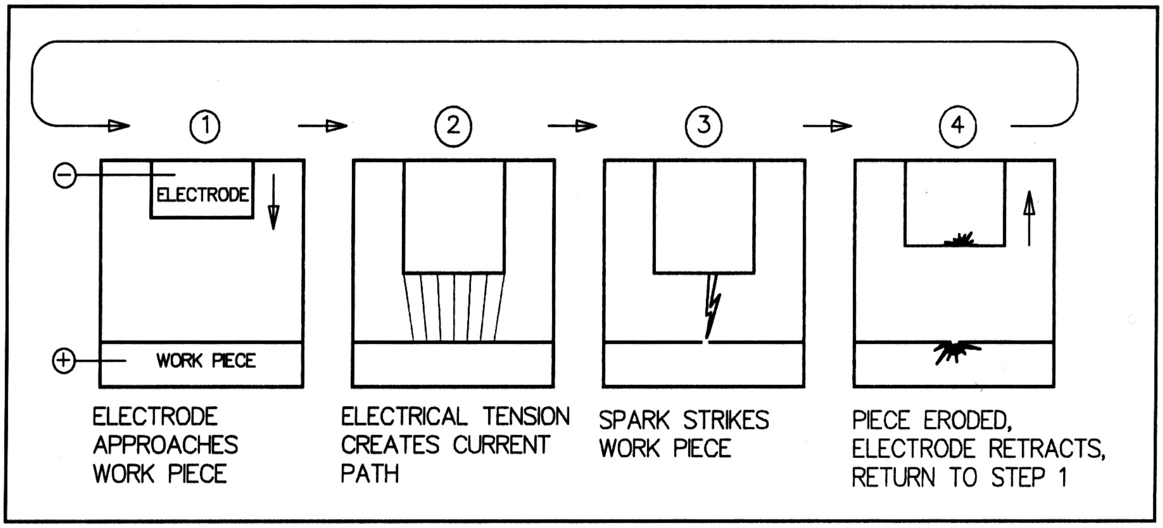


Fig.2. The EDM cycle

particles, electrons. The electrons will travel from the cathode to the anode. This is because these particles are negatively charged and are attracted by the positively charged anode. The avalanche of electrons hit the anode surface very violently, generating enormous heat due to the mechanical impact of the electron bombardment. This is why the anode wears somewhat faster than the cathode. The temperatures generated can reach levels of 6000-10000 degrees Celsius at the impact zone. This area is melted away, even partly evaporated, leaving a minute crater as the end result.

1.2 Spark Discharge Circuit

Creating the spark is achieved through an electrical discharge circuit. This can be based on an inductive or a capacitive circuit or a combination of the two. An inductive discharge circuit could be devised and would resemble that of a car ignition system. Yet it would operate at much greater current discharge values.

Capacitive discharge circuits are greatly used for EDMing. Capacitors offer simplicity and ruggedness and can release their electrostatic charge acutely. The immense power with which a capacitor can release its stored energy is similar to hitting an object with a spring-loaded hammer. This is better explained by representing the capacitor with a spring. When a spring is compressed and held in this state it has stored the energy used to compress it. Charging a capacitor is the same, only it stores electrical energy. If the spring is allowed to acutely unwind (the capacitor discharges) it will instantly release its energy at a very high power level. This high power level is achieved simply because the release time (or discharge time for capacitor) is so short. If any resistance is encountered it will lengthen the time to release the stored energy. This will lead to the reduction of the power produced. Since the EDM unit described in this manual allows almost zero resistance discharges (practically short-circuited), the power level is consequentially high. The end result is that the sparking is like having many small spring-loaded hammers slamming on the work piece, chipping pieces away bit by bit.

A basic capacitor discharge circuit would be comprised of the following:
- DC power source
- Capacitor
- Anode terminal (work piece)
- Cathode terminal (electrode)

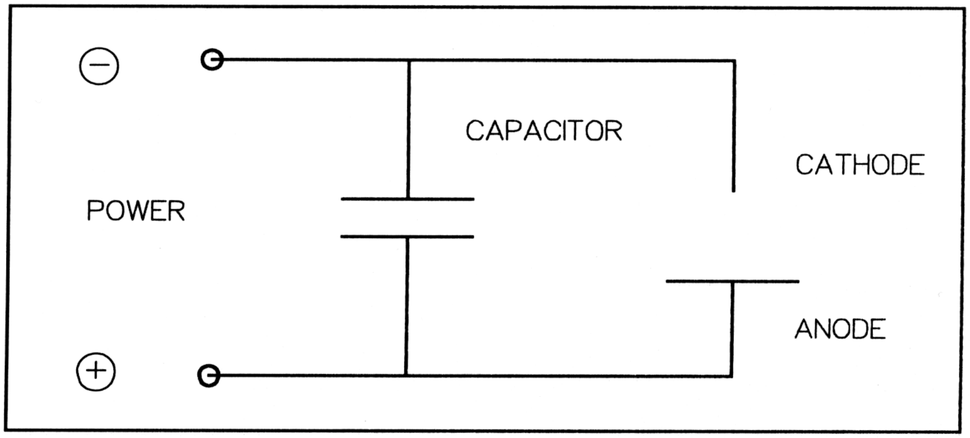


Fig.3. Schematic of capacitor discharge circuit

The capacitor and anode/cathode gap are placed in parallel to the DC power source. The anode/cathode gap is in the “normally open” position. When the power source is activated the capacitor is almost instantly charged up. Closing the anode/cathode gap (bringing the electrode and work piece together) would allow a spark to jump the gap, depleting the capacitor of its charge. Opening the gap would allow the capacitor to charge up again. The sparking can then be repeated again in the same fashion.

1.3 Spark Gap

The spark gap refers to the space between the electrode and the work piece. It is necessary that this gap be maintained throughout the erosion operation. If the electrode makes contact with the work piece it will constitute a short circuit and the process is halted. In most cases the electrode will then have weakly welded itself to the work piece.

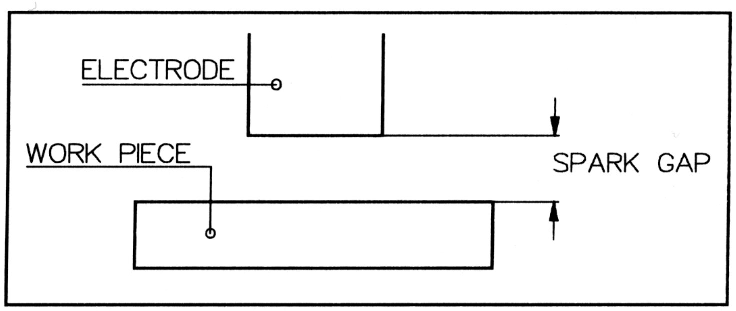
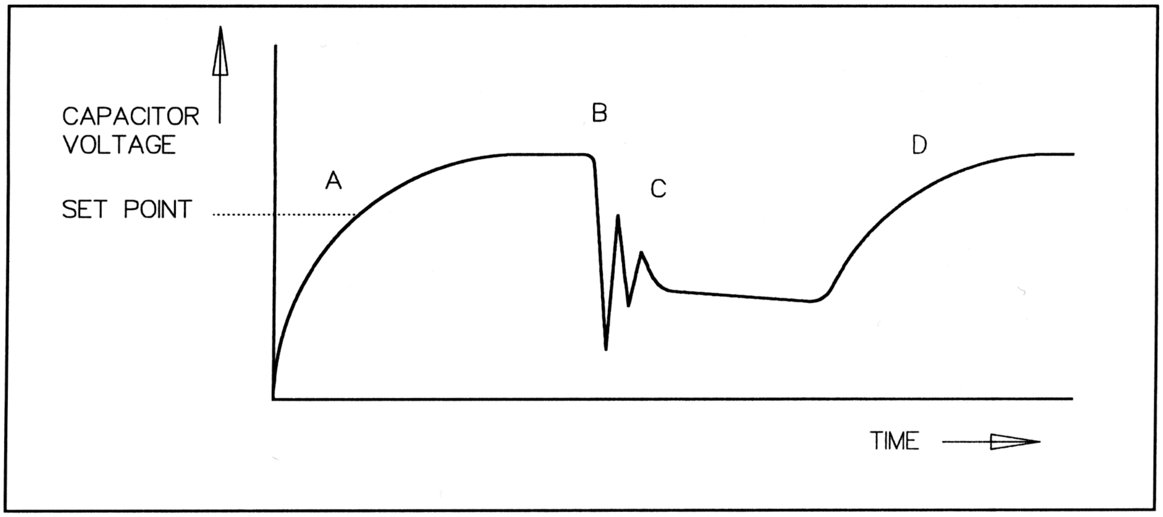


Fig.4. Spark-gap

The spark-gap distance is maintained by a feedback circuit. This circuit determines the state of the process over a certain parameter reference (this state is usually represented by the level of voltage over the EDM circuit capacitor). When the voltage is above the set reference point, the feedback circuit sends a signal to the PC and the motor feed is initiated. The electrode moves closer towards the work piece. As soon as sparks strike the work piece the capacitor voltage will recede to under the set point. The feedback circuit immediately cancels the signal to the PC and the motor feed is "paused". The spark gap increases as sparks slowly erode into the work piece surface. At one point the gap becomes too great for the sparks to strike. The capacitor has a chance to fully recharge. The Feed is then resumed as soon as the capacitor voltage is above the set reference point.



A. Capacitor voltage is above set value, electrode moves towards work piece.
B. Electrode sparks work piece. Electrode feed is paused. Capacitor voltage recedes.
C. Gap becomes too big for strikes to continue due to erosion of work piece. Sparking stops.
D. Capacitor recharges and electrode feed is resumed as soon as the voltage again goes above set point.

Fig.5 EDM capacitor duty plot

1.4 The Electrode

Like any tool, the EDM electrode will start to wear the more its used. In comparison to normal cutting tools the electrode wear can be very significant. As previously explained, the electrode (cathode) is the source of the discharge. The electrons are emitted from it and strike the work piece (anode). Although the work piece receives the greatest amount of mechanical/thermal punishment, the electrode is being attacked as well. The electrode profile will be reduced because of this. Sharp corners, for instance, will quickly become blunt.

Decreasing the amount of electrode wear can in part be achieved by using appropriate electrode materials. Relatively soft, low electrical resistance materials with high melting temperature appear to work best for most EDM applications. A soft material won't break away as easy as a hard material. The low resistance minimizes the amount of heat produced by the conducted electrical current. The high melting point of the material allows it to better withstand the thermal punishment. In other words, it has better wear resistance.

Copper and its alloys are most frequently used for the EDM electrode. It's not always the best material but it scores "good" for most jobs. Copper is not that hard to work nor that expensive in the amounts required. It's also sold in many different profiles. However the type of material best suited is dependent on the application. Graphite electrodes can be used for high removal rates in which heavy electrode wear is tolerated. This can be for pre-working a desired profile. Graphite has a very high melting point. On the other hand for low removal rates where high precision is required, certain copper tungsten alloys may be best suited. These offer the best wear resistance.

1.5 The dielectric

Choosing the correct electrode material alone won't retard its wear enough. In addition the discharges may start to arc instead of spark, creating more of a messy oxidized melt of the electrode and work piece than a clean cut. Some other technique must be applied to reduce these adverse effects. This is most effectively achieved by using a fluid to cool the electrode. The electrode and work piece are submersed in a fluid or this is administered in the sparking zone.

Having the process perform in a liquid environment presents other benefits as well. One aspect is that the liquid serves as a flushing/rinsing agent. This by immediately carrying away eroded fragments from the strike zone, which would otherwise contaminate the workings of the process. Another aspect is that the liquid acutely cools the melted metal surface of the work piece thereby inducing a thermal shock. Micro cracks in the material are created by the shock and can cause fragments of the material to break away. Hence, the thermal shock assists the erosion process and promotes a clean-cut surface.

However not all liquids will suffice for the EDM application. The conventional EDM process is not an electrochemical erosion process based on electrolysis. What this means is that material is removed through localized spark discharges and not by the electrolytic break down of the work piece. The electrolysis process would eat up all the surface of the work piece (corrosion) and any other metal in the EDM circuit that is submersed in the liquid. It's the reverse of electroplating. To prevent this effect the fluid must poses sufficient electrical insulation. The level of insulation is usually expressed as the dielectric value. High dielectric value equals out to high electrical insulation.

When the fluid possesses a high enough dielectric value the capacitors are allowed to charge up more easily. This is because the current path from the electrode to the work piece now takes more effort to be created. As a capacitor charge rises so does the voltage over it. At a certain value the electrical tension (voltage) will break down the insulation of the fluid. The end result is a spark discharge. When the dielectric value is to low the voltage over the capacitors will pre-maturely break down the fluid, electrically. This will create the current path too early. Little or no sparking will occur since the capacitor does not have the chance to fully charge up.

There are several fluids on the market that are suited and even specially designed for EDMing. Most of these fluids are hydrocarbon based. Some are in fact no more than low viscosity oils originally intended for lubrication of precision mechanisms. Apart from the fact that they are reasonably flammable, and most always corrosive, they can be quite toxic. Their use requires strict handling precautions (see Safety Protocol).

In an attempt to try and avoid having to use commercial EDM fluids (which can also be costly) an investigation was carried out to find substitutes. Many different fluids were investigated, from anti-freeze to brake fluid to distilled water (under certain conditions water can be used). But the fluid that scored, on average, the "best" regarding its safety, cost and effectiveness was none other than house hold vegetable oil. The next best was lamp oil. The ignition temperature of vegetable oil is relatively high, it's non-toxic and inexpensive. Obviously it's not the best but it will perform well enough for most jobs. Its foremost shortcoming is that it is not very thin (low viscosity). Hence, its wetting properties are not that good. The importance of this property is noticed when the surface of an EDM eroded work piece is inspected. The surface has somewhat of a bumpy melted appearance. This due to the oil not being able to sufficiently wet the area being eroded. Also, vegetable oil makes the work place smell like fried chicken.

Vegetable oil is not easily ignited. Despite this, it is required, by established norm, that the sparking must occur at least 40mm under the surface of any oil used for EDMing. This to lower the chances of the oil being ignited (see Safety Protocol). Lamp oil is less thick in comparison to vegetable oil. It will perform better than vegetable oil but requires stricter handling as it is more easily ignited.

1.6 The Work Piece

What types of work piece material can be used in an EDM process? Obviously the work piece must be electrically conductive. Besides metals, there are some technical ceramic materials that meet this requirement as well, like (Silicon Carbide) SiC. Naturally some materials are better suited for EDMing than others. This depends on several factors. The choice of electrode material also has bearing on the EDM capability of a certain work piece material. For instance, a steel work piece using a copper electrode gives good results.

2. EDM Background and Applications

The erosive nature of electrical discharges of high current between two terminals (cathode and anode) had been demonstrated many years ago. Benjamin Franklin was probably the first to document this. Years later it became a well know phenomena considered, by most, to have an impairing effect on the workings of electrical contacts and switches. That was until about the 30's when this phenomena was applied to machine materials.

Several manufactures now produce high precision machines that can make very fine cuts with precision in the micrometer range. Units can cost many thousands of Dollars and incorporate multiple axis computer control with just about any feature applicable. EDM is most frequently applied towards the manufacturing of dies for producing injection-molded products. It is also applied for the fabrication of profiles that could not be produced by other means. For instance cooling holes in turbine engine blades. The holes can be thinner than a pin and run as long as the length of the blade. There are also micro-EDM process machines for Micro Systems Technology. These machines combine EDM with lithography techniques (similar to chip manufacturing). The technique allows the production of highly intricate and accurate EDM electrodes at the micron size level.

There are also other types of EDM processes like, Wire EDM and EDM milling. Wire EDM uses a metal wire, which functions as the electrode to cut very precise profiles in a work piece. EDM milling is similar to conventional milling only the cutting process is based on EDM.

3. Previous Setups

The Sink EDM unit design described in this publication came about after several previous setup's had been built and tested. Development started at ground zero.

Initial EDM units were made using a small transformer with rectified DC output. The output was connected over a capacitor bank. By taping the electrode on the surface of a work piece the circuit would be closed and sparks would be created, thereby eroding the surface. Each time the electrode was pulled up the circuit was opened permitting the capacitor to recharge. Using this setup, inscriptions could be made. But its cumbersome workings and limited performance left much to be desired.

One of the first high power units built used an old electroplating transformer as the EDM power supply. The transformer was rated at 1000 watts. Its rectified pulsating output could supply in excess of 100 Amperes. This was an inductive system. A small diameter copper tube served as the electrode. The electrode was made to tap up and down with a stroke of about 3mm at around 200 RPM. This was realized using a simple self-made crank mechanism, which was driven by a variable speed power drill. Each time the electrode made contact with the work piece a current would flow through, heating the contact point. The electrode would then be retracted by the crank mechanism and sparks would fly. When an inductive system breaks contact the self-inductance wants to counter act the break in supply current. The result is high electrical tension, which produces a spark between the break point (just like an engine ignition system). The spark blasts the heated material away and eventually erodes a path for the electrode to sink in. To extinguish the spark and prevent arcs from forming, water was pumped at a high rate through the electrode. This also cooled the electrode and flushed the eroded material away. The water was pumped using an old washing machine pump in a closed circuit filtered system.

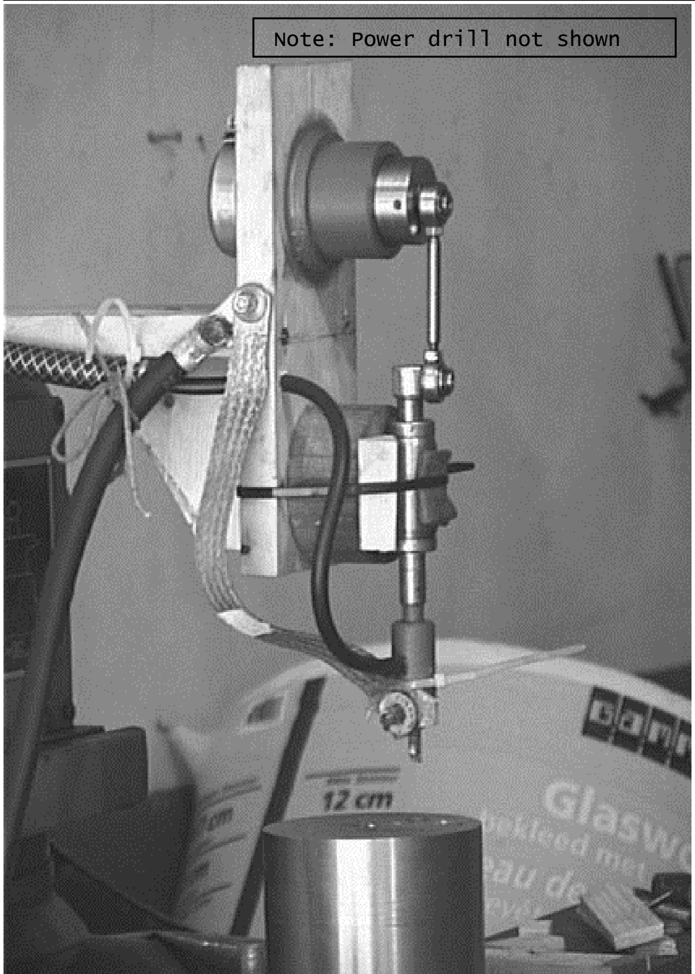


Fig.6. Experimental EDM unit

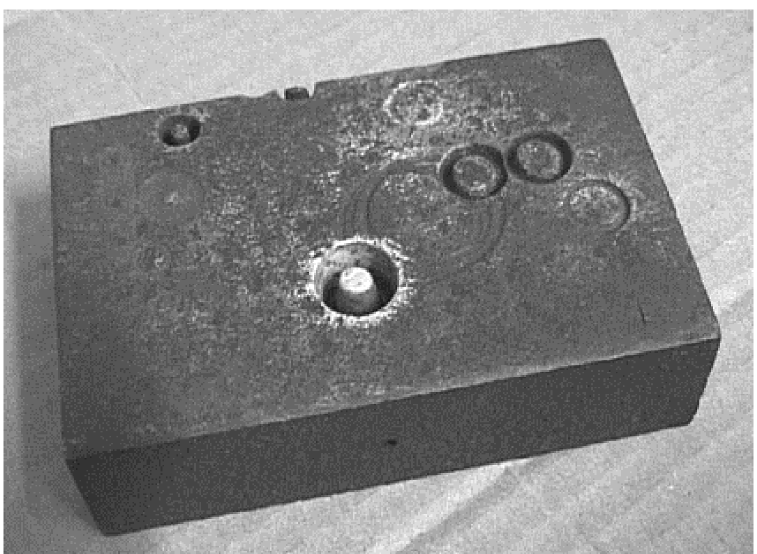


Fig.7. Test piece

The unit was adapted to an old machine with a manual feed z-axis to move the electrode in a controlled fashion. Due to the high current, the electrode would quickly work its way through the work piece (the surface had a sand blasted appearance). However the system would overheat just as fast. The electrical spikes in the circuit where probably also polluting the mains. To remedy this, some current limiting electrical load would have to be placed within the circuit. Light bulbs proved adequate. They can dissipate the generated short circuit heat and also act as progressive current limiters.

Other tests where made using this setup. Eventually this led to the creation of the more docile Sink EDM prototype described in this manual. This also led to the creation of a Wire EDM setup. A manual from Proved by Practice Publications for a 2 axis CNC Wire EDM setup will be appearing in the very near future.

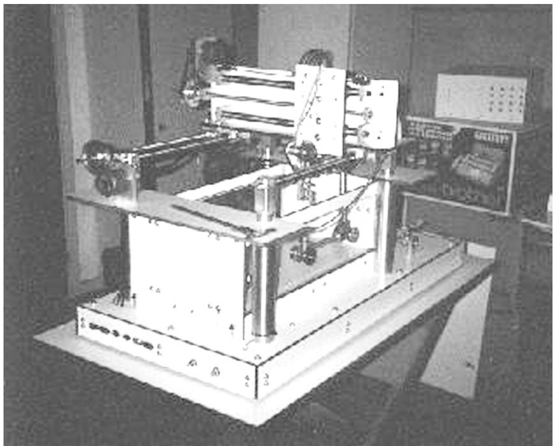


Fig.8. The W-EDM unit

4. The Sink EDM Setup

The Sink EDM design concept described in this manual is a PC controlled single axis system. It uses the parallel port to send instructions to the unit and receive data. The entire setup is comprised of 3 main systems, namely:

1. The mechanical unit
2. The electrical units
3. The testware

The total cost of the unit depends on where components are purchased. It will become evident that the largest portion of the cost is due to the required components and not the materials. In other words changing the design and limiting the use of construction materials would only reduce cost marginally, if at all. It would also probably lead to lower precision and less flexibility of the unit.

This manual is Metric system orientated as it is directed towards an international market. Most countries employ this system. In addition countries that don’t are more or less familiar with it. The following applies:

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Millimeters * (1/25.4) = Inches
Cubic Centimeters * (1/3785.4) = US gallons
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Attention should be given to the lead screw diameter and pitch (DR.5, part 3C). The diameter should, preferably, allow a snug fit within the inner diameter of the bearings that carry it. The pitch of the lead screw determines the resolution of the unit. Lowering the pitch increases resolution and system torque. But this is at the cost of maximum speed. The metric lead screw has a pitch of about 1.25mm, or roughly 0.04 Inches. Choose the closest lead screw pitch that corresponds.

Mains voltage for the components listed in the “Electrical Setup” section are for 220V. For countries that have 110V simply use this value when selecting components. However, output should more or less conform to the values listed. Example, a transformer with 220 in and 60V, 6 Amp. out is required. Find a transformer with a 110 V, or which corresponds with the mains voltage used. It should deliver 60V, 6 Amp.

4.1 The Mechanical Unit

The mechanical unit is largely comprised of composite plate, a small variety of aluminum profiles, basic components and fasteners. The unit has two main assemblies, the "guide way" assembly and the "tank" assembly.

The guide way assembly offers precision travel with a stroke of about 30mm. The travel is realized using a NEMA 17 sized stepper motor to position and control the electrode chuck sled. The motor is directly coupled to a lead screw. The lead screw is carried by two radial ball bearings. These are clamped together over a piece of aluminum corner profile. An offset block is placed in between the bearings to reduce the slant position error of the lead screw. There are 2 nuts placed adjacent to one and other with a spring in between to minimize backlash of the sled. This forces the nuts apart. This is a "passive anti-backlash" set up meaning that backlash is canceled out by manual adjustment. Since the EDM unit will not meet any high speed/load guide way travel it is unlikely that the lead screw will show any significant wear during each operation. Also the lead screw thread pitch is very consistent over a long length. Backlash needs then only to be canceled out by periodic adjustment. The guide way assembly also has home switches to limit travel of the electrode chuck sled.

Another feature of the unit is that the guide way assembly is easily detached from the tank assembly for remote use. The guide way assembly has a bracket attached to the back to allow it to be clamped down for this purpose.

The dielectric tank is an optional assembly. Builders may desire a larger tank for specific applications. The tank described in this manual has a capacity of about 960 cc. The set up includes a closed circuit filtered pumping unit, which delivers high dielectric flow over the sparking zone. This forced flushing induces better process characteristics and separates eroded debris from the sparking zone. Flushing away this debris prevents the process from being contaminated and also allows a faster more accurate cutting of the work piece. The tank also includes a dump valve to easily drain the fluid out when the unit is not in use.

The tank assembly has a universal clamp, which can hold down most work piece shapes. The tank can manage a maximum work piece size of about 75mm by 75mm by 75mm. Depending on the area that needs to be worked and the shape of the work piece, larger dimensions can sometimes be clamped in as well.

4.2 The Electrical Units

The EDM power supply is a capacitive discharge system. The unit can be very dangerous. A charge becomes present in the EDM circuit capacitors when the unit is turned "on". Yet this charge remains present after the unit is turned “off”. The capacitors are still loaded. This charge must immediately be discharged after the unit is turned "off". Use a screwdriver with an insulated handle to short the terminals of the EDM circuit. A loud spark will result. This procedure protects the operator from accidental electric shock due to the capacitor charge. This is especially important when making adjustments to the unit after the unit is turned “off”. Another aspect is that the EDM circuit uses the mains for power. When opening the EDM circuit housing be alert that mains voltages are present. ALWAYS unplug and short the terminals of the unit before opening the housing. Discharge capacity of the EDM circuit can be selected based on 20 different capacitor combinations. Minimum capacitor setting is about 50 mF and maximum setting is around 1000 mfd.

To maintain gap clearance between the electrode and work piece during operation, the unit resorts to a feedback circuit. The circuit is based on a conventional relay circuit with an adjustable set point.

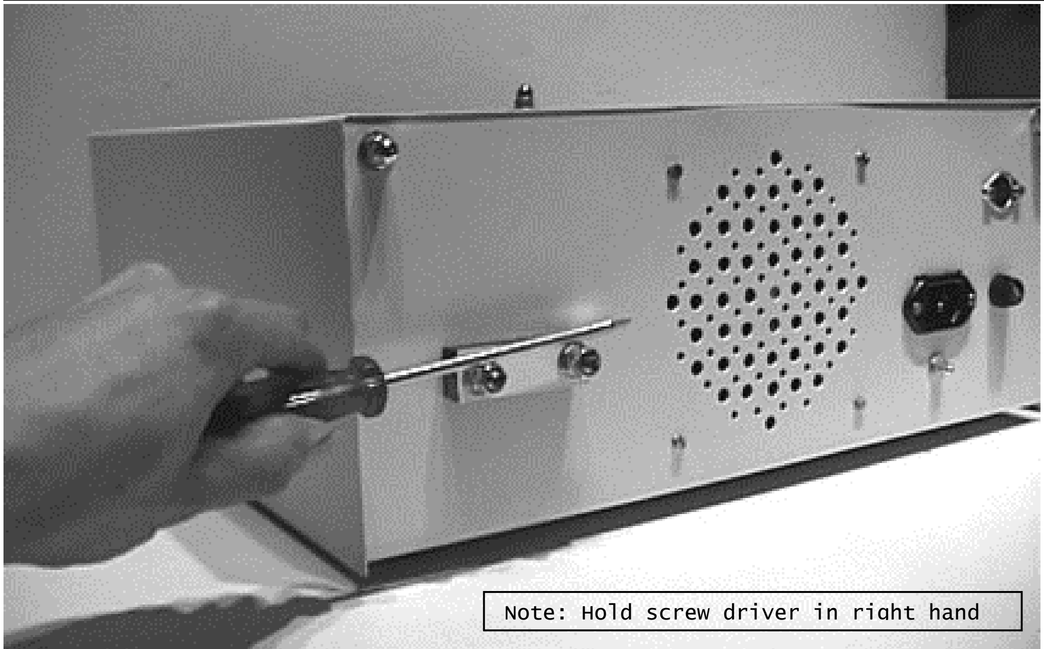

Fig.9. Discharging the EDM circuit

The SEDM unit is designed to use a Camtronics Inc**.** driver for the stepper motor. This is a 2 Amp, 12-volt driver that offers very good performance. It has many features (see Suppliers Section).

The speed control circuit is used for regulating the fluid pump flow. These days speed control circuits are very common. There are a number of companies which sell inexpensive and completed circuits (see suppliers section). Since the pump is not of a specific model, it is necessary to find the best suited control circuit based on the specifications of the acquired pump.

4.3 The Testware

The function of the testware, that accompanies this manual, is to interpret the feedback circuit signal and control the electrode feed accordingly. This by commanding the stepper motor to "pause" and "retract" the electrode a few steps under certain circumstances. The testware also controls parameters such as stepper motor speed, stroke of the sled, the amount of retraction steps and other aspects.

4.4 Tools

Tool	**Remark**
Variable speed drill press	**Drill chuck must accommodate drill sizes up to 12mm. Note: For this project larger sized drills are necessary (especially for the electrical connectors). However some hardware stores provide larger sized drills that have been grounded down on the clamping side to accommodate smaller size chucks.**
Hand-held power drill	**Drill chuck must accommodate sizes up to at least 10mm. Note: this tool is used to complement the drill press.**
Power saw with table	**This is an optional tool for cutting the plate material. Most distributors of the plate material will saw the material to size for you.**

Hand saw	**For cutting metal.**
Band saw	**For cutting metal. This is optional since most parts are small and easily cut using a handsaw.**
Fret saw	**for metal cutting.**
Center punch	
Hammer	
Bench vise	
Drill 2mm	**Metal cutting HSS drills are required. Note: larger drills are required but depend on certain components dimensions.**
Drill 3.2mm (For M4 Thread)	
Drill 6mm	
Drill 8mm	
Drill 10mm	
M4 tapping set for internal thread cutting	**Preferably use the 3 part set, not the single machine tap. Use cutting fluid.**
Allen key set	
Flat screw driver	
Precision calipers	
Band ruler	
Cable insulation remover	
Pliers	
Counter sink drill	
Small course grinding head	**For power drill.**
Paper tape	
Super glue	**cyanoacrylate**
contact glue	**High strength “all purpose” that is water/oil resistant. Note: glue is used to seal off areas in the tank. It must be a bit viscous like syrup. Polyester resin could also be used (harder to work with).**
Wrench set	
Soldering iron	**High power (25W)**
Lead clipper	
Multimeter	
Double sided tape	**High strength**
Course file	
Medium course file	
Solder	**For electronics!**
Scissors	
Phillips screw driver set	
Pin set	
De-greasing agent	**Automotive.**

5. The Electrical Setup

Warning: The EDM power circuit can be very dangerous (see Safety Protocol)

The electrical setup is comprised of 4 different units, namely:

1. EDM power circuit
2. Feedback circuit
3. Stepper motor driver circuit
4. Pump speed controller circuit

These 4 units could be integrated into two separate housings. One for the EDM and feedback circuit and the other for the stepper motor driver and pump speed circuit. Computer casings may suffice best for this. They are already equipped with many of the connectors brackets needed for the unit.

However a housing for the EDM/FB circuit could also be built. An example for constructing a suitable housing is depicted in the drawings. The design is very basic but requires careful attention to construct. A housing could also be constructed using thin metal plates and brackets, which are secured using bolts.

The circuit drawings are largely self-explanatory and should be easy to follow. Yet some explanations are given as to the workings of the circuits and tips to assist in the installation.

5.1 Building Tips

- Try to avoid that the high current EDM lines cross over or are laid in the direct vicinity of other circuitry. This could otherwise induce cross-talk and may cause the circuitry to perform improperly.
- Install passive components like resistors and capacitors first. Active components, like ICs, are the most sensitive and should be installed last. Observe anti-static precautions and use IC sockets. If an IC fails it can then be replaced easily. Try not to touch the pins.
- Whenever possible test component values using a multimeter. This not only determines if the component functions but also if it’s the right one.
- Make sure that capacitor pins, and other polarized components, are fitted correctly. If installed incorrectly they may burn out or even explode. Usually the side of the capacitor will have markings that indicate which pin is the anode.
- Use thick stranded cable (audio speaker cable) for the EDM wiring. Try and keep all cables as short as possible.
- Use a solder iron that has sufficient power to work fast. Use only solder that was specified specifically for electronics use. After soldering clean the circuit using an appropriate PCB cleaner.
- Use cable strap mountings to neatly hold down cables. Work as systematically as possible. After all is done check that lead clippings and other material are not laying around in the housing. This type of debris can cause shorts.
- Check if the main transformer (T1) works by measuring the output voltage with a multimeter. The primary side of a transformer usually has thin coil wire while the secondary side has thick coil wire. Be careful, the primary is connected to the mains.

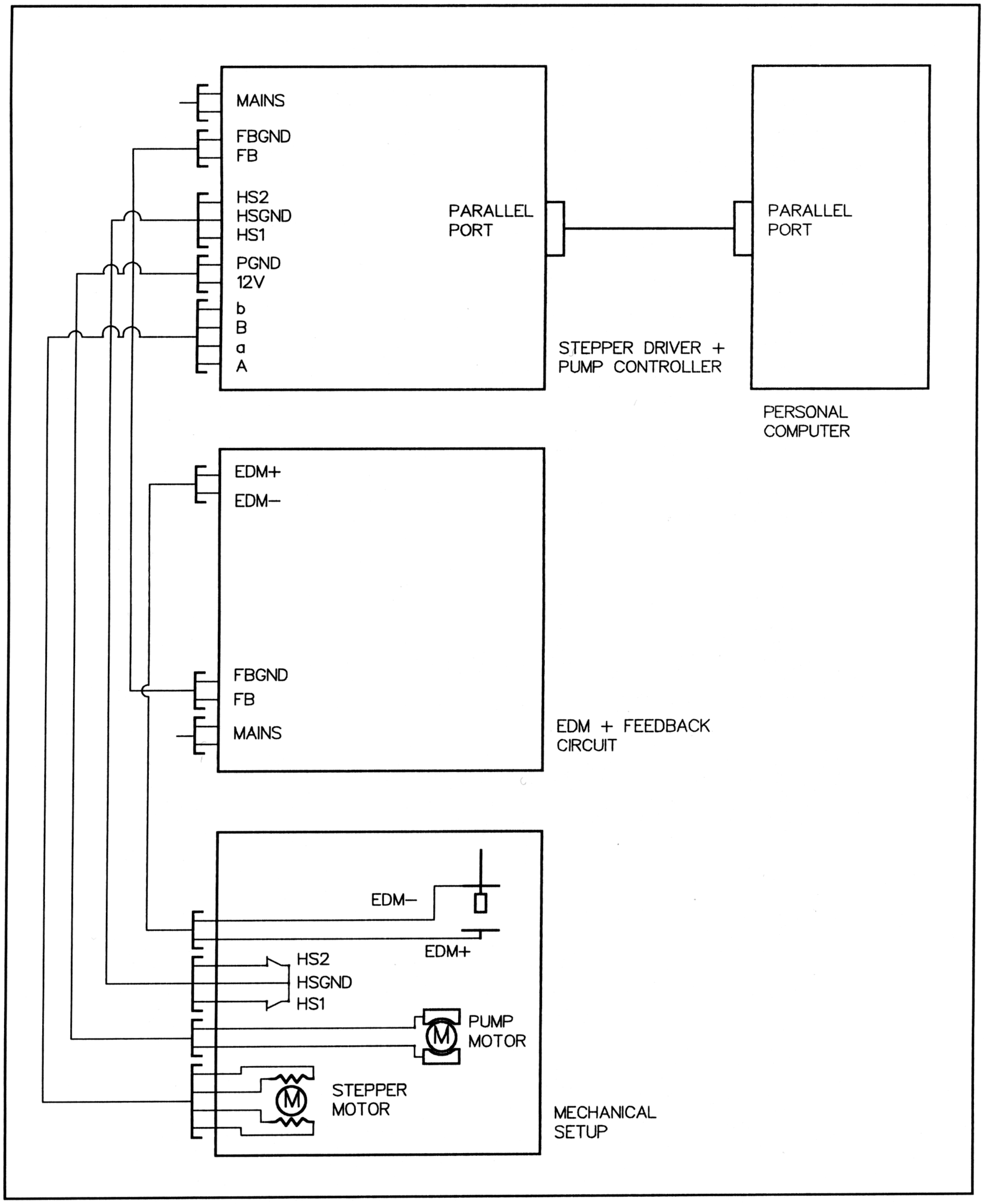

Fig. 10. Global connections

- Bad solder connections on the circuit board and at connectors are most frequently the source of problems. Check using a multimter.

5.1.1 The Housing

The housing depicted in the drawing uses a relatively thick aluminum plate as the base and thin plates, of the same material, function as the panels. The thin plates are folded into form. Since the case is all metal it acts as a heat-sink for the components. To improve cooling performance the top panel has a number of vent holes drilled in the front sides.

The size of the housing can be determined by placing all the components in a desired configuration (drawings give the suggested placement of components).

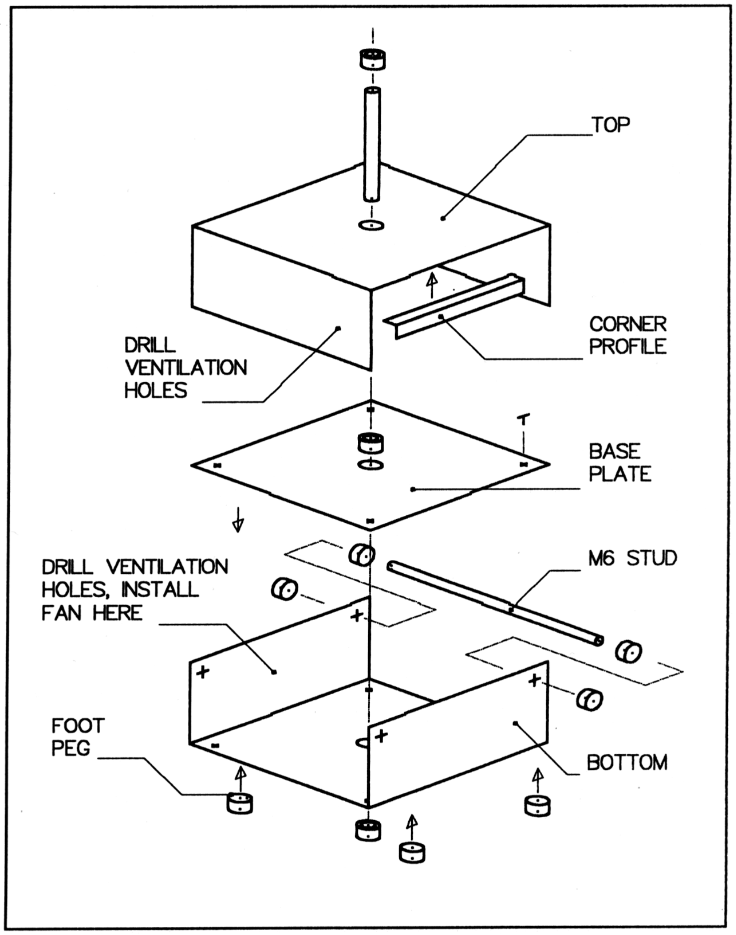

Fig.11. Housing construction

The dimension is then measured and oversized about 15% to allow for placement of wiring, panel switches etc. The housing can only be picked up by holding the front and back underside. Picking it up from the side could bend the top casing.

Bending or folding the thin plate material is the hardest part of making the housing. The initial bend can best be made using a door. Use a piece of scrap to practice. Mark the fold line using a pen. Place the plate between the door and its frame on the hinges side (doors with extra side profiles will not suffice). Line up the fold line with the door corner and slowly close the door. Make sure that the plate does not shift while doing this. The plate will bend a bit. Careful not to pull the door out of its hinges! Remove the plate. Check that the initial fold is along the marked line.

Place the plate on a flat surface and put the thick base plate on it. The base plate should be just in front of the fold line while allowing sufficient clearance to make the bend. While standing on the plate combination place a flat piece of wood on the backside of the panel to pull it back and further bend the panel into shape.

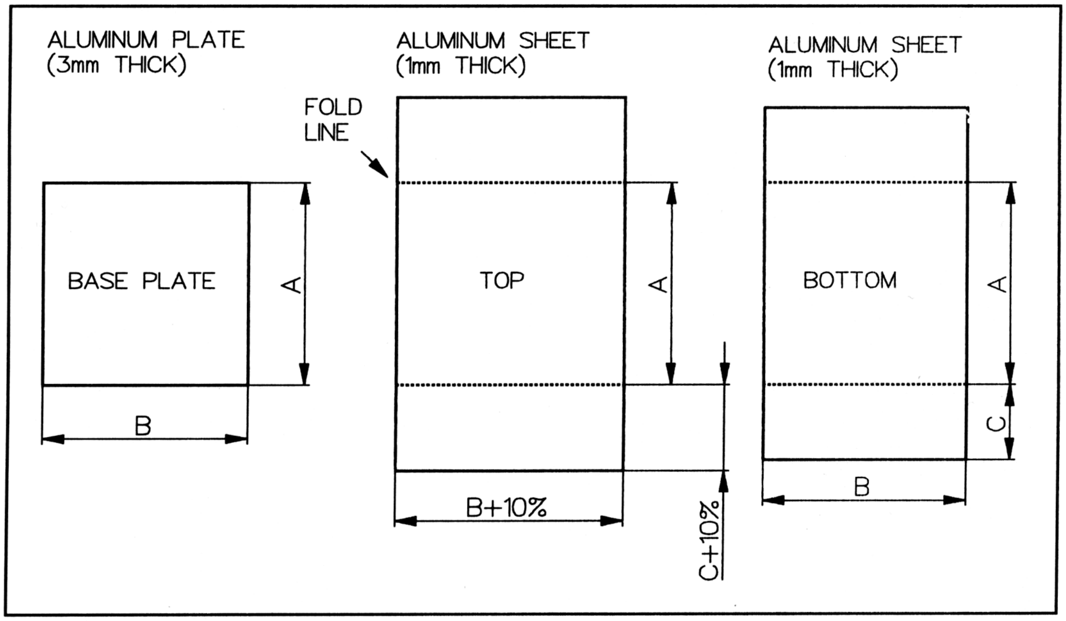

Fig.12. Housing materials

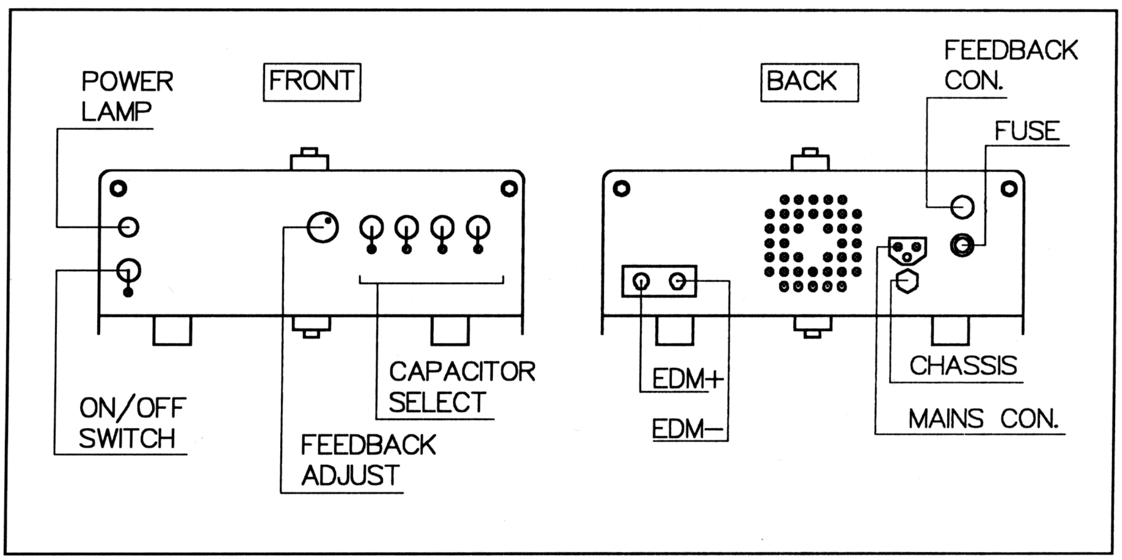

Fig.13. Front/back panels

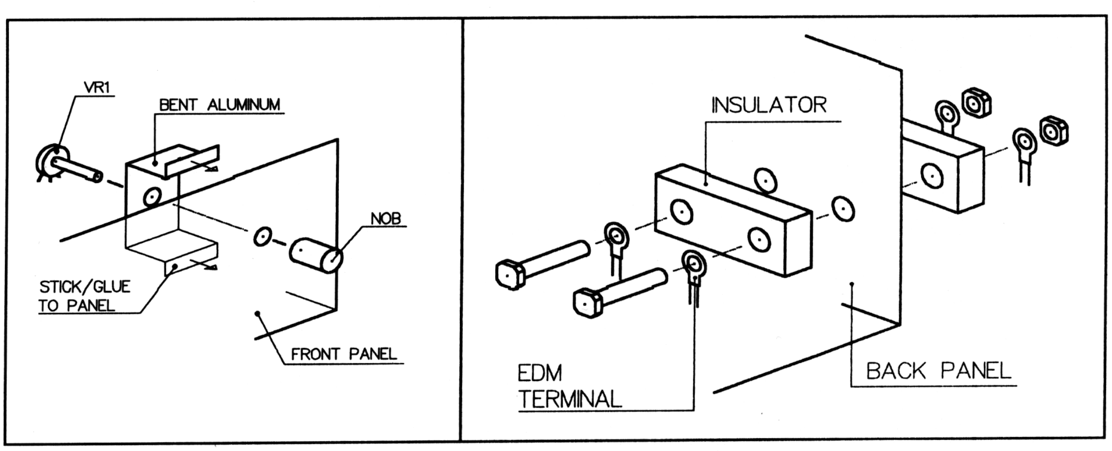

Fig.14. Construction tips

Try not to bend in one single stroke but in several smaller steps. This gives a chance to inspect if the bending is proceeding correctly. Apply pressure towards the middle of the panel backside and as close to the fold line as possible. Check that the panel is not bending in other areas. The material will allow some degree of correction. Drill component holes only after the panels have been bent into shape.

Fig.15. The completed housing

5.2 Calculations

Just like a mechanical assembly the components of the EDM circuit need to be made to fit together correctly, electrically that is. The following elementary calculations show how to do this. They provide ball-park figures. However, the calculations are not necessary to build the circuit. Gathering the listed components and following the schematics of the circuit will allow the completion of the unit just as well. The calculations simply give an insight for builders interested in better understanding how certain aspects of the unit have been designed and work. This can be important when selecting components that do not exactly conform to the component list. In addition, if components fail the cause may be more easily located. And lastly the calculations may be useful when making modifications to the circuit.

5.2.1 The EDM circuit

The EDM power circuit described here is a 300-Watt capacitive discharge circuit. The unit is made up of very common and inexpensive electrical components and will perform most adequately for this project.

Electrical Setup					
EDM Circuit Table 1					
Component	Qty.	Name	Description	Source	Remarks
T1	1	Transformer	40V; 6-8Amp	Electronics	Salvage
T2	1	Transformer	9V; 0.5Amp	Electronics	
C1	1	Capacitor	3000uF; 150V; Elco; Radial	Electronics	
C2	1	Capacitor	50uF; 150V; Elco; Radial	Electronics	
C3	1	Capacitor	100uF; 150V; Elco; Radial	Electronics	
C4	1	Capacitor	200uF; 150V; Elco; Radial	Electronics	

C5	1	Capacitor	300uF; 150V; Elco; Radial	Electronics	
C6	1	Capacitor	500uF; V; Elco; Radial	Electronics	
L1	1	Power Light	Mains voltage	Electronics	
L2	4	Light Bulb	Mains Voltage; 100W	Electronics	
LF	4	Bulb Foot	Bulb Foot for L2	Electronics	Surface Mount
BR1	2	Bridge Rectifier	100V ; 35Amp	Electronics	
F1	1	Fuse + Holder	Mains Voltage; 3 Amp; Fast	Electronics	Chassis Mount
S1	1	Toggle Switch	Mains Voltage; 3Amp	Electronics	Chassis Mount
S2	4	Toggle Switch	100V; 10 Amp	Electronics	Chassis Mount
X1	1	Connector	Male + Female; 2 pins; 0.5 Amp	Electronics	Chassis Mount
X2	1	Connector	Mains	Electronics	Chassis Mount
W1	4 Mtr.	Elec. Wire	Speaker Wire, High Current	Electronics	Highly Stranded
V1	1	Ventilator	Mains Voltage; Large	Electronics	
CT	4	Crimp Terminal	Ring Type	Electronics	Fit W1
CB1	1 Mtr.	Elec. Cable	2 lead; 0.5 Amp	Electronics	Stranded

Table 1. EDM circuit components

The basic workings of the circuit are simple. It uses a large high current transformer to separate the circuit from the mains and step down the voltage. A rectifier bridge then converts the AC voltage into DC. The output from the bridge is directed to a large value buffer capacitance and then through a high power resistor. The resistor limits the short circuit current to a value that is under the maximum tolerable current of the transformer. This protects the transformer from burning out. The resistor needs to dissipate the short circuit power that is developed.

The output of the resistor is directed towards a bank of capacitors ranging from a low to a high capacitance value. Each capacitor can be selected individually, using toggle switches, to provide the desired capacitance. The positive line (Anode) from the capacitors is connected to the work piece via the tank assembly (see DR.3 at the end of this manual). The GND line from the transformer is attached to the electrode (cathode).

With the EDM circuit turned "on" the transformer will load the switch-selected capacitors almost immediately. An electrical voltage will be present over the electrode and the adjacent work piece. When these two come sufficiently close together the electrical tension will cause a spark, generated from the electrostatic charge of the capacitors, to jump the gap and strike the work piece. The gap resistance will then rise again allowing the selected capacitors to recharge (This is the reason that a good dielectric fluid is required. If the insulation properties of the dielectric are poor then the recharging process of the capacitors will be impaired). The capacitors will then again cause a spark to strike the work piece once their voltage breaks down the resistance of the gap.

However an electrical effect takes place after each spark which, if not canceled out, would start to erode the electrode more rapidly. After each spark discharge the current will start to ring back and forth in the EDM circuit until it dampens out. The current is changing direction periodically. This effect can be better illustrated using the mechanical analogue of the effect. When a metal rod is secured at one end and is tapped with a hammer on its other end (tuning fork for example) it will cause the rod to vibrate or ring back and forth at its natural frequency. This same effect applies to the electrical circuit

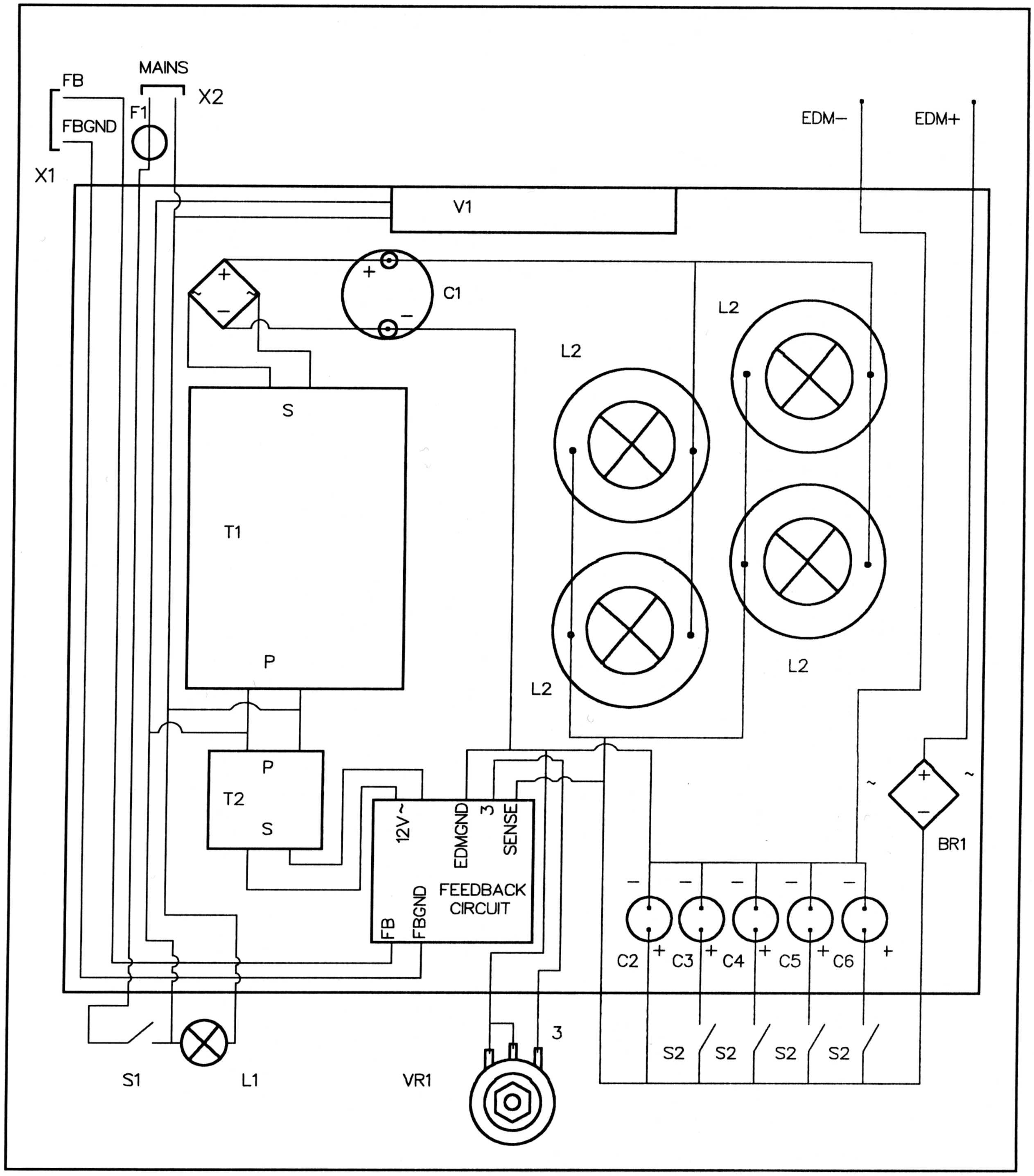

Fig.16. EDM circuit schematic

The hammer is represented by the spark discharge and the rod is represented by the electrical circuit. The ringing has a detrimental effect on the electrode since the current periodically changes direction. In other words the electrode becomes the anode for a moment and receives, during this period, the incoming spark discharge. Hence, the electrode will start to prematurely erode since its also taking the punches. To prevent this ringing effect, a rectifier is place between the work piece line and the output from the capacitors. The spark discharge can now only jump the gap from the electrode to the work piece and not the other way around, protecting the electrode.

Fig.17. Housing internal

5.2.2 Short Circuit Resistance

The transformer used in this project is a single unit. Although smaller transformers set in parallel could be used, to increase the maximum current, it is not advised to do this. Outlets, which sell salvaged electrical components, are common in most places. Most always a good-sized transformer can be found. Large sized transformers are preferred due to their high heat sink capacity.

As previously explained the required transformer should step down the mains voltage to about 40 volts and allow 4 to 6 amps maximum current. Naturally if the transformer output is shorted the current will rise above this level, and may cause it to burn out. A resistive load is therefore required to limit this value to under the maximum value. The equation to determine the resistor value is as follows:

```
U 1.4 / I = R

U = Voltage (Volts)
I = Current (Amps)
R = Resistance (Ohm)
```

For a 40 Volt, 6 Amps transformer:

```
40 * 1.4 / 6 = 9.3
```

Hence, a resistance value of 9.3 Ohm is required to safeguard the transformer by keeping maximum current to under 6 Amps. This resistance value is low with respect to the current that will be passing through it. A lot of heat will be produced and the resistor must be able to dissipate this. The amount of heat can be represented by the power developed. The calculation is as follows:

```
U * 1.4 * I = P

P = Power (Watts)

40 * 1.4 * 6 = 336
```

The resistor must be able to dissipate 336 Watts of power. There are a number of different types of resistors that can meet the value of 9.3 Ohms and dissipate 336 watts of thermal power. Take into account that these are ballpark figures. The components chosen do not have to meet these calculated values exactly. However they must not be much less than these values.

Probably the most inexpensive type of high power resistor available is the common light bulb. This type of resistor performs as an active current limiter. The resistance increases as voltage over the bulb increases. This attribute can be helpful in preventing voltage spikes from the EDM circuit passing through the transformer and polluting the mains. The light from the bulbs also acts as a diagnostics indicator of the circuit. Hence, it can be used to isolate problems or failures in the circuit. Apart from light bulbs, high power carbon resistors in anodized heat sink housings could be used. This type of resistor permits a tight high-tech looking package with high tolerance values. But they offer little extra advantage over the common light bulb for this application. They are also about 10 to 15 times more expensive than bulbs.

A common 100-watt light bulb offers about 50 to 70 Ohms of resistance. This is 5 times more resistance than needed and 3 times less power than required. However placing a number of these bulbs in parallel can reduce the total resistance value. The sum resistance of a parallel resistor circuit is always lower than the smallest resistor value. Since the bulbs all have the same resistance value, the following calculation applies:

```
R / LBn = Rt

LBn = Amount of light bulbs
Rt  = Total resistance (Ohms)

50 / 4 = 12.5
```

note: this equation only applies when each resistor has the same resistance

12.5 Ohms is above the minimum value. This is okay. However, the resistance also determines how fast the connected capacitors will charge up. If the resistance value is much greater then 9.3 Ohms it will cause the capacitors to charge up slower. As explained, light bulbs do not have a constant resistance value. The greater the voltage over them the higher their resistance becomes. In practice this effect has proved not be of that much influence. The reason is explained later. But it's good to keep the total nominal resistance no more than about 50 % greater than the calculated value. For builders that wish to get a bit more out of the circuit, 5 bulbs of 100 watts each in parallel could be used. This will amount to 10 Ohms total resistance. This is just above the 9.3 value.

Since each bulb is a 100-watt resistor the 4 bulbs will have a combined power of:

```
P * 4 = Pt

Pt = Total power (watts)

400 watts
```

This is about 15% above the 336 watts calculated. That's good. The more the better. All it means is that it can handle the minimal required thermal power dissipation value. The total power dissipation if 5 bulbs are used will jump to 500 watts.

5.2.3 Discharge Power

The total time that a capacitor requires to fully charge depends on its capacitance and the resistance that the current meets. This can be calculated as follows:

```
Rt * Ct = t

Ct = Total Capacitance (Farads)
t = tao (time factor)

Lets say that Ct = 500 microF

12.5 * 0.0005 = 0.00625
```

The t represents a time factor. Normally when this t value is multiplied by 5 is depicts the total time needed to charge the capacitor to more than 95 % of its capacity.

```
0.00625 * 5 = 0.03125 sec
```

It is evident from the equation that increasing either the resistance or the capacitance will increase the charge time as well. However take into account that we are working with milliseconds. The amount of power that the capacitor will develop when it discharges can be calculated as follows:

```
5 * (R * Ct) = T

Rd = Discharge resistance
T = Time (milliseconds)

Lets say that Rd = 0.5 Ohm and Ct = 500mF

5 * (0.5 * 0.0005) = 0.00125 sec
```

Encountered resistance for the discharge is different from the charge resistance. This is because the discharge occurs over the electrode and work piece and not over the bulb resistors. Hence, the resistance is very low and consequentially the discharge time is as well. The power developed per discharge is:

$0.5 * Ct * U^2 = E$

```
U = Volts
E = Energy (Joule)

0.5 * 0.0005 * 58 * 58 = 0.841 Joule
```

The duration time at which this energy is released, the power, is 0.00125 sec.

```
E / t = P

0.841 / 0.00125 = 680 watts!
```

The equation reveals that increasing the voltage and/or decreasing the resistance, thus discharge time, will proportionately increase the power of the spark. Since the voltage is squared in the equation it has the most effect.

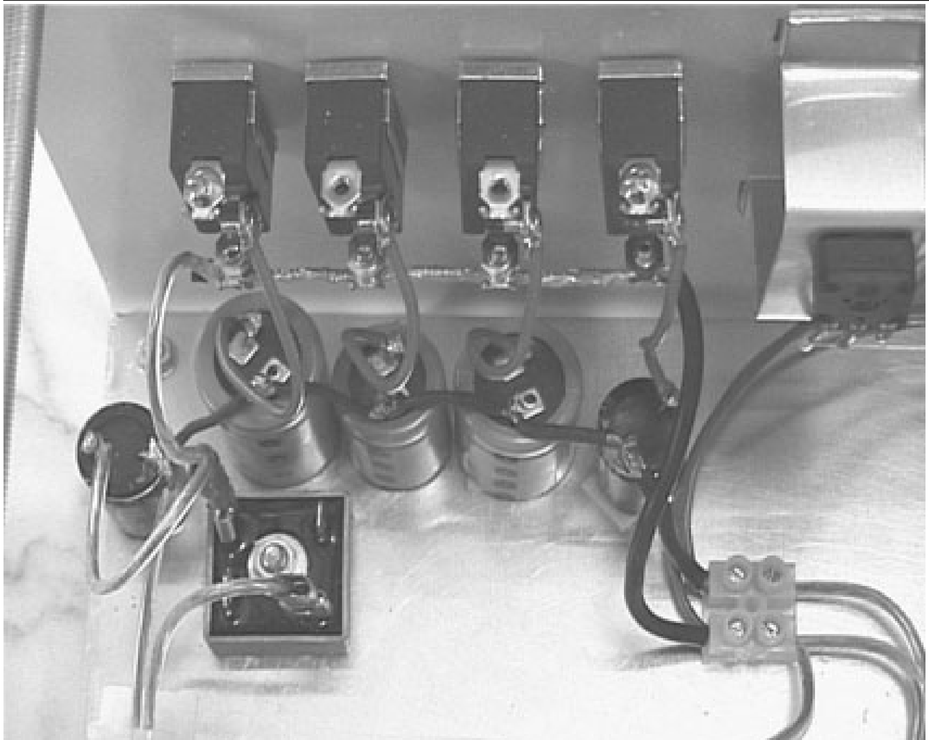

Fig.18. EDM Capacitors

High power discharges result in a high material removal rate. But this is done at the cost of precision and surface quality. The electrode will display a more beaten surface. Hence high power discharges may serve to pre-erode a desired profile in a relatively short time. Selecting a lower value capacitance has a more docile effect. Discharge power is less and the erosion rate decreases but so does the electrode wear. The work piece will display a more precise cut with better surface quality.

5.3 Feedback Circuit

The function of the feedback (FB) circuit is to maintain a certain spark gap distance throughout an EDM operation. This is necessary for the process to function correctly. If the electrode and work piece touch, no sparking will occur and the EDM circuit may start to over heat.

The feedback circuit uses a reed relay to insure circuit separation. The relay is transistor switched. The FB circuit senses the EDM circuit voltage by connecting a line from the capacitors (anode) to the transistor. The voltage from the capacitor is first divided between 2 resistors (R2 and VR1). Due to the high value of the first resistor and the input resistor of the transistor, reduced voltage is present and only low current will pass. The sensitivity of the FB circuit can be adjusted by the variable resistor VR1 (sense adjust).

To maintain a correct spark gap, a signal is provided to the computer by the FB circuit based on the state of the capacitor charge. Capacitor charge is high when no sparking occurs and low when it does occur. It goes to zero when the electrode and work piece are short circuited. The level of voltage over the terminals of a capacitor is directly related to its level of charge. If this level is above a certain set value, the feedback circuit sends a signal to the PC. This signal is interpreted by the software, which in turn instructs the stepper motor to run. Consequentially The electrode is fed towards the work piece. At one point sparks will strike and the mean voltage over the capacitor will decrease as its charge is being depleted. When the voltage goes under the set-point, the feedback circuit senses this and cancels the signal to the PC. The software then, almost immediately, instructs the stepper motor to briefly "pause" its motion accordingly. After a moment of spark strikes the software then gives instructions to "retract" the electrode from the work piece a bit. The "pause" time can be pre-set in the software as well as the degree of "retraction" steps (larger electrode surface area requires longer pause time). The retraction of the electrode creates a larger spark gap distance and allows the eroded material to be more easily flushed from the strike zone. This prevents shorts and promotes better process workings. When the capacitors are charged up again, and above the set-point, the circuit will resume sending the signal to the PC and the process continues.

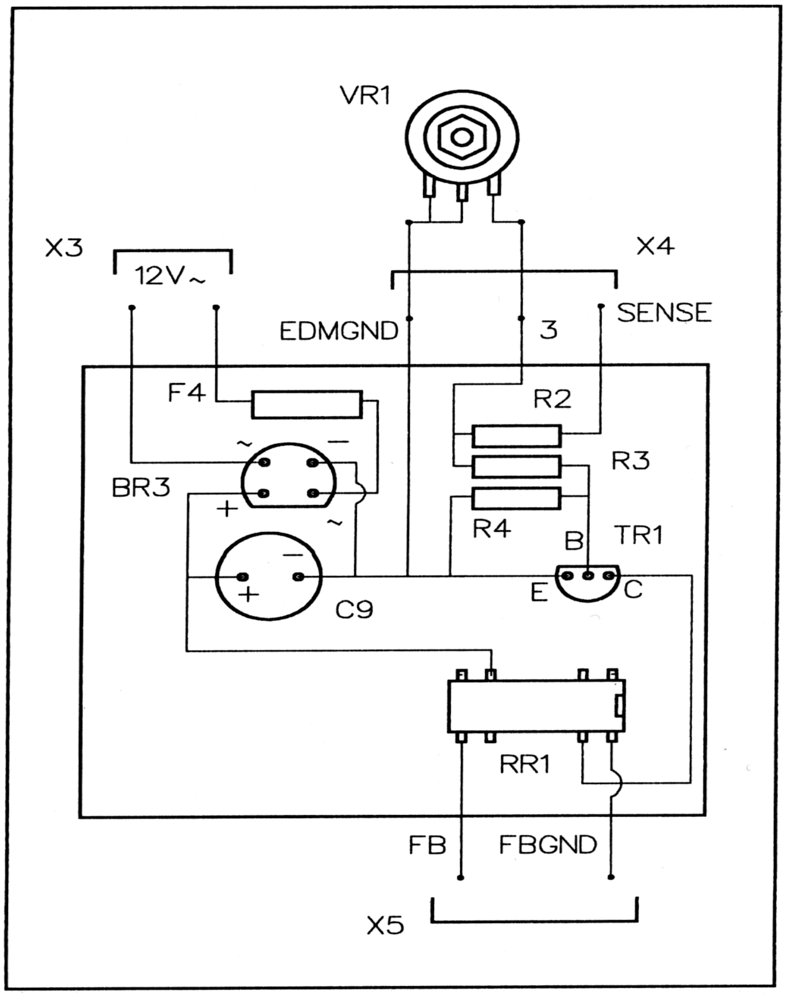

Fig.19. Feed back circuit schematic

The feedback circuit is comprised of only few basic parts. Taking the time and effort to specially make a print for this circuit would not present that much advantage. Using a test board and connecting the components based on the circuit drawing would work just as well. The test board is made of many equally spaced copper islands on a resin plate. Each island has 3 holes to solder component pins and wiring in.

Electrical Setup					
FeedBack Circuit					**Table 2**
Component	Qty.	Name	Description	Source	Remarks
R2	1	Resistor	10Kohm; 0.25W	Electronics	
R3	1	Resistor	330 Ohm; 0.25W	Electronics	
R4	1	Resistor	100Kohm; 0.25W	Electronics	
TR1	1	Transistor	BC 237	Electronics	
RR1	1	Reed Relay	12V; 0.1 Amp	Electronics	Normally Open*
C9	1	Capacitor	500uF; 30V; Elco; Radial	Electronics	

BR3	1	Bridge Rectifier	30V; 1Amp	Electronics	
F4	1	Fuse + Holder	30V; 1Amp	Electronics	PCB Mount
VR1	1	Variable Resistor	1Kohm	Electronics	Chassis Mount
X3	1	Connector Block	2 Pins; 1Amp	Electronics	PCB Mount
X4	1	Connector Block	3 Pins: 1Amp	Electronics	PCB Mount
X5	1	Connector Block	2 Pins; 0.5Amp	Electronics	PCB Mount
W2	1Mtr.	Wire	Low Current, Small Diameter	Electronics	Stranded
ICS	1	IC Socket	14 pin DIL	Electronics	PCB Mount**
BW	1 Mtr.	Bare Wire	0.5 Amp	Electronics	For Circuit Brd.
B	1x	Board	Board; 3 Island solder trace	Electronics	
* Circuit connections for the reed relay may differ from drawing. Consult data sheet for reed relay used					
** Reed relay is a 12 pin DIL. Take this into account when making board connections					

Table 2. Feed back circuit components

A separate 12-Volt transformer (T2) is listed in the component list for the feedback circuit power. The ground lines (GND) of the feedback circuit and the EDM circuit must be connected. After soldering inspect the circuit for shorts.

Install the circuit into the EDM housing. Use PCB stand-off's, tie wraps and mounts to neatly integrate the wiring and PCB into the housing. When all is complete and double checked for shorts and/or incorrectly connected components, turn the circuit "on". Holding the insulated portion of a screw driver, tap the EDM terminals with it. Strong Sparks should develop and the relay should react to the tapping by closing and opening. Use the "sense adjust" (VR1) to locate at what point this happens. After testing turn the EDM circuit off and discharge the capacitors using a screw driver (always do this). (Note: It has occurred more than once that the relay of the FB circuit does not become active when the EDM circuit is initially turned "on". By tapping the EDM terminals with a screw driver the relay should become active).

5.4 Driver Circuit

The single axis Camtronics Inc**.** stepper motor driver circuit used for this project is a low-cost high quality unit. The components used are tried and true, and have served the industry for years. The driver incorporates all the required features for its application in the EDM unit. The Camtronics manual, which accompanies the purchase of the driver, provides complete information on the installation procedure. The driver can be purchased as a kit (see the Suppliers Section).

The unit inputs step & direction signals to operate the attached stepper motor. This is an industry standard. The "step" signal determines the amount of steps per second that the driver will instruct the motor to make. The "direction" signal simply determines the direction that the motor shaft must rotate

Be very careful never to cross and short the output lines of the driver. It is not short circuit protected. Also, do not detach motor leads while the driver is "on". This will induce voltage spikes, which may damage it and other connected circuits.

The driver requires a 12 volt power supply. This is realized using a transformer to step down the mains voltage to 12 Volts. The output from the transformer is rectified and then filtered using a capacitor. The capacitor flattens out the DC voltage into a more stable DC component.

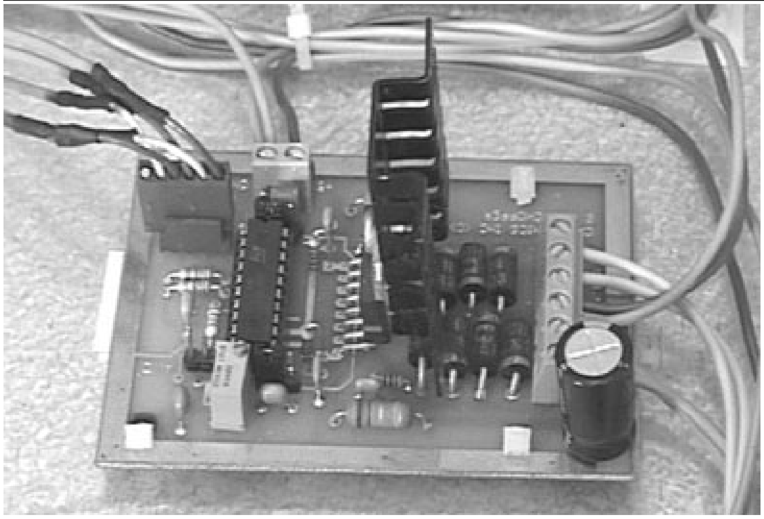

Fig.20 Camtronics single axis driver

Apart from the 12 Volt supply, the driver also requires a 5-volt logic. This is realized using a voltage regulator, which is placed parallel with the 12 volt.

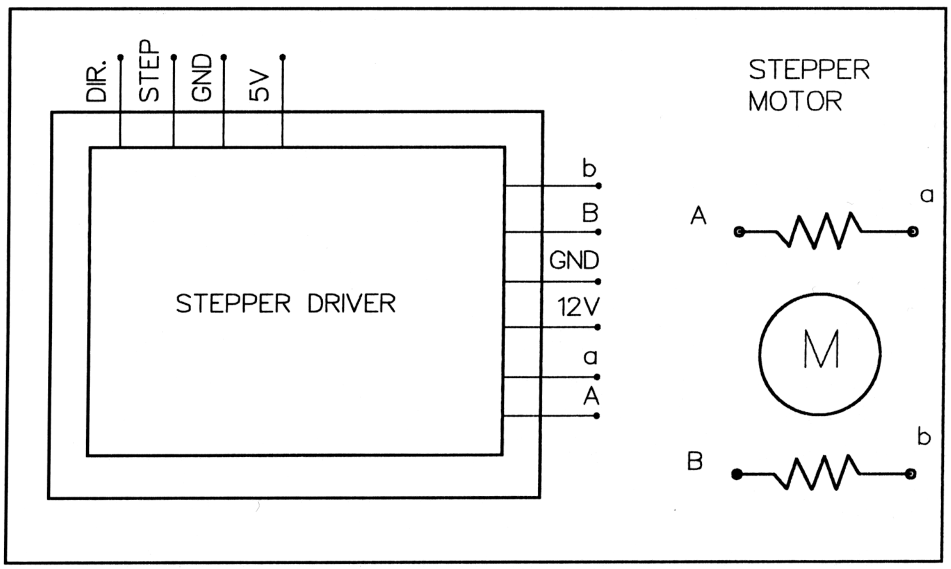

Fig.21. Schematic of driver circuit module

Fit a small heat-sink on the voltage regulator. The circuit diagram shows how the components are setup. The diagram also includes the home switch and FB circuit resistors.

It is also possible to power the 12 Volt driver and supply the 5 volt logic using a computer power supply. This is a switching power supply. Camtronics supplies information on how to hook this up. (note: this was not tested for this manual)

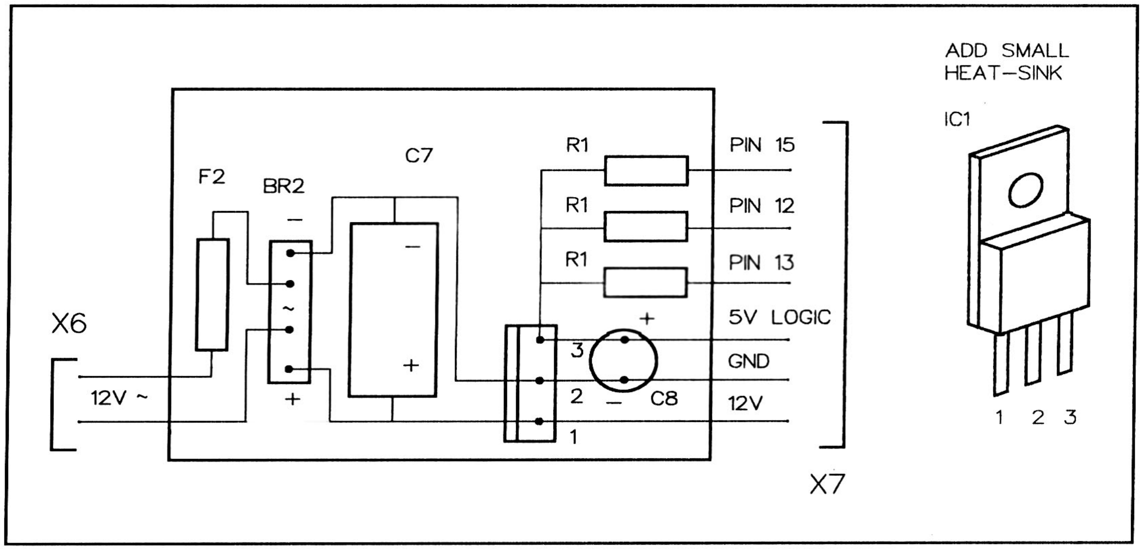

Fig.22. The power supply

The amount of current that the driver should supply the stepper motor is around 0.5 Amp. The driver manual will provide information on how to set this.

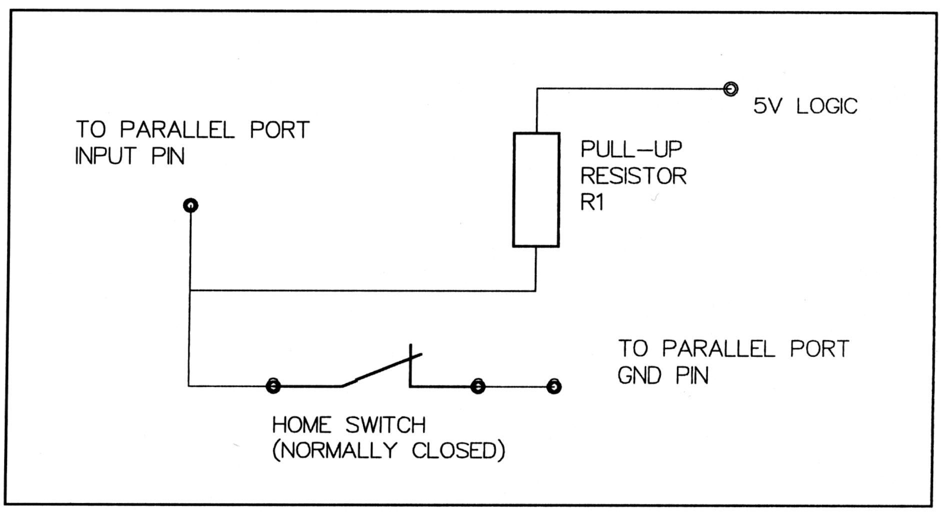

Fig.23. Home switch schematic

The wiring scheme for attaching different types of stepper motors is given in the Camtronics driver manual. A procedure to determine this is also briefly explained in the next section.

Electrical Setup					
PowerSupply+Related Components					**Table 3**
Component	Qty.	Name	Description	Source	Remarks
T3	1	Transformer	12Volt; 2 Amp	Electronics	
R1	3	Resistor	2K2; 0.25W	Electronics	
C7	1	Capacitor	1000uF; 30V; Elco; Axial	Electronics	
C8	1	Capacitor	22uF:30V: Elco: Radial	Electronics	
BR2	1	Bridge Rectifier	30V; 2 Amp	Electronics	
IC1	1	Voltage Regulator	7805	Electronics	
VR2	1	Variable Resistor	Depends on Pump Circuit	Electronics	

F2	1	Fuse + Holder	2 Amp; Fast	Electronics	PCB Mount
S4	1	Switch	30V; 1-2Amp	Electronics	Chassis Mount
V2	1	Ventilator	12Volt DC; Medium size	Electronics	
X6	1	Connector Block	2 Pins; 2 Amp	Electronics	PCB Mount
X7	1	Connector Block	6 Pins; 1 Amp	Electronics	PCB Mount
X8	1	Connector	2 Pins; Male + Female; 2 Amp	Electronics	Chassis Mount
X9	1	Connector	4 Pins; Male + Female; 2 Amp	Electronics	Chassis Mount
X10	1	Connector	DB-25 Parallel Port, Male	Electronics	Solder Buckets
X11	1	Connector	3 Pins; Male + Female; 0.5 Amp	Electronics	Chassis Mount
X12	1	Connector	2 Pins; Male + Female; 0.5 Amp	Electronics	Chassis Mount
X13	1	Connector	Mains Voltage; Female	Electronics	Chassis Mount
W3	2 Mtr.	Wire (Black)	Low Current, Small Diameter	Electronics	Stranded
W4	2 Mtr.	Wire (Red)	Low Current, Small Diameter	Electronics	Stranded
W5	2 Mtr.	Wire (Blue	Low Current, Small Diameter	Electronics	Stranded
W6	2 Mtr.	Wire (Green)	Low Current, Small Diameter	Electronics	Stranded
CC	1	Computer Case	Desk Top (Horizontal)	Electronics	Salvage
CB2	1 Mtr.	Elec. Cable	2 lead; 0.5 Amp	Electronics	Stranded
CB3	1 Mtr.	Elec. Cable	4 lead: 2 Amp	Electronics	Stranded
CB4	1 Mtr.	Elec. Cable	3 lead: 0.5 Amp	Electronics	Stranded
MC	1 Mtr.	Mains Cable		Electronics	For X13
B2	1	Board	Board 3 Island trace	Electronics	

Table 3. Power supply + related components

5.4.1 Stepper Motor

The stepper motor intended for this unit is a NEMA 17 sized motor. It’s a 0.9 degrees per step motor that has a holding torque of about 22 oz in. Only 4,6 & 8 lead motors can be used for this unit.

Several different types of stepper motors exist. The hybrid type is frequently used and pertains to this unit. Stepper motors are the answer to low cost motion control. However they do not have a feed back system to monitor and correct any positioning errors.

The workings of a hybrid type stepper motor is basically the same as a that of a solenoid. A solenoid is an electro-magnet. When a voltage is applied to its terminals it causes a magnetic field to be set in its winding. Consequentially it causes the core to be forcefully pulled inward. A stepper motor basically does the same. The difference is that the configuration allows for rotational motion of the core instead of linear.

The stepper motor is comprised of multiple windings (stator) that surround the core (rotor). The rotor is equipped with many small teeth or notches in a permanent magnet package. When the windings are provided with a voltage the resulting field attracts certain teeth and repels others depending on their magnetic polarity. The shaft, which carries the rotor, will then move a step. As long as current flows through the windings the motor will forcefully hold that position. This is commonly referred to as the "holding torque" of the motor. The motor should always provide much more holding torque than the application requires. If this is not done then steps may be lost and motion accuracy will recede. (Note: Stepper motor torque recedes rapidly as RPM increases). If the polarity of the windings are reversed in a “take over” fashion it will cause the rotor to again take a step based on the same principal as explained. The direction that the shaft rotates depends on the polarity of the windings and when this changes in relation to other windings.

The stepper motor lead connection can be determined using a multi-meter. The resistance is measured at its wires. If the value is infinitely high then this constitutes that the wires are not related to the same coil winding. If the value is low then they are related. This is for stepper motors with 4 wires. Related wire pairs are connected to the related driver outputs. This is commonly labeled as (A and a) for one pair and (B and b) for the other pair.

For 6 wire motors it gets a bit more difficult. This is because 3 wires are related. Yet one of them is not of use here. When the 3 related wires, using the previously explained procedure, are found it is necessary to determine which wire pair results in the highest resistance value. This wire pair is connected. For 8 wire motors the procedure is the same only now there are 4 related wires of which two need not be connected.

5.5 Pump Speed Control Circuit

The fluid delivery of the EDM unit is realized using a pump. Controlling the amount of fluid delivery may not be needed for most jobs yet it may be sometimes useful. This may arise when delicate machining must be carried out and/or if the nominal flow of the pump is too high.

The speed circuit should coincide with requirements of the pump. The type of pump used must allow constant operation without overheating. Many DC pumps will not allow this. However an automobile fuel pump intended for fuel injection delivery uses a cooled motor. These are positive displacement pumps. The fuel normally surrounds and flows through the motor while it is being pumped through. This cools the motor and thereby allows constant operation. Using oil does the same.

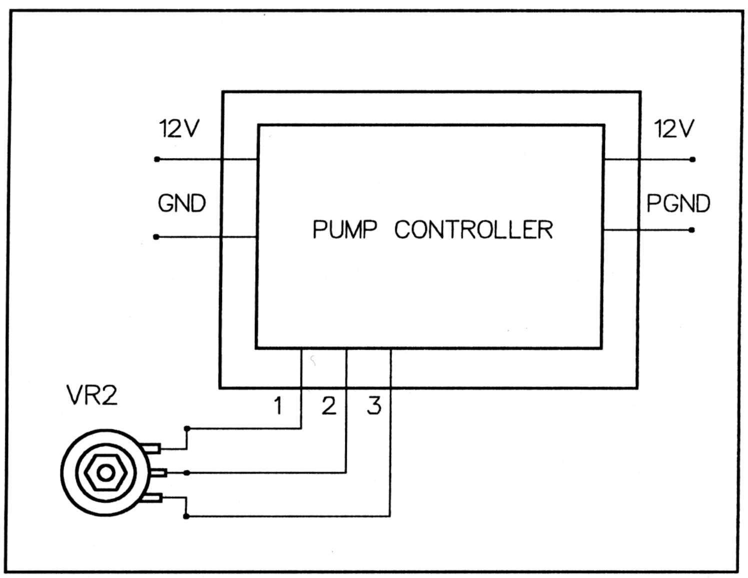

Fig.24. Schematic of pump control circuit module

Fuel pump motors usually require 12 volts and 1-2 Amps. The speed control circuit should be rated to supply at least 25% more current at this voltage. Obtaining an inexpensive speed control circuit to handle this should not be a problem. "Pulse Width Modulated" circuits are the most efficient.

The power supply for the stepper motor driver could also supply power for the pump speed control circuit. Make sure that total current does not exceed that of the power supply transformer and connected components. The circuit components are orientated towards a pump that requires no more than 1 Amp. If a common power supply is used for the driver and pump control circuit it may cause interference for one or the other circuit. Usually a larger filter capacitor remedies this. If this does not help then the pump speed control circuit must receive a dedicated power supply.

Fig.25 Back side of driver/power supply housing

An induction motor pump could also suffice for this project. These are centrifugal type pumps, which use the mains voltage for power. They produce high delivery at low pressure, are rugged and can withstand constant use. Usually they can be found in washing machines. However this type of pump must be used with caution as it directly uses the mains voltage. It should at least be inclosed in a housing that protects the operator from accidental shock.

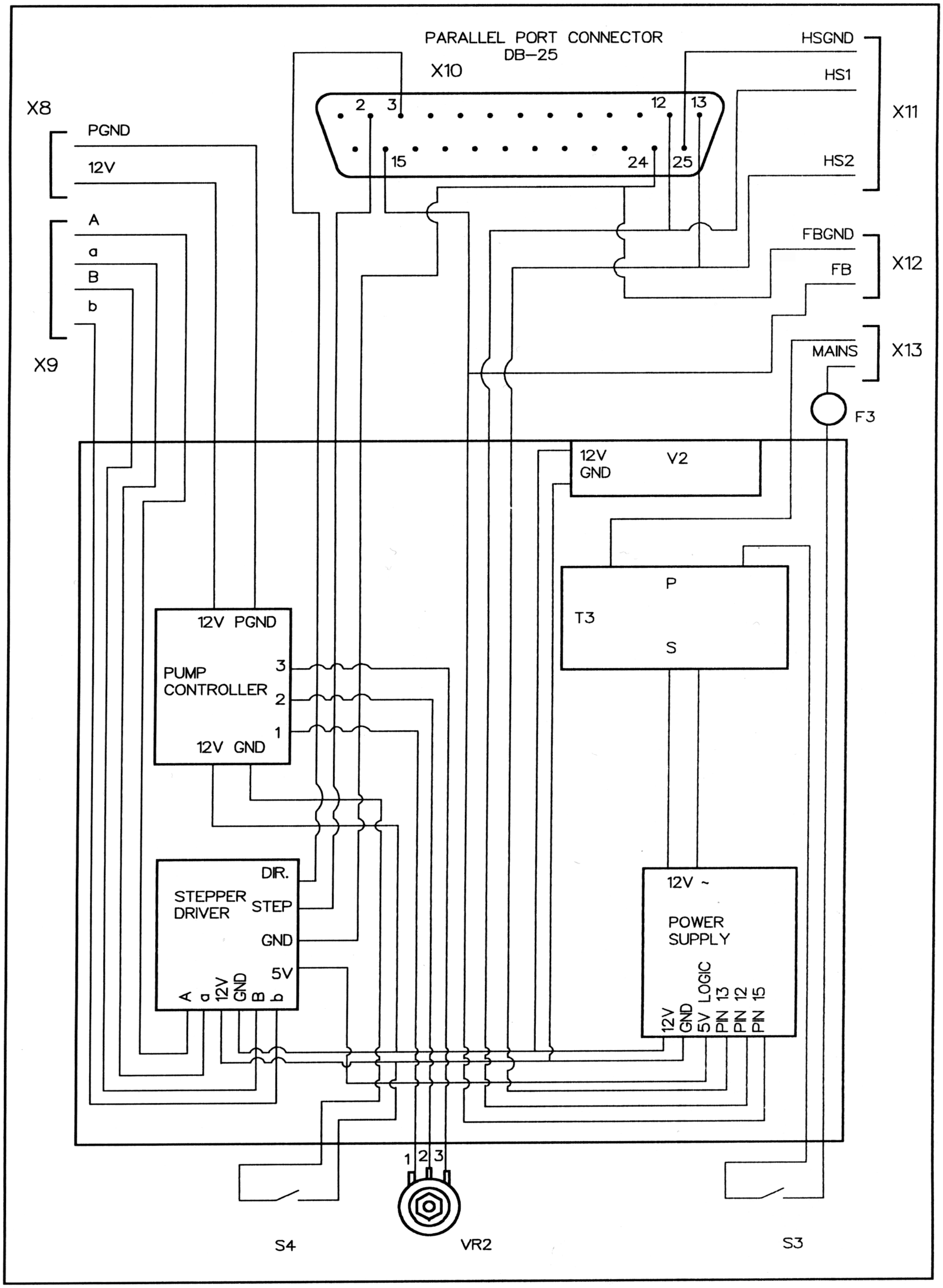

Fig.26 Circuit connections

6. The Mechanical Setup

The mechanical set up is comprised of 4 different assemblies, namely:

- Assembly A, (the guide way)
- Assembly B, (the electrode chuck)
- Assembly C, (the lead screw)
- Assembly D, (the tank + pump circuit)

Each assembly is made up of parts and components. Parts are defined as modified materials/components. Components are pre-manufactured materials, like a pump or a bearing.

Drawings of the parts can be found in the last section of this manual. Depending on the complexity of the shape, some parts are drawn from a 3D perspective. All other parts give a 2 dimensional perspective based on the American projection system. The drawings are not to scale. A description of each part regarding type of material etc. can be found in the “Drawings & Lists” section of this manual. Also included in this section is a list of all “Mechanical Setup” components and the material profiles and sizes required for the unit. This makes it easy to gather the material quickly. The lengths of the materials listed are always a bit longer than required so builders don't come up short.

The drawings do not list a tolerance on the part dimensions and hole positions. However, try and keep a general tolerance of 1mm (0.04”) on all measurements. This can be somewhat tight. Yet, to a degree, reservation has been made for measurement errors by much over-sizing the holes in parts. Obviously this does not apply to parts that must fit into or over another part.

To pin point where holes must be drilled, based on the drawings, it's always best to measure out from a single origin point. This is done to cancel out any error made in the sawed length of parts. For example, in a flat strip of aluminum that was sawed 2mm too long, 2 holes are needed. The holes are both 6mm from the sides of the part and must be 38mm apart to fit correctly. Measure from one side the 6mm distance of the first hole and mark this. Then from this same origin point mark the next hole at 6mm + 38mm. This will compensate for the length error. If the second hole were marked by measuring 6mm from its own side then the length error would be entered in the 38mm distance. This would mean that the 38mm distance is now 40mm. The part would have to be discarded as it is out of the required specification.

The positions where holes need to be drilled can be determined using a measuring caliper. Using the caliper lightly scratch cross hairs in the material that represents the hole position. Mark a dot at the intersection of the cross hairs using a magic marker. Then use a center point to punch in a small notch on the marked spot. This will assist the drill in finding the correct position to drill. Counter sink the drilled holes on both sides of the part and deburr. Deburring parts can mean the difference between the unit working right or not.

The guide ways for the SEDM unit are drawer slides. These are widely available. The type used for this unit is made of steel, including the bearings. They offer the highest precision and load rating in relation to cost of most all other types of guide ways.

There are a number of drawer slide suppliers. For this unit drawer slides produced by Thomas Regout were chosen (see Suppliers section). Slides of a different manufacturer with equivalent dimensions and similar quality can also be used. However more modifications to the alternative slide, and maybe other parts, may be required to properly integrate them into the unit.

The slides have been defined as parts since they require some modification. The standard slide length, and thereby its travel, need to be reduced before they can be integrated into the unit.

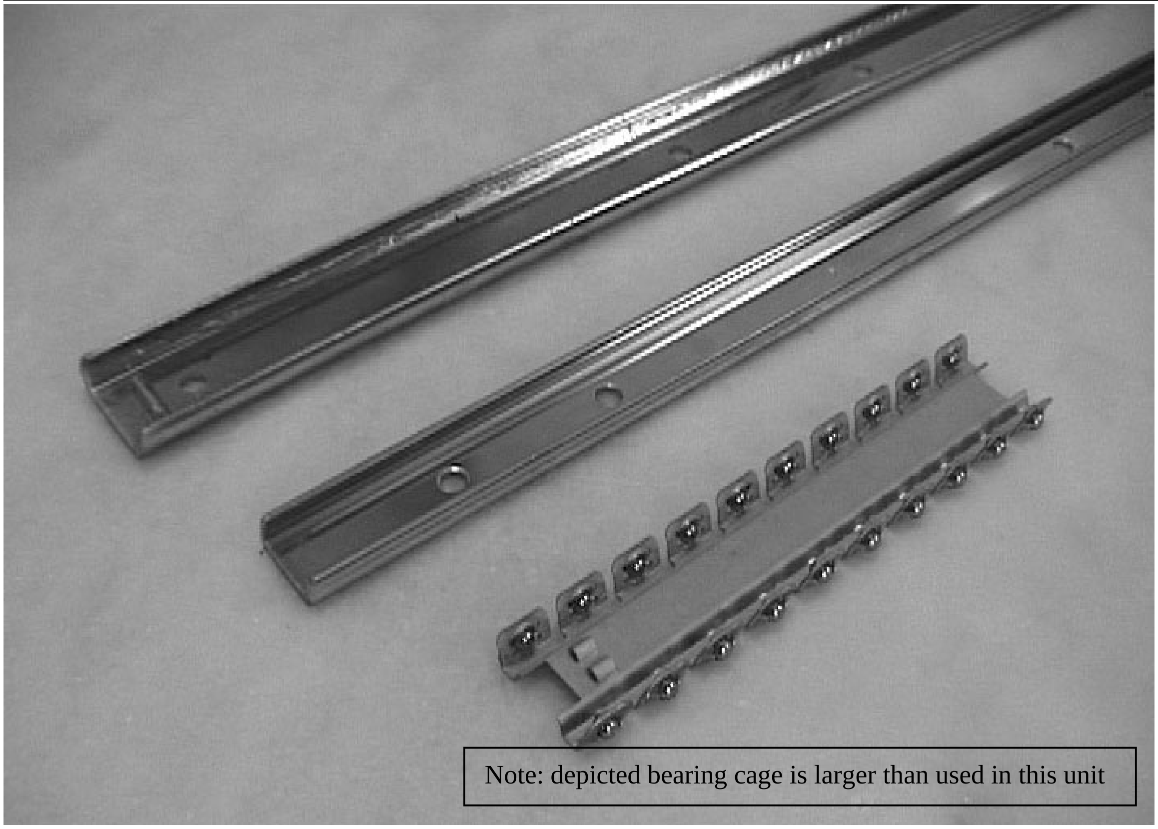

Fig.27. Drawer slides, dismantled

Most all hole sizes that need to be drilled are about 6mm, some are 12mm. Certain parts may require larger sizes yet the chuck of most power drills may not be able to accommodate this. However large drills can sometimes be purchased with the clamping end grounded down to a smaller size. Another alternative is to grind the hole to size using a power drill with a grind head. This is, however, cumbersome work.

Parts, material and components are listed in the “Drawings” section of this manual.

6.1 Manufacturing

The drawer slides are the first to be modified. Each slide is made up of 3 parts:

1. outer rail
2. inner rail
3. bearing cage

The lengths of both the inner and outer slides need to be reduced according to drawing DR.8. Before this can be done, the slides need to disassembled. The outer slide has a lip that serves to stop the travel of the inner rail. This needs to be bent back or grounded off. This lip can be found on the side that has its first installation hole at 27 mm from one end of the slide (this is depicted on DR.8 for orientation purposes). When bending make sure the slide is on a flat surface and held the firmly. This must be done with care so that the rest of the slide does not become deformed. If the lip is to be grounded off then care must taken not to let the slide get too hot. The slides are made of soft steel. But they can lose some springiness, induced by cold working manufacturing, when heated.

After the lip is bent back or removed, the inner rail and bearing cage can now be extracted. The length of the outer and inner rail can now be reduced according to DR.8. Place one of the rails in a workbench clamp. The clamp force should not damage or bend the rail (small strips of soft wood between the clamps can be helpful). Cut the rails using a good hand saw. Work easy and prevent any excess bending of the rail while sawing. Repeat this for the other rails. After the rails are cut to length deburr them using a power drill with a small grinding head and/or use a low course file. The bearing cages also have a small stop notch. This should be removed by carefully grinding it off.

Clean the rails and bearing cage using a de-greasing agent. Most automotive stores carry these kinds of products. All the grease and fragments from the sawing/de-burring process must be removed. Inspect that this is done well. Re-grease the cage. Do not over grease, this will attract dirt. The re-installation of the rails will be carried out later.

For the most part the unit uses a composite material called Trespa as the main construction material. Other materials could also be used but may be inferior to Trespa. Lexan, aluminum and steel are also used for this unit. Working these materials properly requires different techniques and handling. The manufacturing is largely drilling and some sawing. Most builders will have no problem doing this. However to be thorough, explanations will follow as to how best to work the materials and what precautions must be taken.

Trespa is a composite material made up of a paper reinforced thermoset. Nowadays it's used for everything from building panels to laboratory instrument constructions. The material has a special, usually white colored, hard surface. This surface is scratch resistant and has a professional appearance. The base material won't decay or swell over time. It's strong, ridged and resistant to most chemicals. Trespa allows grinding to shape without threading like most plastics normally do. However it has no mercy when worked incorrectly. This aspect applies to the material Lexan as well, which is used for the front tank plate.

Sawing Trespa does not present any special problems. But drilling the material is a different story. The material is somewhat brittle. When drilling, the drill can sometimes take a bite bigger than it can chew. This can cause the drill to be forcefully pulled in. Apart from the drill probably breaking, this situation can be dangerous if the part is not held down firmly enough (clamp work piece down whenever possible). Some guidelines are required to reduce the chances of this situation from occurring. First of all the rotation speed of the drill is very important. Large holes should be drilled at slow speed while small holes at a higher speed. Drill speed should not be higher, at any drill size, than about 500 RPM and about 200 RPM for drills larger than 8 mm. An indication of a correct drill speed can be seen by the type of chips produced. Long curled chips represent the correct speed. Powder sized chips along with a burning odor and a darkened drill head obviously indicates that the drill speed is too high. When first drilling a hole the hard top layer must be broken through by feeding the drill somewhat hard yet in a docile manner. When the base material is entered the feed must proceed in a steady easy manner (this takes some practice). Take into account that the drill must also punch through the hard layer on the underside as well. Do this with a very docile feed.

The type of drill used must be appropriate for the job and of good quality when drilling Trespa. HSS (High Speed Steel) drills for steel will suffice for holes up to about 4 mm. Larger holes should be drilled with drill bits meant for drilling holes in brass. These are also HSS drills. Yet this type has crown cutting edges which are at and angle of 0 degrees (opposed to the 15 degrees cutting angle for working steel). Drills meant for brass almost appear to work through the material in a scrapping fashion instead of directly cutting through it. They are less prone to biting and latching into the material than drills meant for steel. Also they have less tendency to chip off pieces of the top layer. However drills meant for brass can be expensive. An alternative is to modify standard drills meant for steel. This is done using a flat stone type material normally used for sharpening knives called a whetstone. While holding a drill bit in one hand position the flat side of the stone parallel to the drill. Moving the stone in an "up and down" manner slightly grind flat a facet on both cutting edges of the drill crown. The flat stone surface must remain parallel to the drill while this is done or the angle will not be correct.

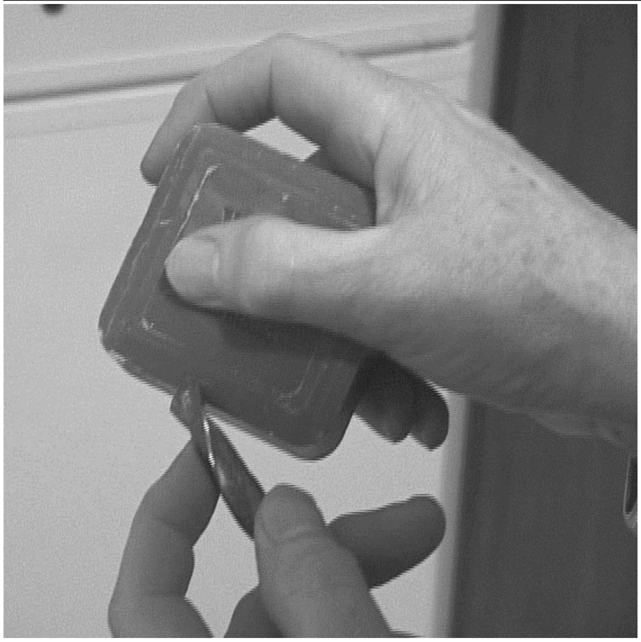

Fig.28. Modifying HSS drill

When large holes need to made it is best to first pre drill a hole with a smaller drill. This will accommodate the drilling process. With aluminum or steel the pre drill size is not that critical. Trespa however will more easily cause the drill to bite if the pre-bored hole is to big in relation to the desired end hole size. For instance a hole that needs to be bored to 8 mm should first be pre-bored to about 3mm and no bigger.

When drilling holes in Trespa (or any other material for that matter), use plenty of cooling fluid. Trespa has a high coefficient of friction and will blunt tools rapidly when dry drilling is performed. Dry drilling may also promote drill biting as well.

Lastly, a power hand drill is sometimes easier to use than using a drill press for certain tasks. However it is most always less precise.

6.2 Assembly

Before starting assembly make sure that the parts have been properly de-burred. As a final precaution lightly sand the mounting sides of all the aluminum parts. Do this by taping down a sheet of course sandpaper (normally intended for wood) onto a flat clean surface. Holding a part firmly down on the paper slide it over in a steady controlled fashion once or twice. Do not sand too much or unevenness will result. File away any excess burrs. Clean all parts in soap and water and allow to dry.

Each part is identified by a number followed by an assembly letter. Unless otherwise specified, the numbers refer to the assembly step procedure. For example, part 1A is related to part 2A and intended to be assembled in that order.

Assembly C, the lead screw, is held in position by a set of radial bearings that are clamped together using two nuts listed as components C17 (see DR.5). It is important that the C17 nut is only in contact with the inner race side of the radial bearing. If the nut contact diameter is too large it will drag over the bearing seal making it harder to turn the lead screw. Another aspect that must be taken into account is the length of the nuts. Normal short length nuts tend to wobble when screwed on the lead screw. This wobble cannot be tolerated for this application. Long length nuts wobble much less and are acceptable.

The lead screw should turn easy and not require the use of a lubricant. Lubricants tend to attract debris. At most only a small amount of lubricant may be applied. Better yet, brass nuts should be employed. This provided that they incorporate equal or higher form and dimension quality.

It is important that nylon or hard rubber washers be used. This pertains to all fasteners for the tank assembly that could lead to a potential leak. To further ensure sealing integrity of the tank it is advised to apply a small amount of silicon sealant to these washers and their bolts. It is no fun having a completed unit that leaks.

The unit requires different hose diameters as plumbing parts, pump and the filter may have different nozzle sizes. Use connectors to interconnect these hoses. It is sometimes possible to fit a smaller hose into a larger one.

6.2.1 Guide Way Assembly

The guide way assembly is listed in the drawings as Assembly A. The guide bed, part 1A, is the first part to start with. Mount parts 2A on. Before securing them down, make sure that these two parts are parallel as possible to the sides of the guide bed. Measuring from the inside surface, parts 2A should be about 74 mm apart.

Mount the outer rails of parts 3A onto the brackets 2A. The rails should be offset about 3mm from the surface of the guide bed. Install the bolts from the outer rail side. Use bolts with low height heads so the inner rail surfaces will not run against it.

Before re-installing the bearing cages and inner rails, first mount parts 4A and 5A on the left-sided inner rail (home switch side). Mount parts 6A onto the inner rails. Position parts 6A for now, do not secure them down yet. Each rail will be installed from the corresponding outer rail under side. First place a bearing cage about one-third its length into the outer rail races. Holding a cage in place slide a rail into the cage. When it reaches the outer rail it will feel a bit locked in. Release pressure on the cage and gently feed the inner rail further into the outer rail. The cage should invite more of the inner rail to slide in while it is being fed into the outer rail. Do the same for the other slide combination. Position parts 6A about 45mm from the under side of the guide bed (measure from the top surface of parts 6A to the bed underside). The top surface of parts 6A should also be parallel to the bed underside. When completed, extract the inner rails from the outer rails. Secure parts 6A.

Glue (using a very small drop of super glue) parts 5C on to part 7A according to the drawings. Check that they are glued on flat and that their holes are aligned with the corresponding holes of part 7A. The gluing of parts 5C to 7A is only to hold them in position to permit easier installation of assembly C. Position and secure part 1B on 7A. Reinstall the slides as previously explained. Secure 7A to parts 6A. Check to make sure that the parts are still parallel to the guide bed. The rails should run easy in their races. If this is not the case then one or more of the following may be the cause:

- Fastener(s) has been secured to tightly
- There is dirt on the rail races
- Some part has not been mounted parallel enough to another related part
- The heads of bolts may be too high, blocking rail travel

Mount part 8A onto 1A. Insert and secure home switch components. Mount 9A to 1A.

6.2.2 Electrode Chuck Assembly

This assembly is listed as Assembly B in the drawings. Insert part 2B into 3B. Add a small amount of glue to secure and seal in part 2B. Position the offset block, part 4B, onto the chuck bracket, part 1B, using part 5B. Part 4B must have the side with the M4 thread on the right side when looking at the front of the guide way assembly. Secure part 4B by adding a drop of super glue to corner contact points.

Extract part 5B by unscrewing the corresponding nuts. Guide part 5B into part 3B until touches part 2B (see DR.2). Screw in the set screw and apply glue to secure and seal the two parts. Reinstall 5B/3B combination into the chuck bracket assembly. Clamp a connector terminal C15 to electrical cable C16. Secure the terminal to part 4B. The lower side of part 1A has a hole to hold down (using a bolt and C15) the other side of the cable. The cable could also be directly connected to the connector rack connection if the unit is not intended for remote use. This connection is the negative pole of the EDM circuit. The cable should have enough slack to allow unrestricted movement of the chuck through its stroke.

Place, using double sided tape, a tie wrap mount, C13, onto the right side of part 7A. Use a tie wrap, C14, to neatly hold the cable in position. Attached a hose line over part 2B. The hose line length should at least run over the top of part 1A and then down behind it. Leave enough slack so that the chuck is not restricted in its stroke. Place a tie wrap mount on the left side of part 7A. Use a tie wrap to hold down the hose. The tie wrap must allow the cable to be moved when the chuck position is moved up or down in the chuck bracket.

6.2.3 Lead Screw Assembly

This assembly is listed in the drawings as Assembly C. Before assembly, make sure that lead screw, part 3C, is not bent. Also, if possible, polish it and check for burrs. A nut should screw on easy and not encounter resistance.

Based on DR.5 screw nut C17 onto the lead screw, part 3C. Place the spring, component C5, over 3C. Pull back the spring and screw on another C17 nut. About 5mm of the lead screw should extend from the nut C17. Both C17 nuts should be pushed away by the compressed spring and be about 15mm apart. Insert the lead screw sub-assembly under 7A and position using the two other parts 5C. Clamp the two C17 nuts. Do not secure yet.

Screw C18 and then C17 onto the lead screw 3C based on DR.5. Except for part 4C, slide/screw the rest of the component, including part 1C, over the lead screw as depicted in DR.5. About 10mm of lead screw should extend out from nut C17. Components C4 function as offsets for the bearings. They prevent the bearings from dragging over the surface of bracket 1C.

Position and secure as accurate as possible, part 1C on guide plate 1A. Position and clamp the bearings in place by tightening their adjacent nuts C17. Do not over tighten or the bearings will not permit the lead screw to turn easy. Secure the previously positioned parts under part 7A. Turn the lead screw 360 degrees by hand. This should turn relatively light (taking into account the drag from the spring tensioned nuts under part 7A). If it does not, adjust the lead screw position a bit at 7A and/or at the C17 bearing nuts until it turns relatively easy. Turn, by hand, the lead screw and check that the nuts do not become lose. While holding C17 tighten nut C18. This will prevent C17 from loosening during operation. Turn the lead screw and move the sled all the way up and down and back again. The drag of the lead screw should not significantly change.

The lead screw may tend to wobble when turned. This causes the lead screw to turn a bit easy then hard. This may be due to the following:

- lead screw is bent
- lead screw is not correctly positioned
- lead screw/bearing clearance is to much

If the clearance is too much, apply tape around the lead screw and slide the bearing over this. The amount of tape should just be enough to cancel the clearance. Do not apply more tape than this.

The nuts C17, which are separated by spring C5, comprise the backlash unit. The nuts are clamped down between parts 5C. Axial thread clearance (backlash) can be canceled out by slightly loosening the bolts at one of the clamped nuts C17. The compressed spring will now push the nuts away thereby canceling out the play. Re-tighten the bolts.

The lead screw is attached to the motor shaft C1 via part 4C. This is a hard link meaning that any misalignment of the shaft and the lead screw will not be compensated for. The result is that the lead screw may periodically turn hard. The misalignment may be due to 3 things:

- Shaft and lead holes in part 4C are not concentric
- Shaft and/or lead screw holes in 4C have too much clearance

- A combination of the first two aspects

The clearance can be canceled by applying a layer of tape to the lead screw and/or motor shaft. The amount of tape should be just enough to cancel the clearance and no more than that.

Add part 4C on to the lead screw, on top of C17. The motor shaft is usually only about 10mm in length. Since the motor is attached to bracket 6C, only about 6mm will extend out. The shaft should extend into part 4C as much as possible. This without 4C touching the surface of part 6C. This can be accomplished by adding washer rings to act as shims between part 4C and the C17 lead screw nut until a proper clearance is obtained. Apply an adhesive to the set screw to ensure that part 4C and the motor shaft do not loosen during machining.

Position using part 6C on to the guide bed. Install the stepper motor, C1. Insert the headless bolts into part 4C and secure the shaft of the motor. Make sure that the lead screw and motor shaft line up correctly by turning the lead screw to feel the drag. The remnant torque of the motor is minimal. The lead screw drag should feel the about the same as when the motor was not installed.

6.2.4 Tank Assembly

This is listed in the drawings as Assembly D. It is important that all assembly D parts be washed. This to insure a good bonding surface as gluing at certain plate sections is required. The adhesive is used to seal the cracks at the intersections of the plates to prevent the EDM fluid from leaking out. It also adds to the ruggedness of the assembly.

Mount parts 3D to wall plates 1D and 2D. Check that they are positioned correctly (parallel to the plates and at same height). Do not secure yet. Mount in position and secure bracket parts 4D to wall plates 1D and 2D. Mount and secure parts 5D to 2D. Use nylon or hard rubber washers to seal off and prevent the EDM fluid from leaking through at these fastener areas. Applying a small amount of silicon in between the bolts and the washer is advised.

Part 6D is the tank floor plate. It has a drain hole in the middle for the plumbing T-section, C6, that needs to be fitted. It’s best to install this component first. There are a many types of plumbing pieces on the market, especially in PVC. Some readers may chose other ways to attach a T-section to part 6C. The type used here is made of PVC and is fitted using a collar.

Slide in the collar of the T-section into part 6D. Allow at least half the collar length to extend from the floor plate. Add a few small drops of super glue to fix it in place. Apply a layer of PVC glue around the extending collar and slide the T-section over it. When the adhesive is completely cured add a fast drying contact adhesive around the plate T-section intersection to insure sealing. Do the same for the collar/floor plate intersection.

After the adhesive has fully cured, take plate 6D and place it between the wall plates 1D and 2D by resting it on the mounted parts 3D.

Insert the four 8D parts in the two wall plates 7D. Take this sub-assembly and place it over the other sub-assembly of plates 1D, 2D and 6D. Tighten the nuts somewhat and move the plates as precisely as possible together in position. Make sure that the surface worked on is flat and free of debris.

When all the plates are positioned neatly together, including the floor plate 6D, tighten the nuts to hold the plate securely in place. Unless sawing errors have been made, the plates should not extend material from the sides or be slanted. Check that the unit does not rock on the flat surface.

Carefully apply super glue to all possible intersection corners points. This is done to fix the plates in position prior to the sealing procedure. Do not to apply too much to fast, especially around the transparent front plate, 1D. Super glue crystallizes and displays a frost like appearance, which can look sloppy when too much is added. Careful not to glue parts 8D to the plates. Apply some more super glue later at the intersections to reinforce the bond. However, this time allow the glue to seep through into the cracks of the plate intersections a bit.

When the adhesive is fully cured, extract the two bottom parts 8D carefully. Apply super glue in the revealed intersection areas as well. Extract the two last parts, 8D.

Tilt the tank at a 45-degree angle and support this position using a small object. One of the plate intersections is now positioned as a valley. Very carefully, at a slow even pace, administer a semi-thick flowing contact glue in this intersection valley. The glue is used to seal the intersection. It must not be too thin or it will seep through the intersection crack and flow out. It should not be too thick either or it won't creep into seal the crack. Allow the adhesive to fully cure. Do this same procedure for all the other inner intersections of the tank. Make sure that all intersection areas are sealed. Do not apply too much adhesive. This may promote the adhesive to peel of due the stress induced by the curing. Instead of contact adhesive, polyester may also be used for those who have experience using it (polyester can become very messy when used incorrectly). Use a syringe to administer the polyester in the intersection valleys.

Silicon sealant is not used to seal the intersection cracks. Administering it correctly requires a lot of attention as it is too thick to creep by itself into cracks. Model shops do however carry silicon sealant that is less thick. Yet these do not seem to poses enough adhesive strength and peel easy.

When the adhesive in nearly fully cured, insert parts 8D. Tighten the nuts of parts 8D gently. Do not over tighten. If a crack sound is heard when tightening, this may be the adhesive acutely losing its bond. Check to make sure that the adhesive has not come lose at one or more intersections. Remember to use nylon or rubber washers followed by a metal washer to seal off the tank holes around the inserted parts 8D. Add a small amount of silicone between the washers and the nuts to insure sealing of the tank. Check the positions of parts 3D and secure them in place. Allow the adhesive to fully cure.

Seal off all the open holes in the tank with tape and fill the tank with water. Check to see if any areas leak. If so, find the source and seal off with the adhesive.

Mount and secure valve component C8 in part 10D. Attached an appropriately sized hose line between C8 and 3 way or T-section C6. Attach at the other end of C6 another hose line for the filter and the pump.

Place part 9D in the tank. Use nylon or rubber washers of equal height to seal off the fastener holes in 6D. Apply silicon to seal off the tank. The washers must allow the plate 9D to be offset from 6D at a height of about 1 or 2 mm. This to allow the fluid to drain. Insert and secure part 10D

Clamp a connector terminal, C15, to cable C16. Insert and secure part 11D in plate 6D with the connector terminal in between using nuts. Use nylon washers. The cable is the positive connection for the EDM circuit. Slide the clamp arm, 12D, over 11D.

Test the sealing integrity of the tank again using water by blocking off any drain holes (do this without the pump attached or it may rust on the inside). Allow the water filled tank to remain that way for about an hour. Check then if any of the water has leaked out. Remedy any leaks. Try and find the source and seal it off as close to it as possible. Drain the water completely.

Glue the foot pegs, C12, onto base plate 13D and allow to cure. Place the completed sub-assembly onto base plate 13D and secure. Attached the pump in front of the transparent plate using tie wraps and tie wrap mounts. Connect the rest of the hose lines to and from the pump.

Position and secure the assemblies (ABC) to the completed tank assembly D. Use tie wraps to neatly hold the plumbing and cables in place (connect the pump and wiring as well, use tie wrap mounts).

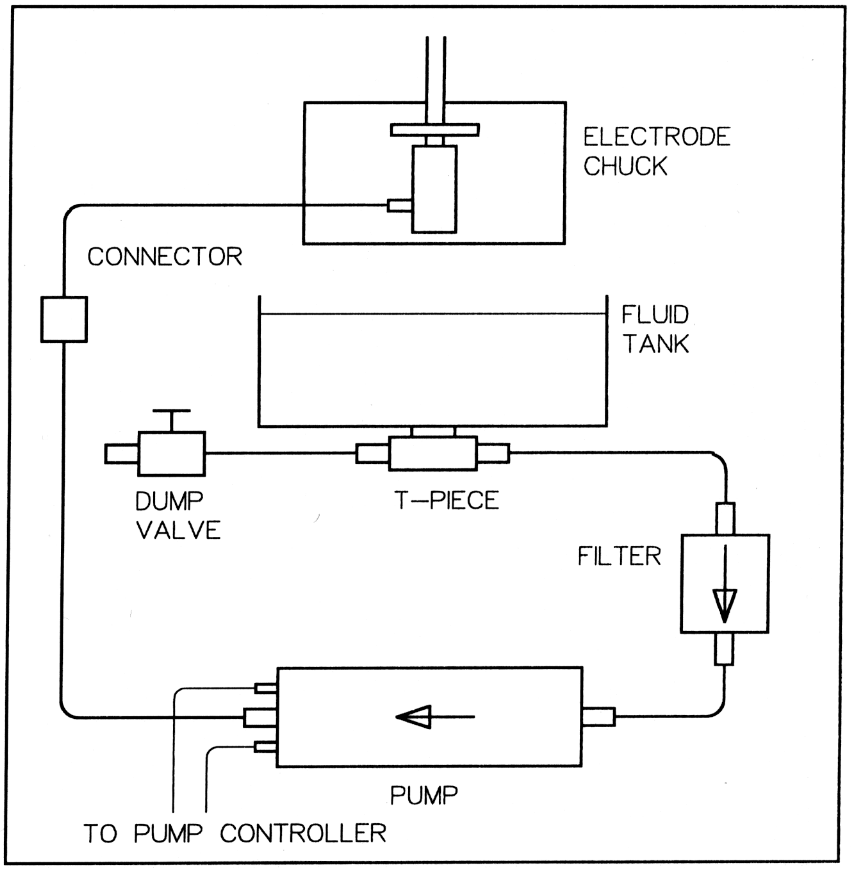

Fig.29. Schematic of fluid circuit

When it's ABSOLUTLY certain that the tank and plumbing does not leak, administer vegetable oil in the tank. Use enough to fill the tank to just above part 9D. Apply 12 volts to the pump motor and test the pump circuit for leaks. The pump must first prime the circuit since there may be air in it. Run the pump for about 5 minutes (the motor should not overheat). There is always some fuel left in the pump. The odor will be evident (keep away from sources that may ignite this). Discard the oil appropriately and repeat the procedure using fresh oil. Repeat this procedure until the scent of fuel is no more. Do not use this oil for EDMing, it may now be much more flammable. Attach the appropriate connectors to the connector rack, part 14D. The EDM connections require an electrically insulated heat resistant standoff (trespa) so that no short circuit is possible (see DR.20). Mount and secure part 14D to the base plate 13D. Connect the wiring. If the guide way assembly is to be used for remote use as well then extra connectors between the connector rack and motor/home switches should be spliced in.

When the system is in use an air pocket may start to reside in the filter. Try to avoid this.

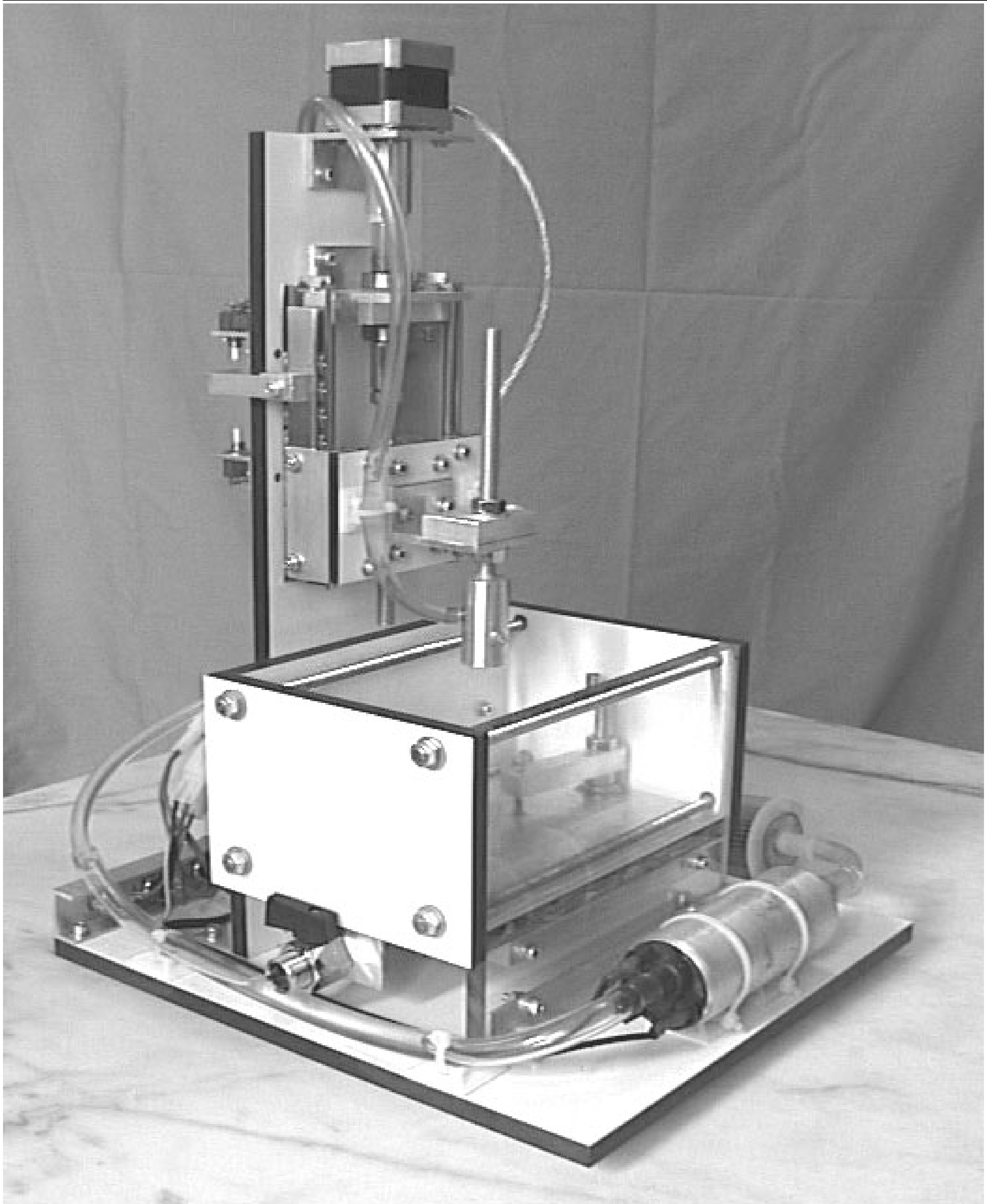

Fig.30. Completed assembly

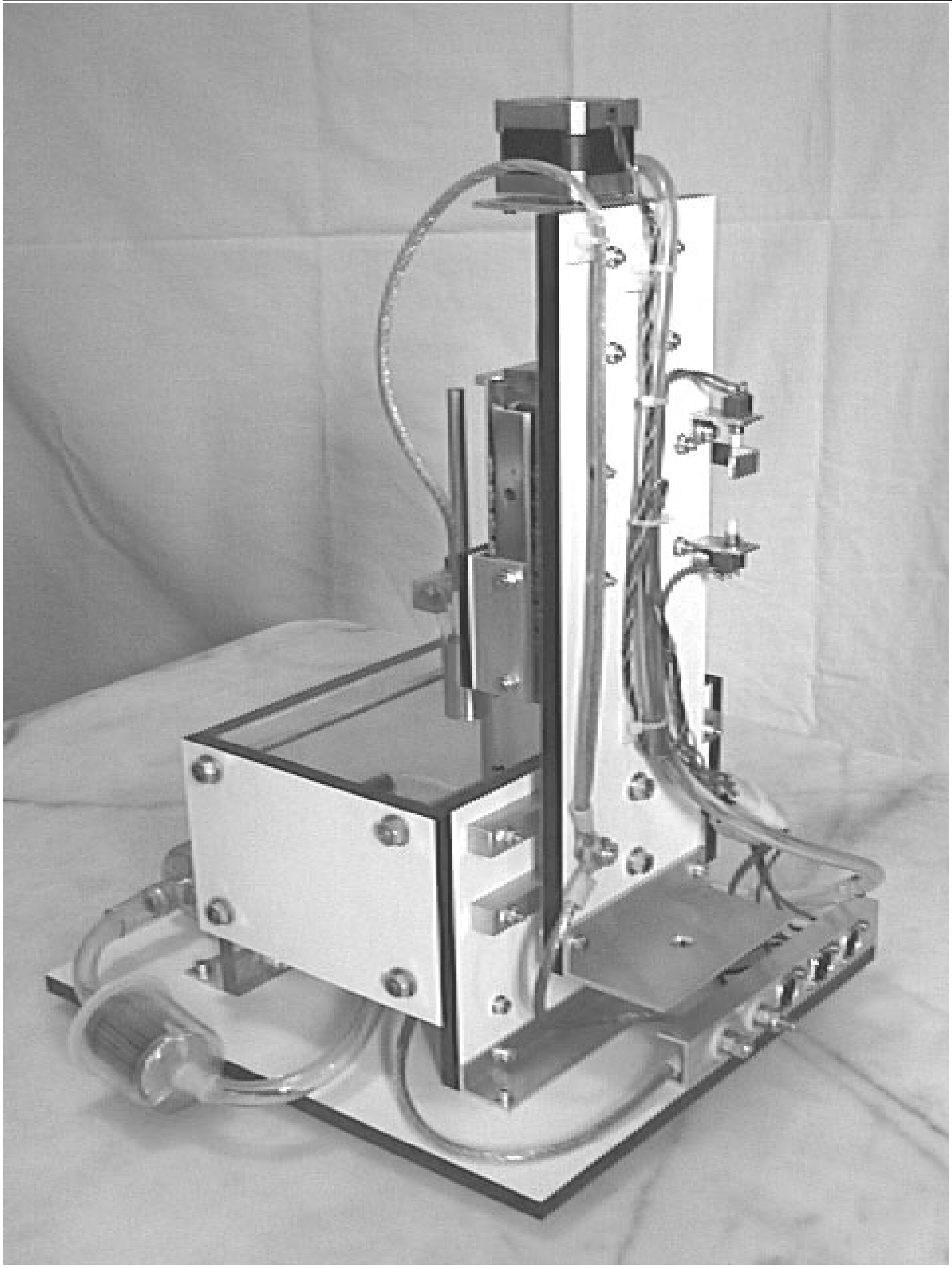

Fig.31. Completed assembly

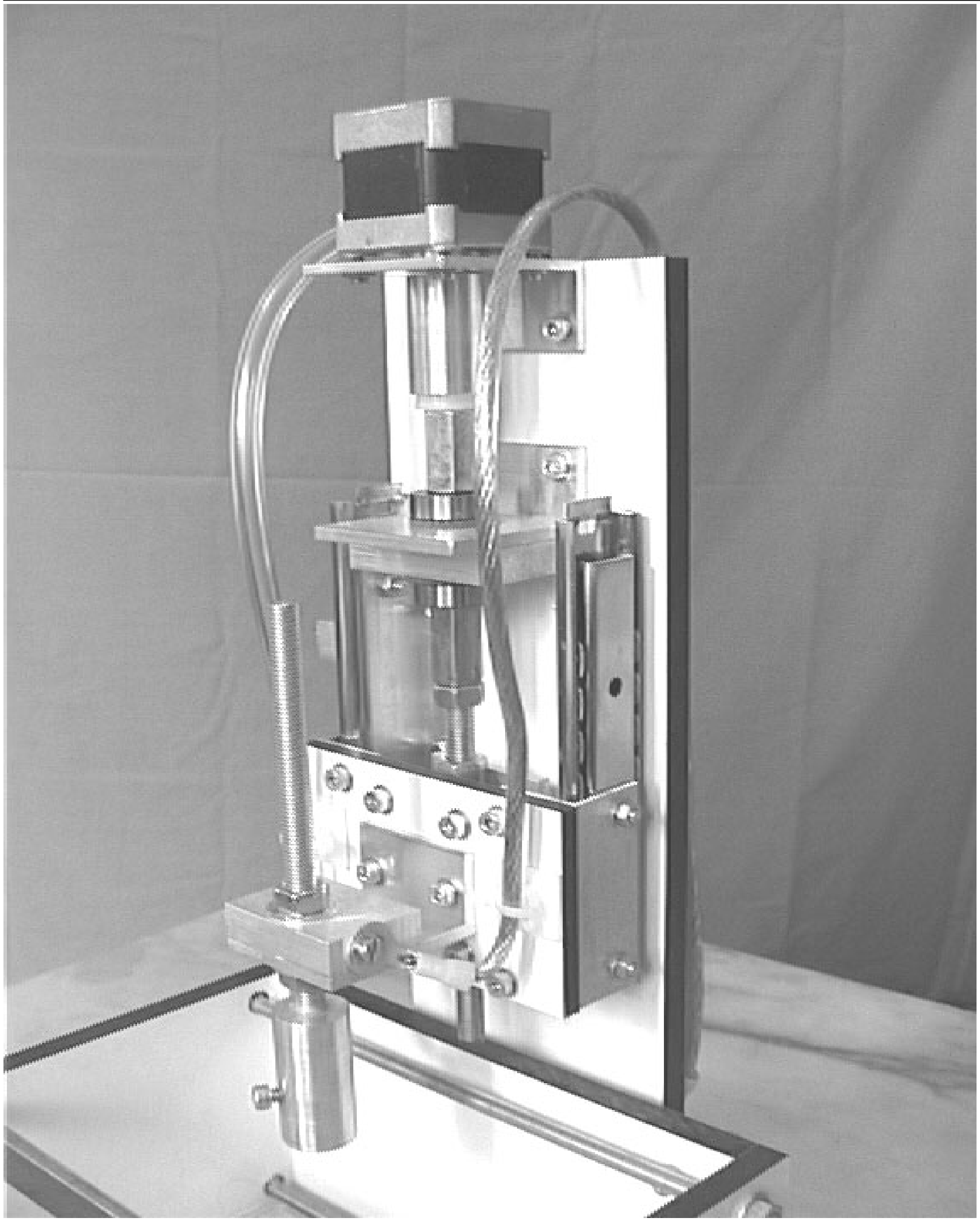

Fig.32. Completed assembly

7. Software and Interfacing

The software that accompanies this manual is called testware as it only includes the most essential instructions for the SEDM unit to perform. A supplier of more advanced software will become available.

An executable file of the testware is provided on the disc. This is called TESTWARE.EXE. The disc also has a README.TXT file to assist in the installation and use of the program. The last two files, which saves and reads program settings, are called MSF.DAT and MTSF.DAT. These files should not be tampered with.

The contents of the disc need to be installed on the hard disc in a directory named C:/SEDMTW/. Although the program can be used in Windows it should always be “run” in DOS (do not run Windows for the SEDM unit, this is a less stable environment).

The PC communicates with the SEDM unit (the outside world) through the parallel port. The parallel port is normally used as the printer port. It allows fast transmission and reception of data. Yet it's probably the most sensitive port and requires careful use to protect from damage. For this reason it is highly recommended that the PC be equipped with a parallel port that is not part of the motherboard. Otherwise, in case the port shorts out it could have repercussions for the motherboard. For the same reason it is best to use an old 386 or up PC for the SEDM application.

7.1 The Parallel Port

The PC's parallel port has become one of the most popular ports used to communicate with the outside world. This is with regard to motion control systems and robotics. The port usually has a 25 or 32 pin connector. 8 of these pins are for output while 5 are for input and 4 are bi-directional. The other pins are GND pins. For this unit only 2 output pins will be used and 3 of its input pins.

Each output and input pin represents a single bit of information. The parallel port can output 8 bits simultaneously. In other words, in parallel. This makes it very fast for most purposes.

The parallel port pumps out information in binary code. Binary code represents characters as bits, or in this case as 8 bits large. For example: the number "3" is represented as 00000011 (8 digits large). Each of the 8 digits is represented by a bit at the output pins of the port. Take into account that the binary number must be read from right to left. The most right digit represents the "Least Significant Digit". If the number 3 is output to the port then the first 2 pins will change while the remaining 6 pins will stay at their current settings. A few examples of decimal digit to binary digits translation:

```
Decimal binary
0       =  00000000
1       =  00000001
2       =  00000010
3       =  00000011
4       =  00000100
```

The LSD represents a binary number with the decimal value of "1". This is because "2" to the power of "0" is "1". The next digit represents a value of 2. This is because "2" to the power of "1" is "2". The next digit represents a value of "4" since "2" to the power of "2" is "4", and so on. As explained the decimal number 3 is represented by the binary number 00000011. This binary number can be read as follows: start at the LSD, which is a binary "1" and is a decimal "1" as well. The next binary digit is also a "1" which represents a decimal value of "2". The rest of the 6 digits are all "0" so they can be ignored (zero means: not-active). Hence, "1" + "2" is 3. It's that simple.

As previously explained, the driver has two inputs namely, Step and Direction. An example now follows which will illustrate how the driver receives instructions from the parallel port: The step line of the driver is connected to the first output bit of the parallel port which is the LSD. The direction line is connected to the following bit. When the software pumps out a number "3" (hence, a 00000011), to the parallel port, then the step line and the direction line of the driver will both receive a signal. Consequentially the motor shaft will turn one step in a particular direction. If the number "3" is then again pumped out, the shaft will also once again turn one step in that same direction. If the number "1" (hence, a 00000001) is then pumped out, the shaft will turn one step in the opposite direction. It turns in the opposite direction because the second digit from the right is now a zero. The direction line is now low. The signals from the feedback circuit and the home switches follow a similar idea. Only these are input signals to the port.

The speed at which the shaft rotates is set by first looping the output. What this means is that the program source code instructs the computer to pump out, for example, the number 3 over and over again. Instructing the PC to pause or “delay” for a moment after each output sets the speed of the motor. Lowering the value of the delay will result in faster steps and hence higher motor RPM. Naturally the amount of steps that the motor can make per second is restricted. If the speed is to high the motor will simply not run.

The complete schematic of the parallel port hook up can be found in "The Electrical Setup" section of this manual.

7.2 Software

The essential workings of the testware program can be summarized as follows: the program manages and controls the SEDM process based on program settings that the user has entered, in the "Setting Up" sections. It reads this information and also reads input signals from the home switches and the EDM feedback circuit. Based on this information it writes (outputs) information to the stepper motor driver accordingly after the program is instructed to "Start Machine Task".

8. Testing

There are a number of general precautions and guidelines that should be taken into account when using the SEDM unit:

- Turn the PC on before the driver is turned on. The PC may perform procedures, which activate out port pins. Always turn off the PC before hooking up or removing the parallel port connector, or for that matter any connection.
- Long cables to the port should be avoided as the port uses 5 volt logic to communicate. Long cables provide much resistance and can thereby degrade the voltage.
- The printer port interface for the SEDM unit is not optically isolated. This means that the port is not protected from the outside world. In practice this has never proved a problem. Double check that the connections to the port are correct, careful not to cross wires. Do not detached motor leads while the driver is powered. This may induce voltage spikes, which may run back into the port and destroy it.

Except for the EDM circuit/machine connection, hook up the rest of the circuits and "run" the SEDM testware program. The following will appear on the screen respectively (default settings are already listed):

```
S-EDM for the Home Shop

-Testware-

Version 1.0

Copyright 2000 Proved by Practice Publications

Press Enter to continue
```

```
Warning:

Make sure that EDM circuit is turned off

Press Enter to continue
```

```
Main Menu

Press 1: Machine Setup
Press 2: Machine Task Setup
Press 3: Input Test
Press 4: Jog
Press 5: Start Machine Task
Press 6: Exit
```

Since this is testware it does not incorporate much luxury. If wrong values are typed in the program may ignore them or not, without giving warning that they are in error. If any connection is not hooked up, the program may not run.

The first two choices of the Main Menu: Machine Setup and Machine Task Setup, require certain values to be entered. These values will be retained on files named: MSF.DAT and MTSF.DAT.

Pressing 1, then Enter, will lead to the Machine Setup. The following will appear (default settings are listed):

```
Enter parallel port address                     :378
Enter unit (mm or Inches)                       :mm
Enter lead screw pitch                          :1.25
Enter step degree of the motor                  :0.9
Enter maximum feed speed in steps per second    :80
Save values and exit?           (y or n)
```

This field allows the user to set primary values for the machine used. The values will be retained even if the program is stopped and exited. However be aware that whenever this field is opened, all of the previous values are automatically erased. This pertains to the field “Machine Task Setup” as well.

The port address used by most computers for the printer is located at port 378. It is best to use a separate printer port at 278 for the SEDM unit.

Field 2, Machine Task Setup, pertains to setting parameter values for a specific task that the user wants to be executed.

```
Enter cutting feed speed in steps per second          :10
Enter feed pause time in seconds                      :2
Enter amount of retract steps                         :100
Enter cut depth                                       :10
Save values and exit?           (y or n)
```

Fields 1 and 2 need to receive values before the functions of any other fields can be used. Field 3 is the Input Test function. This function can be used to determine if the input switches are working and/or properly connected. The function does not detect the initial state of a particular switch (open or closed). Instead it detects if a switch has been opened or closed. It then displays which pin has received a signal and what it must represent (HS1, HS2 or feedback signal). If the test fails (no signals are detected) then the jog function and the Start Machine Task will not work. Check the connections and that make sure that the correct port has been selected. To test the feedback signal, hook up the feedback line to the PC. Turn on the EDM circuit and tap on the EDM terminals using a screw driver.

Field 4, the Jog Function, is used to position the electrode.

```
Jog Function

 Tap "up" key to jog motor up
 Tap "down" key to jog motor down

Press Esc to exit jog function
```

The jog function allows the manual positioning of the electrode chuck. It also gives an idea as to the maximum stepper motor speed.

Jog the electrode chuck up until it reaches its home position (if the sled goes down instead of up then exchange a stepper wire pair but not both). Making sure that the EDM/machine is "off" and not connected, install a copper tube in the chuck to serve as the electrode (If the pumped fluid sprays too much around the electrode tie a skirt made of fabric or a plastic bag around the chuck. Allow the rest of the skirt to float on the fluid). Make sure that the electrode is properly clamped in and tightened. Install a small test work piece (steel) in the tank clamp. The work piece should also be clamped in tight. If the electrode or work piece move from the their clamped positions it will confuse the process and greatly impair the quality of the cut. Unscrew the chuck nuts and lower the electrode so that it is just above the work piece. The electrode should not touch the work piece. End the jog function by pressing Esc.

Turn the EDM circuit on. Use a screwdriver to tap on the EDM terminals. Sparks should result. The feedback relay should react to this by opening and closing.

Choose field 5, Start Machine Task. The following should appear:

```
              Before running the program check the following:

- Work piece clamped in?
- Electrode positioned just above work piece?
- Fluid administered in tank?
- Pump is running?
- EDM circuit turned on?
- Driver turned on?

Press Enter
```

The program will then ask the user if the task is to be started or aborted. By starting the task the motor will then proceed to feed the sled downward. The screen will list that the task is being executed and display the travel depth of the electrode. Pressing any key will pause the task with the option to resume or abort the task.

When, due to sparking, the capacitor voltage of the EDM circuit collapses, the feedback circuit will disrupt the signal to the relay. The relay will then open and cut the signal to the PC. The screen will display that the sled is retracting a set amount of steps from the work piece. After the set amount of steps is completed, the sled will then again resume its feed towards the work piece. This will continue until the capacitor voltage collapses again due to the sparking. The program will compensate for the retracted amount steps each time.

If the electrode continues to retract over and over again without resuming then this may be due to:

- feedback needs to be adjusted (VR1)
- electrode or work piece is not clamped in properly (moving)
- sled feed rate was too high
- connection of the feed back line is faulty
- feedback circuit is not functioning correctly

The adjustment of the feedback circuit can be made by slowly turning the VR1 adjustment. Do this until the position that permits the motor feed to resume moving the sled towards the work piece is found.

The fluid will slowly start to blacken while the machine task is proceeding. The quality of the fluid will not be greatly impaired by this. However larger work piece debris must be sufficiently cleared from the vicinity of the sparking by the pump action.

Always remember not to touch the unit while the EDM circuit is on. The electrode should spark its way into the material until it reaches the specified depth. If the electrode touches the work piece it may weld to it. The electrode retraction may not be enough to break this weld.

Electrode profiles with similar spark surface will need less FBC adjustment. The greater the electrode surface the more critical the sense adjustment. Adjustment is also required when different capacitor combinations are selected.

After the set cut depth is reached, the electrode will then return to the up home position at maximum specified feed. Turn off the EDM circuit and short the terminals. Repeat the procedure with other materials, sizes and erosion depth. The EDM system is dependant on several critical parameters that require proper adjustment. Only trial and error will lead to a better understanding and control of the process. Experiment with the following parameters:

- cutting feed rate
- pause time
- amount of retract steps
- max feed rate

After use, drain the fluid and seal off in a container. Do not allow the fluid to stay in the tank for long periods of time.

Spark your Imagination

Safety Protocol

The following information advises on some areas that may help prevent accidents. It is in no way complete as it is not possible to foresee all scenario's that the operator may encounter and/or create. When working with the SEDM equipment:

- Try not to use both hands at the same time while touching different equipment. If the operator becomes part of the circuit the current may flow through the heart.
- Try to use only your right hand to touch equipment.
- Work in well-ventilated area.
- Minimize ventilation directly over the fluid tank, this can lead to greater oxygen pick-up.
- Drain fluid after use. Clean the tank with a towel. Do not leave towel fibers in the tank. Debris can burn like a candle wick.
- Do not use old fluid.
- Seal fluid in air-tight container after use. If this is not done fluid will pick up oxygen over a period of time. It will polymerize, become more flammable and act as a flame wick.
- Have a fire extinguisher present. Use appropriate type. Remember oil and water don't mix!
- Use shoes with rubber soles.
- Remember, dirty oil is much more easily ignited.
- Flammable substances should not mix with fluid.
- Always use a screw driver with an insulated handle to short the EDM terminals after it is turned off.
- Sparking must occur at least 40mm (1(1/4) Inch) under the fluid level by established norm.
- If other fluids are used, consult safety data sheets.
- Attach appropriate warning labels to the units, which informs of their danger and use.
- Don not leave unit unattended when machining is in progress.

Suppliers

- Camtronics, WWW.SEANET.COM/~dmauch Supplies stepper motor drivers and other related equipment. High-quality and performance at very low cost.
- Velleman, WWW.VELLEMAN.BE Supplies electronics kits. Very well designed.
- Trespa, WWW.TRESPANORTHAMERICA.COM Find a distributor near you (sign-making stores use Trespa a lot).
- Thomas Regout, WWW.THOMASREGOUT.COM Supplies high precision slides at low cost.

Drawings & Lists

Mechanical Setup					
Part Description List					**Table 4**
Part	Qty.	Material	Name	Reserved	Remarks
1A	1	Trespa	Guide Bed		
2A	2	Aluminum	Slide Bracket		
3A	2	Steel	Guide Way		*
4A	1	Aluminum	Offset Block		
5A	2	Aluminum	Gauge Plate		
6A	2	Aluminum	Sled Bracket		
7A	1	Trespa	Sled Plate		
8A	2	Aluminum	HS Bracket		
9A	1	Aluminum	Clamp Bracket		
1B	1	Aluminum	Chuck Bracket		
2B	1	Brass	Nozzle		

3B	1	Aluminum	Chuck		
4B	1	Aluminum	Offset Block		
5B	1	Steel	Shaft		**
1C	1	Aluminum	Bearing Bracket		
2C	1	Aluminum	Offset Block		
3C	1	Steel	Lead Screw		**
4C	1	Aluminum	Coupling		
5C	4	Aluminum	Offset Strip		
6C	1	Aluminum	Bearing Bracket		
1D	1	Trespa	Back Plate		
2D	1	Lexan	Front Plate		***
3D	2	Aluminum	Floor Support		
4D	2	Aluminum	Tank Bracket		
5D	2	Aluminum	Mount Bar		
6D	1	Trespa	Base Plate		
7D	2	Trespa	Side Plate		
8D	4	Steel	Beam		****
9D	1	Aluminum	Floor Plate		
10D	1	Aluminum	Valve Bracket		
11D	1	Steel	Clamp Beam		**
12D	1	Aluminum	Clamp Bar		
13D	1	Trespa	Foot Plate		
14D	1	Aluminum	Connector Rack		
* Thomas Regout Drawer Slide. See Material Description List + Suppliers Section.					
** M8 All thread stud. See Material Description List.					
*** Obtain from advertisement boards outlet					
**** M6 All Thread Stud. See Material Description List.					

Table 4. Parts description list

Mechanical Setup					
Material Description List					**Table 5**
Material	Qty.	Profile	Size	Source	Remarks
Aluminum	1	Square Solid	(12 x 12) L700	Hardware	
Aluminum	1	Corner	(50 x 25) T3; L300	Hardware	
Aluminum	1	Corner	(25 x 25) T2; L150	Hardware	
Aluminum	1	Corner	(25 x 15) T2; L600	Hardware	
Aluminum	1	Strip	(30 X 10) L100	Hardware	
Aluminum	1	Strip	(15 x 4) L200	Hardware	
Aluminum	1	Strip	(10 x 2) L100	Hardware	
Aluminum	1	Round Solid	D20; L100	Hardware	
Aluminum	1	Plate	L170; W90; T4	Hardware	
Aluminum	1	U	(15 x 25 x 15) T2; L160	Hardware	
Brass	1	Pipe	D4; L50	Hardware	
Trespa	1	Plate	L180; W140; T10		* + **
Lexan	1	Plate	L180; W140; T10		* + **
Trespa	1	Plate	L180; W120; T10		* + **
Trespa	2	Plate	L140; W100; T10		**
Trespa	1	Plate	L290; W260; T10		**
Trespa	1	Plate	L330; W100; T10		**
Trespa	1	Plate	L98; W60; T6		**
Steel	1	Stud	M8 All Thread L1000	Hardware	
Steel	1	Stud	M6 All Thread L1000	Hardware	

Steel	Pair	Drawer Slide	L300; W27; S185	Hardware	Without Bracket
D = Diameter; L = Length; W = Width; T = Thickness; S = Stroke					
* L180 must correspond exactly for each part					
** See Suppliers Section					
Note: Unit = mm					

Table 5. Material description list

Mechanical Setup			
Component Description List			**Table 6**
Component	Qty	Description	Source
C1	1	NEMA 17 Bipolar Stepper Motor, 22 ozin holding torque	Camtronics
C2	2	Switch, normally closed, momentary type, small	Electronics
C3	2	Radial bearing, rubber sealed, OD 22; ID 8; T7, pre-lubed	Hobby
C4	2	Fiber washer/gasket, used in plumbing, OD 24; ID 20; T2	Hardware
C5	1	Coil spring, OD 20; ID 18; L50	Hardware
C6	1	3-way plumbing section (T-section), PVC or brass, small	Hardware
C7	1	Fuel filter, axial flow	Automotive
C8	1	Valve, teflon sealed, ball type, small	Hardware
C9		Reserved	
C10	1	Fuel injection pump with integrated DC motor, 12Volt	Junkyard
C11	-	Plumbing, should match pump + filter etc.	Hardware
C12	3	Foot pegs (use door stops)	Hardware
C13	25	Tie wrap mount, small	Electronics
C14	50	Tie wraps, short	Electronics
C15	8	Cable terminal connector, ring type	Electronics
C16	2Mtr.	Elec. Speaker wire, thick, highly stranded	Electronics
C17	4	Hex nut, M8, L24	Hardware
C18	7	Hex nut, M8	Hardware
OD = Outer Diameter; ID = Inner Diameter; T = Thickness; L = Length			
Note: Unit = mm			

Table 6. Component description list

Mechanical Setup				
Fastener Component List				**Table 7**
Qty	Description	Size	Material	Type/Remark
8	Washer	M8	Steel	Round
2	Washer	M8	Nylon/rubber	Round
1	Bolt	M8; L10	Steel	Internal hex, cyl.
16	Nut	M6	Steel	Hex
20	Washer	M6	Steel	Round
16	Washer	M6	Nylon/rubber	Round
2	Bolt	M6; L15	Steel	Internal hex, cyl.
1	Bolt	M6; L20	Steel	Internal hex, cyl.
2	Set Screw	M4; L5	Steel	Internal hex, headless bolt
4	Bolt	M4; L5	Steel	Hex, low head height
8	Bolt	M4; L10	Steel	Hex, low head height

4	Bolt	M4; L 20	Steel	Hex, low head height
2	Bolt	M4; L 10	Steel	Internal hex, cyl.
1	Bolt	M4; L 15	Steel	Internal hex, cyl.
24	Bolt	M4; L 20	Steel	Internal hex, cyl.
2	Bolt	M4; L 25	Steel	Internal hex, cyl.
5	Bolt	M4; L 30	Steel	Internal hex, cyl.
4	Bolt	M4; L 35	Steel	Internal hex, cyl.
46	Nut	M4	Steel	Hex
40	Washer	M4	Steel	Round
6	Washer	M4	Nylon/rubber	Round
L = Length				
Note: Unit = mm				

Table 7. Fastener components