

# SHAGMATIC BUILD MANUAL

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# L E G A L D I S C L A I M E R

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## PART 2. WHAT IS THE SHAGMATIC MACHINE

The Shagmatic is a Do-It-Yourself novelty sex machine. This manual is its documentation and build instruction. The current design is the result of developing and building Sex Machines for over five years. As in all designs, it is a compromise between a number of factors. The most important of these is to provide a unique and pleasurable experience through the use of the machine. The intention is to provide a different experience from that obtained with other machines. The key to this is the "joystick" controller and the way in which the machine follows its instructions. Most sex machines produce repeated motion. The most sophisticated can be "programmed" with some degree of variation. This machine is completely different. It responds to human input. It is essentially a force amplifier. Any movement of the joystick is reproduced with greater force by the motion of the machine. It is both very sensitive and very powerful. I believe that this machine represents a very reasonable choice of operating specifications, however the design is very adaptable and anyone who with different opinions can vary the design to suit their needs. A faster, more powerful machine is possible but the cost will be very high. A machine that produces absolute motion with precision is also possible but will also be expensive and probably dangerous.

The design uses a friction drive wheel. This provides simplicity along with a degree of safety. If presented with too great a resistance to motion of the ram, the wheel will slip protecting the user. The machine is adjustable for different degrees of force/slip. If a machine with no chance of slipping and better approximation of absolute positioning, it can be built with a direct drive mechanism such as a timing belt and pulley. Machines of this sort have been tried, but I changed to the current design for a number of reasons. The chosen motor is a compromise between power and ability to accelerate. The motor was chosen for its large shaft and bearings. A smaller diameter motor with a smaller shaft can accelerate faster but it is weaker and requires an outbound bearing for support of the weaker shaft. This adds complexity and requires more precise machining. If a faster accelerating machine is desired it is suggested that a Nema 27 double stack hybrid stepper motor of use the highest torque obtainable instead of the Nema 34 motor.

It is also possible to build this machine with a servo motor that is controlled with a step and direction controller for a brush type servo motor such as the one made by Gecko. This adds additional cost and complexity and also requires the use of overheat protection for the motor unless a very expensive motor with internal thermal protection is used. The reasons mentioned above along with several others have resulted in the current design. If you build the Shagmatic or are interested but are concerned about its limitations, I can provide suggestions as to how to adapt the build to your needs. Be warned that the cost of components may be very high for the "ultimate" machine

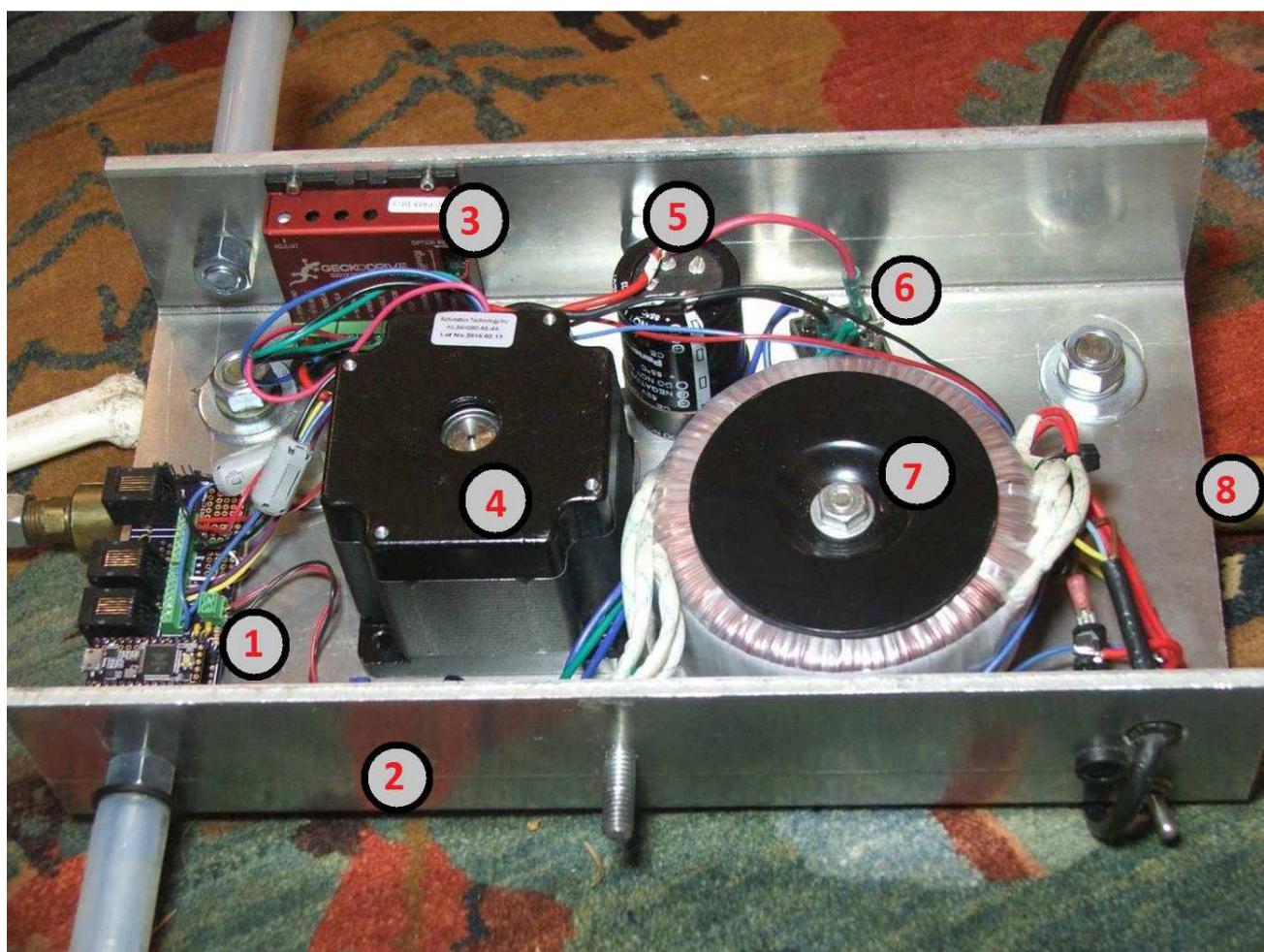
## PART 3. BUILDING YOUR OWN SHAGMATIC

### 3.1. OVERVIEW

So you want to build your own Shagmatic. Congratulations on being an elite kinky person willing to put so much time and effort towards the pleasure of others (or yourself). Be sure to read the manual well before starting your build. Expect parts costs around \$ 400 and hours anywhere from 10 to 100, depending on your skill, experience and tool set.

The machine consists of three major assemblies and two user interface options. The major assemblies include the motor unit, the power supply/electronics unit and the support assembly. Each of these assemblies can be built exactly to plan or may be modified to suit the needs of the individual builder. In this document I will make it clear which dimensions and parts choices are considered critical and should not be changed. I will also suggest which design aspects may safely be modified. A lot of time was spend developing this design. Many alternative choices were rejected so before making changes, either substantial or minor be sure to read the recommendations in this document carefully to avoid building an inferior machine.

That said, check out what you'll be building on the overview on the next page.



Main components overview

### 3.1.1 COMPONENTS OVERVIEW

1. Shagmatic board – where controllers go and programming resides
2. Chassis – U-profile or wooden box
3. Controller board – where the motor gets its power (based on instructions from the shagmatic board.)
4. Motor – This is the stepper motor making the RAM assy move
5. Power supply Adapting the voltage of your 110 VAC (US, Japan) or 230VAC (Rest of world) to ~50VAC.
6. Ram assembly – The steel shaft moving back and forth when the machine is in use.

## 3.2. BEFORE YOU BEGIN – CHECKLIST

### 3.2.1 TIPS LIST

Here is a list of tips that will prove useful when building your machine. Tips may be repeated in other sections as well.

1. There are many ways to approach the construction of this machine. You can follow one particular design/plan exactly or you may make changes as you see fit. Understand that this machine in its variations is based on over 40 years building and fixing electronic and mechanical devices. I will attempt to provide useful tips based on this experience. If you do not think some suggestions are important, think again before you decide to ignore them.
2. Most of the suggested tools are not in fact necessary. The whole machine could be built with a sharpened stick and a flat rock but it might take forever and not turn out too well. If you appreciate good tools and like to collect them, by all means get every one listed in the recommended tool list.
3. Whenever drilling holes in the chassis enclosure or elsewhere, be sure you know where the drill bit will go once through the hole. If you are working on a partially assembled machine, do not make the mistake of drilling into a mounted component. **DO NOT DRILL ANY HOLES IF THERE IS EVEN A SLIGHT CHANCE OF DRILLING INTO THE TRANSFORMER, THE CONTROL BOARD OR ANYTHING ELSE OF VALUE. REMOVE ALL VALUABLE COMPONENTES IF THERE IS ANY CHANCE OF DRILLING INTO THEM.** You may wonder how I learned this important lesson (not very well the first time as I later did it again)
4. The stepper motor is best mounted with no 10 screws which fit the mounting holes easily. However, there is very little clearance for the nuts if they are placed inside against the motor flange. This is because the motor design is pushing it for a Nema 34 motor and the housing is in the way of regular sized nuts. There are a couple of ways to deal with this. First of all, do not install all four screws until you are pretty sure the motor will not be removed again. Use regular nuts until you are sure the motor will stay mounted. Then you can use Nylock nuts which are difficult to hold while tightening because a nut driver or socket will not fit unless it has a very thin wall. You can hold the nuts with just the right type of small pliers or you can use a large blade screwdriver to hold the nut against the motor housing. You can also mount the nuts on the outside of the box instead of inside. If you do this make sure the screws and nuts do not protrude so far as to hit the ram tube. Most likely you will have to cut the screws short from a standard length. The most elegant solution is to use coupling nuts which stand very tall. You need to cut slots in the ends of the nuts to receive a screwdriver. I have seen nuts of this type but do not know where to buy them. It is also possible to use smaller screws such as no 8 and to use washers to spread the load on the top plate and motor flange. Be sure to use strong screws such as stainless steel or grade 8.8 steel. Lower quality screws will not be strong enough in the smaller size. Narrow hex nuts may also work but are difficult to find. McMaster Carr does sell them.
5. Grounding in the wooden / Corian box is only required for components that are outside of the box and that could come into contact with high voltage AC current. The only component that requires grounding in this design is the stepper motor. It runs on 64 volts or less DC which could give an annoying shock so it might as well be grounded.

When connecting the ground terminal to the motor flange via one of the mounting screws, be sure to scrape the paint off the flange to insure a good electrical connection. The mounting screw for the transformer is adequately insulated from the transformer by the rubber mounting washer so it is not necessary to ground this screw but feel free to do so if you want. The most important things to do are to use a 4 amp fast blow fuse on the AC input so that any shorts will be likely to blow the fuse and cut off the AC current. Put the fuse on the black or "hot" cord lead. This is also the lead that should be switched. On 220VAC power grids use a 2A fuse.

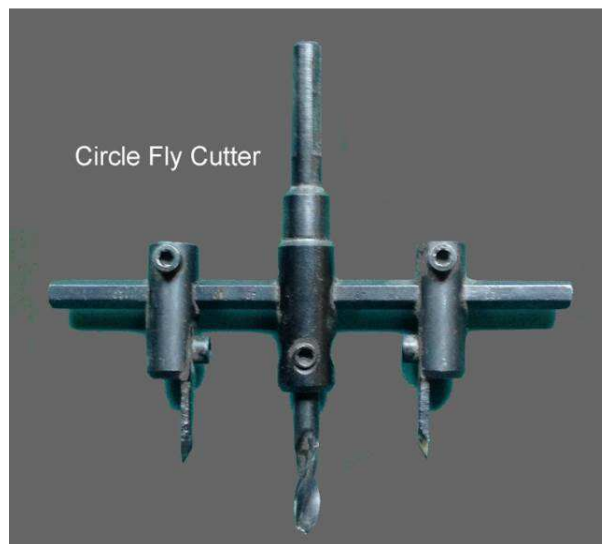
6. The filter capacitor will hold a charge for about 30 seconds once the power is shut off. If for any reason you want the machine to power down sooner so that you can restart it more quickly, you can install a bleed resistor across the filter capacitor. I do not recommend this unless you are constantly starting and stopping the machine in an unusual application.
7. It is not especially easy to burn up any of the components used in this machine if one is reasonably careful. The Gecko G201X (stepper driver) is protected against most faults but it is not protected against reverse polarity input so be sure to test the polarity before connecting it. The G203V is protected even against reverse polarity input but it will blow an internal fuse that will need to be replaced. If you are not good with wiring electronic components it might be good to invest in the more expensive G203V. All connections other than stepper motor power supply are 5 volts or ground and are very unlikely to cause any damage even if connected incorrectly. Still it is a good idea to check the wiring several times before energizing the circuits. Remove the Teensy board and check the polarity of the voltage at the input connector with a multimeter. Then turn off the power and plug the Teensy back in once you know the polarity is correct. Reverse Polarity will destroy the Teensy.
8. The stepper motor needs to be connected correctly in order to work properly. As long as you connect the four wires to the A and B phase connections on the stepper driver, no damage will be done but it will not work correctly unless the wires are connected properly. Measuring between pairs of the 4 wires will show low resistance between some pairs of wires and open circuit between other pairs. The ones with low resistance will be the motor phase coils. These pairs should be connected as pairs to the A and B phase connections as shown on the driver. Do not worry about which pair is connected to A or B and do not worry about the polarity of either pair. Once the machine is assembled fully and turned on with the ram shaft in place, it will begin the boot process. At the end of the process the ram will move fully forward until the limit switch is reached. It will then withdraw fully to the other switch. If it moves backwards first, the motor is connected incorrectly. All you need to do is reverse the two leads on one of the phases. Do not reverse both, just one pair. The motor will then move in the correct direction.



### 3.3. REQUIRED TOOLS LIST

The following tools are recommended but the creative builder should be able to get by without some of them

- table saw or chop saw or miter box
- drill press and or hand drill
- fly cutter for large motor hole
- 7/8" forstner bit for rj connector holes
- letter E drill bit or 1/4" drill bit
- misc small drill bits
- screwdrivers flat and phillips
- wood clamps or binding strap to hold frame while gluing
- soldering iron or gun
- cigarette lighter for heat shrink tube
- saber saw for idler slots file for slots, can use keyhole saw
- wire cutters and strippers
- hack saw
- misc pliers and adjustable wrenches
- socket wrench set helpful but not necessary
- punchdown tool if using 8 wire socket for 3 knob control
- sandpaper, paint brush for finish
- countersink if using flat head screws for box assembly



A circle fly cutter is very useful for making the large hole for the motor.

## PART 4. PARTS LIST

Description	Spec	Link	Unit price	System Price
NEMA34 465 oz-in Stepper Motor	KL34H260-60-4A	<a href="#">here</a>	\$59,00	\$59,00
G203V or G201X Digital Step Drive (G203 is fully protected)	G320-X	<a href="#">here</a>	\$121,00	\$122,00
drive wheel custom made				
idler rollers custom made				
tire for drive wheel, 2" urethane shore A duro 40		<a href="#">here</a>		
tire for idler wheel 1.5" OD EPDM 1/8" wall thickness		<a href="#">here</a>		
tube for drive ram custom knurled				
bushings to hold limit switch magnets in ram tube (part of adapter below)				
custom adapters for drive ram 1 or two for single or double ended system				
rubber bumpers for ram (optional)				
encoders for two knowbcontroller with switch		<a href="#">here</a>		\$1,38
encoders for two know controller without switch		<a href="#">here</a>		
Teensy 3.1 microcontroller included on controller board		<a href="#">here</a>		
8 position .1" spacing headers for in out connections		<a href="#">here</a>		
3 position 5.08 mm header for power entry		<a href="#">here</a>		
custom Shagmatic board assembled				\$150,00
hall effect switches ATS 137		<a href="#">here</a>	\$2,00	\$4,00
neodymium (sp) magnets for limit switch	TBS			
torroidal transformer, check for best voltage before buying	AN 2222	<a href="#">here</a>	\$29,00	\$29,00
bridge rectifier 4 amp 100 volts or anything more			\$4,00	\$4,00
filter capacitor 20000 mf 100 volt				\$5,50
capacitor bracket Use 1.25" emt conduit clamp				\$0,50
power entry module with switch mfg Adam Tech IEC-GS-1-100 Jameco	2095525		\$2,95	\$2,95
misc 3/8"bolts nuts etc. to mount idlers				
misc set screws for drive wheel etc				
1 1/2" ABS or copper tube for toy holder				\$0,50



quick connects for toy holder (harbor freight or other source)				\$4,00
1/4" close pipe bushing for quick connect to ram				\$0,75
joystick encoder EMS22Q51-D28-LT4-ND (digikey)				\$41,56
joystick wheel (hood bumper available at auto supplies =)				\$2,00
3/4" PVC pipe 4" for joystick housing (buy 2 ft length)				\$2,00
3/4" PCV pipe cap for joystick housing				\$0,35
modular jack RJ11 6 wire Jameco		<a href="#">here</a>	\$1,25	\$2,50
modular cable 7 ft 6 wire Jameco	115617		\$1,95	\$1,95
misc wire for signal and power				\$2,00
material for uprights aluminum steel or other material				
material for base				
materials to build power supply and electronics enclosure				
bolt to hold drive unit to uprights				
nuts washers and spacers to connect bolt to uprights				
clamp lever for above bolt				

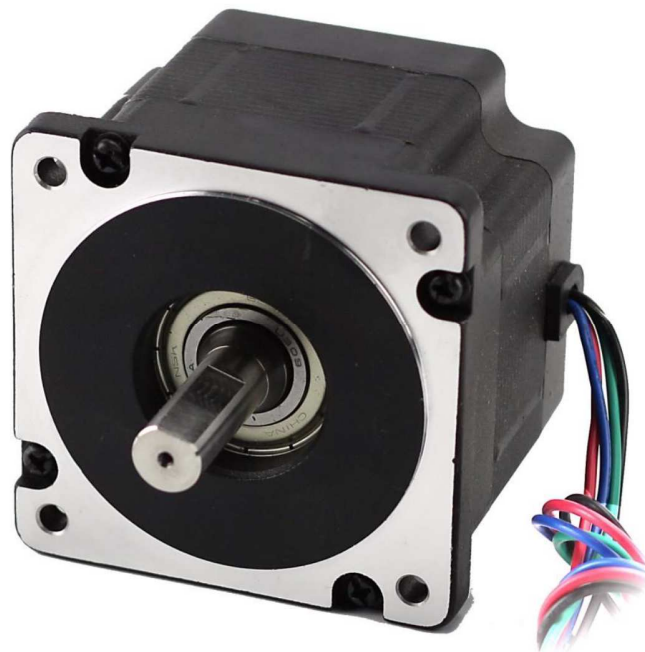
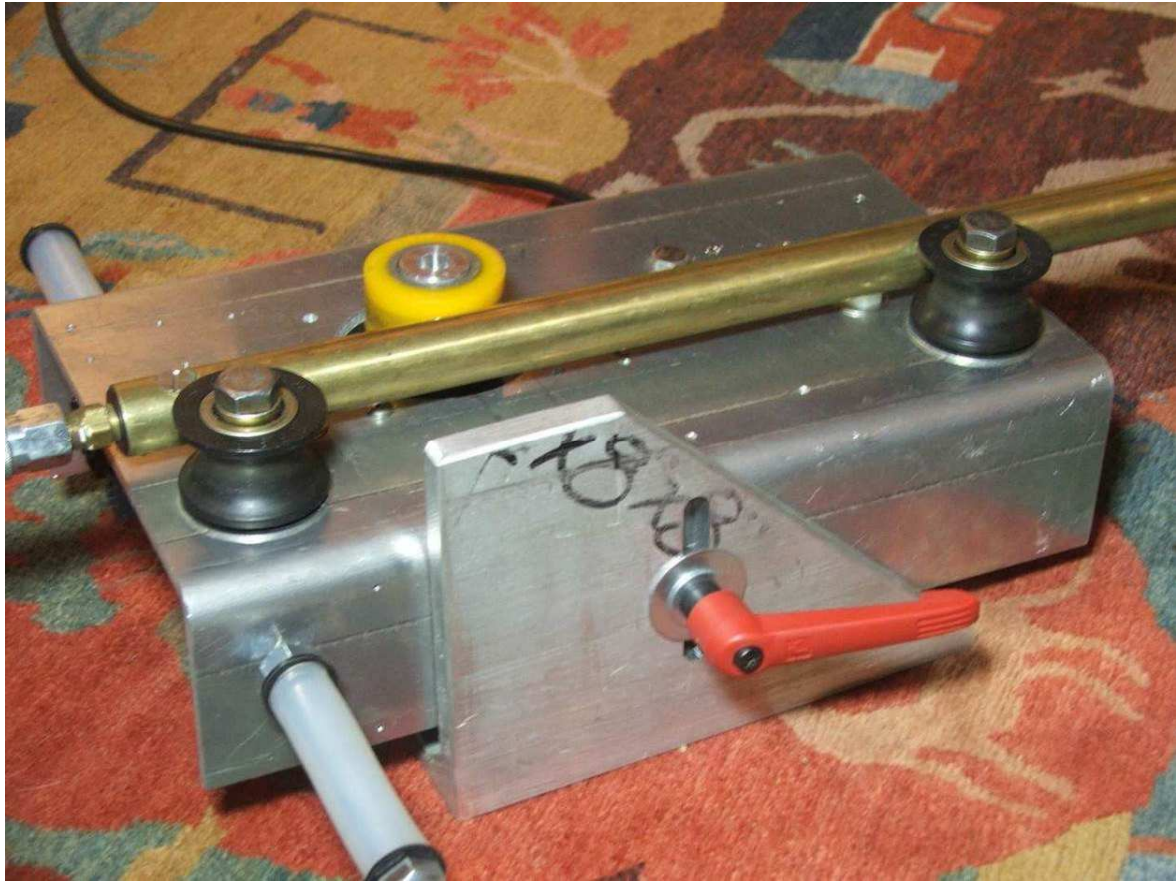
## PART 5. SHAGMATIC COMPONENTS

### 5.1. MOTOR ASSEMBLY

The latest design is a box made of Corian plastic sheet and hardwood. The design looks very promising and is much more attractive. Pictures and details will be added to this manual and this new design is likely to become the default.

The design shown below consists of a base plate on which is mounted the motor, two idler wheels and limit switches. This design uses a U channel of 1/4" aluminum. This plate may be made of steel, aluminum, engineering plastic such as PVC or high quality plywood or MDF board. A template is provided from which a 1/8" steel plate may be fabricated. It is recommended to use a suitably thicker material if using aluminum or other material. There should be no flexing of the plate between the motor and the idlers. If thicker material is used, it may be necessary to mortise the motor into the back of the plate in order to put the motor shaft forward enough. For this reason, it is highly recommended that the plate be made of steel or aluminum no more than 3/8" thick. 3/8" Corian seems to be perfectly suitable for the top plate as well as any high density quality cabinet grade plywood. It is necessary to enclose the power transformer and other high voltage AC components in a grounded metal enclosure or to isolate them completely from other metal components and to enclose them in protective insulating material. This may be accomplished by either enclosing all high voltage components in a grounded metal enclosure or to isolate them from user contact with insulating material. Plastic and wood serve this purpose well. It is highly recommended that this machine always be connected to a GFCI (ground fault circuit interrupter) either an outlet with this circuit or a separate power cord or strip with a built in GFCI. In addition, the motor and any other exposed metal components that may contact high voltage must be connected to the ground wire. This is not necessary for the ram tube so long as all other parts are well grounded.

If a metal enclosure is used, the stepper driver and rectifier bridge should be mounted onto the metal to provide heat dissipation. If a metal surface of sufficient area is not provided in the design of the enclosure a separate heatsink may be required for the bridge and the stepper controller. This machine draws only a few amps through the rectifier so if a 40 amp or larger bridge is used, a heat sink is not necessary. Rectifiers are cheap so buy one much larger than necessary. The Gecko driver will require heat sinking if the current limit is set at over a value listed in the manual for the stepper driver used. The Gecko drivers are thermally protected and will not burn up if overloaded but the machine will stop working and may resume with unexpected motion. It is essential to provide adequate heat dissipation to the controller. A 1/8" thick piece of aluminum of 8 to 10 square inches surface in free air should be adequate. Do not glue it directly to an insulating surface such as wood as air must be free to circulate around the metal. A commercially made heat sink of adequate size may also be used. Be sure to use heat conductive grease or a heat conductive pad between the Gecko and the heatsink. Tighten all screws evenly to insure good contact between the Gecko and the heatsink.



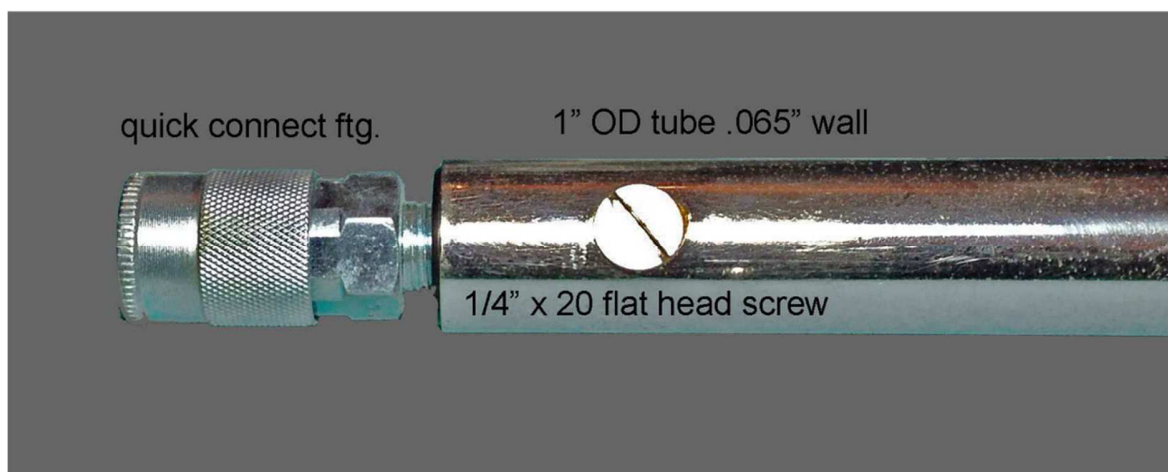
## 5.2. MOTOR

Connect the stepper motor to the controller according to the instructions provided with the controller. Four wire steppers are the easiest to connect. Just connect the two wires of each phase to the marked terminals on the controller. A multimeter or continuity tested should be used to determine which pairs of wires connect to the same phase coil. Low resistance will indicate pairs of wires connected to the same coil. If the motor runs backwards, switch the wires of just one of the phases. Motors with 6 require that you determine which wire are the common center connection of each center tapped coil. These wires will not be used and should be insulated so they do not contact anything else in the system. Eight wire motors generally require consulting the data sheet and also choosing the way you are going to wire them, series or parallel.

Wires from the controller to the motor should be kept as short as possible. If you are using a separate power supply/control box, try to keep the motor wires away from other wiring or components. You may shield the cable that houses the motor wires but do not ground it anywhere or you will cause interference to the Shagmatic board or joystick controller.

## 5.3. RAM ASSEMBLY

### 5.3.1 RAM BACICS



The ram tube is undergoing redesign to suit tubes of different wall thickness and different attachments. Information will be updated once the new design is finalized. Additional toy holders will also be shown including a "Vaculock" attachment.

The Ram is the metal shaft providing the motion on the machine, powered by the motor. It has toy holders on it's ends, see details in the build steps part of the manual. The ram tube is made of 1" OD 1/8" wall aluminum brass or stainless steel tubing. Quick connect air fittings are used to allow easy replacement of connected toys. A bushing is needed to adapt the 1/4" pipe thread of the quick connect fittings to the 1" tube. The bushing is a tight press fit into the tube so it might be helpful to sand it until it fits more loosely. It has a hole through which a 5/16" x 2 1/2" flat head machine screw is inserted to hold a 1/8" to 1/4" pipe thread adapter. A nylock nuts is placed on the inside end of the screw. Once the screw and nut are securely tightened, the quick connect fitting is screwed onto the bushing. It is a good idea to use thread locking compound such as loctite to make sure it does not loosen. See the ram tube pictures for details. Thin wall stainless steel or brass may be used but the size of the bushing and magnet holding grommets will be different. The length of the tube need to be minimally the desired maximum stroke length plus the distance between the idler rollers plus an additional 4 inches.

If the machine is to be located at a distance, a longer tube is required. There is no limit to how long the tube may be but additional mass of the tube will limit the acceleration rate of the machine. If a long tube is used it is advisable to use the lightest material possible. It is also possible to extend the reach with a longer length of 1/4" pipe used on the toy connector type 1 shown below.

The current design uses a thin walled tube that is easier to find at building supplies and other common places than the .125" wall tubing suggested previously. This tubing has a wall thickness of approximately 1/16" or .068" A nylon bushing 3/4" by 2" with an ID of 5/16" is used instead of a custom machined part. This allows either a 5/6" bolt or a 1/4" bolt or machine screw to hold the 1/4" to 1/8" pipe bushing. If a 5/16" bolt is used, the head will have to be turned or sanded down so it will fit inside the quick connect fitting when it is screwed onto the pipe bushing. Use vise grips or clamp the rounded off bolt end while tightening the nut. The 3/4" bushing will be a loose fit in the thin walled tube. It will fit tightly in the .125" wall tubing and may need to be sanded to fit. If using the thin wall tube a shim will be needed. This can be made out of .009" to .010" soft sheet aluminum. This may be purchased in small quantities from any building supply as general purpose flashing. A length of approximately 16" will shim the bushing tightly in the tube. Cut a length of 2" wide material 16" long. If using the thin flashing metal only a sturdy pair of kitchen scissors will be needed. Other thicknesses of shim material may also be used but you will have to experiment with different lengths until you get a tight fit. In order to fit the shim to the tube you need to curl it over a 3/8" or so rod. A 3/8" bolt will suffice. Be sure to form the end of the coil to a tight radius. Roll the shim tightly by hand and then reverse the winding to put the outer end of the coil inside. then roll it a few more times. Eventually you will be able to insert the coil in the tube and expand it to fit well when fully expanded in the tube. Then insert the nylon bushing / pipe bushing assembly into the tube. , drill pilot holes for the sheet metal screws through the tube and shim and into the bushing. Then screw the screws into the holes to hold the bushing.

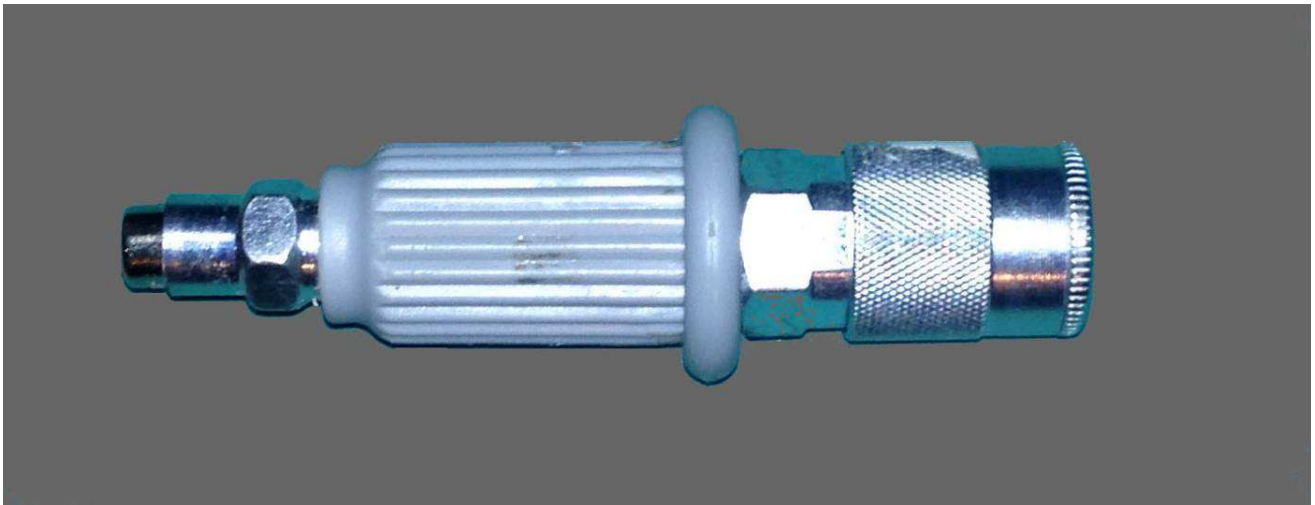
Just came up with an easier way to make the bushing but have not tried it yet. Obtain a wood dowel that is wither the correct size to fit the tube or one that is a little oversized and turn or sand it down to fit depending on tools. The plug should be about 2" long. Drill a hole to fit a 1/4" pipe nipple (3/8" or a little larger). Fit a 1/4" pipe nipple that will be long enough to screw into the quick connect fitting and to reach through the plug and allow a pipe cap or nut to hold it in place. Once the plug assembly is inserted in the tube, you can hold it in place with Short sheet metal screws or you can drill all the way through and secure it with a machine screw or cotter pin.

Another bushing method is also shown below. It makes use of a press in caster socket. The part number and link are shown in the parts list. This socket will be a very tight press fit in the thin recommended wall tube. Make sure the magnet is correctly oriented if using this bushing since it will be difficult to remove to reposition the magnet.

Rubber grommets are used to hold the rear limit switch magnet in place in the tube. If only one end of the tube will have a quick connect fitting you can insert both magnets from the open end. Positioning of the magnets will be described in the future. If both ends are to be fitted with attachments it is a good idea to be sure of the position of the magnets before you close the second end. Depending on the ID of the tube, additional material may need to be inserted in the outer groove of the grommet.

The most recent idea is to use two grommets glued together with the magnet inserted into both of them. Before inserting the magnet. run a string through the grommet and tie it into a loop so the grommet assembly can be removed by pulling on the string. the loop should be made short enough that it does not extend out of the tube.

### 5.3.2 RAM TUBE BUSHING



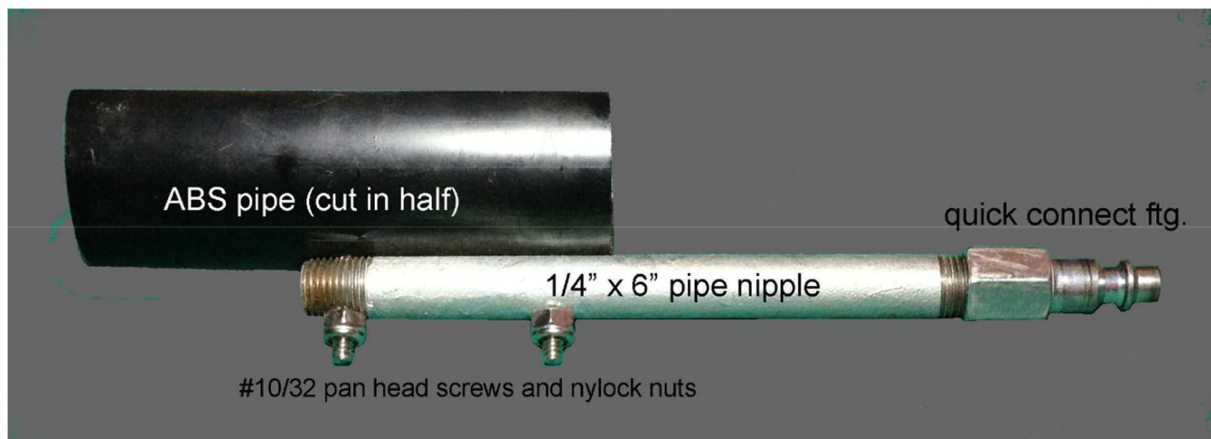
Magnet polarity is important if the limit switches are to work properly. Test the orientation of the magnet before assembly especially if the design of the tube bushings etc is such that reversing the magnet later will be difficult. To pole of the magnet that operates the switch must approach the switch before the opposite end. In other words that end of the magnet that most readily operates the switch must be place toward the center of the tube not the end. Once the machine is assembled and working, the boot routine may be used to test magnet polarity. Turn the machine on and the motor will run continuously in to forward direction until the rear limit switch is triggered. See which pole of the magnet operates the switch and place this pole inward facing in the tube. After the motor reverses, do the same for the front switch. Then the machine will be ready for use. In this idle condition approaching a limit switch with a magnet will cause the motor to move in the direction that would move the magnet away from the switch if it were in a tube . Test to see which pole of the magnet causes this action or which pole causes it to occur at a more readily or at a greater distance.



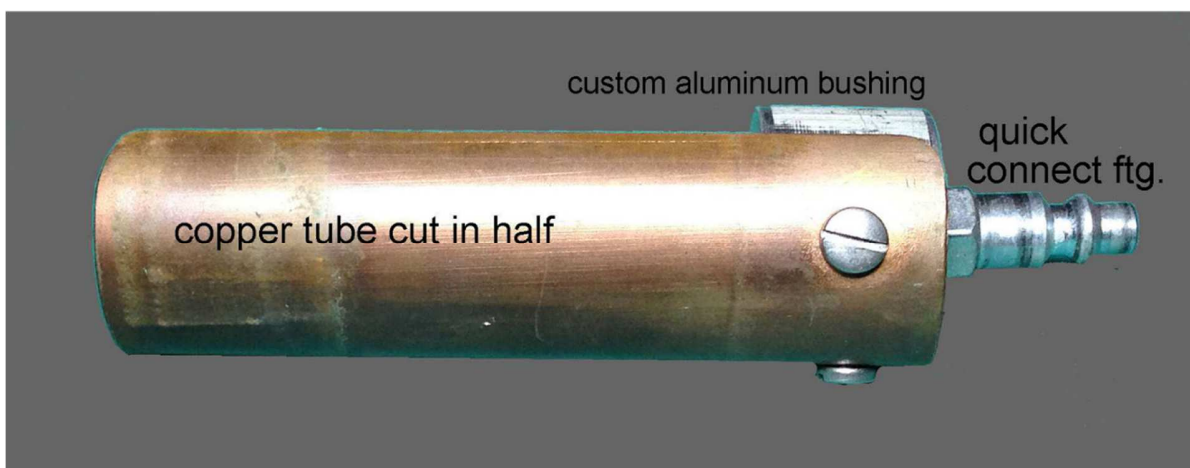
## 5.4. TOY HOLDER TYPES

### 5.4.1 TOY HOLDER TYPE 1 – PLASTIC PIPE HOLDER

Four optional designs shown below. The first design does not require custom made components. All are stock hardware store parts. The six inch nipple in the first design can be made any considerably longer to extend reach.



### 5.4.2 TOY HOLDER TYPE 2 – COPPER PIPE HOLDER



#### 5.4.3 TOY HOLDER TYPE 3 – VAC-U-LOCK ATTACHEMENT

Another options is to use a "Vaculock" fitting attached to the quick connect fitting with a length of 1/4" pipe or directly connected to the tube bushing if only "Vaculock" attachments are to be used. This option will be shown once I make one. Made one but did not take picture yet. It is just a VacuLock attachment stuck on the regular quick connect fitting. There are many ways to do it.



#### 5.4.4 TOY HOLDER TYPE 4 – METAL HOLDER



New easiest most versatile holder yet. Instead of having to cut a tube or pipe in half, this design uses a piece of 1 1/2" angle metal. I uses aluminum because I had it but iron will work too. It is small enough that the extra weight of iron would not be a problem. The connection to the quick connect fitting is half a 1/4" pipe nipple. I did not have one so I made one of aluminum that I did have around. A benefit of the angle metal is that it will hold a wide variety of toy sizes without a problem because they settle into the bottom whether they are small or large diameter. Toys that have suction cup ends can also be accommodated by cutting a slot for the suction cut. Be sure to not cut all the metal away, of course.

### 5.5. DRIVE ROLLER

The current design uses a stock drive wheel that has a 1" bore. Therefore, an adapter is needed to mount it on the 1/2" motor shaft. This can be made of a suitable length that it will position the drive wheel correctly even with a thick base made of plywood etc. If you want to machine your own use a 2" aluminum rod and polyurethane tube. The suggested stock drive wheel is highly recommended and will be better than a custom made one.



### 5.6. IDLE ROLLERS

The idlers may be purchased ready-made or can be made quite easily on a small metal lathe. They may be made of any high quality machinable engineering plastic such as Delrin or Nylon. They may also be made of aluminum or other machinable metal. If made of plastic, the bore can be made with a cheap 7/8" Forstner bit. If made of metal, a boring bar is recommended. A radius slightly over .5" is recommended for the groove in the idler wheel if a 1" shaft is used. This is to provide clearance. Nothing is critical about the idler as long as its position is chosen to provide correct tension on the drive wheel.



## 5.7. LIMIT SWITCHES



There are many options for limit switches which are necessary to prevent running the ram out of the machine in either direction. The controller inputs require a normally open connection to logic ground to operate. Internal pullups and debouncing capacitors allow almost any switch that switches to ground to be used. These include optical, mechanical and magnetic switches. Mechanical or optical require some sort of actuator and are easily damaged so the best choice is the magnetic switch. Hall effect switches can be either made or purchased ready made. Each needs to be connected to the +5 volt supply and the logic ground. The photograph of the Shagmatic board shows the connections. The forward and rearward switches need to be connected as shown. If they are reversed they will need to be corrected. The startup routine will run the ram the wrong way and out of the machine if they are not connected correctly. Another option that is being tested is a reed switch mounted in a cylinder. This is inexpensive and does not require assembly. It just needs to be pressed into a hole. Details will be added to the manual once it is tested. To actuate the magnet switch a by strong magnet is mounted inside the ram tube at each end. A rubber grommet may be used to hold the magnet. The magnet is glued to the grommet and it is then pressed into the correct position in the tube. This may then be pressed to the suitable position in the ram tube. The limit switch itself can be purchased ready-made as either a through hole type (very expensive) or a screw on type which is cheaper but more easily damaged. If using through hole types be sure to get a magnet actuated hall effect NPN open collector type, not a proximity sensor actuated by the proximity of metal. It may be possible to use this type but I have not tried it. I should try it because it might be possible to use a cheap piece of iron as the actuator instead of the expensive magnets. My preferred sensor is a cheap hall effect switch such as the ATS 137 made by DiodesInc. Leads need to be attached and insulated from each other with heat shrink tubing and then the unit is mounted in a 3/8" nylon bolt that is drilled to accept it. Clearance can be adjusted using thin stainless steel washers. A photograph of this design and any others that are proven to work well will be added to the manual very soon. I just found a very nice and inexpensive reed type limit switch that has a threaded housing and nuts to hold it in place. This will be linked in the parts list. The threaded housing makes it very easy to mount and adjust. This switch is highly recommended.

## 5.8. SHAGMATIC CONTROLLER BOARD



The control board houses the code, and translates data from the input devices to instructions for the control board. It's built with future expansion in mind. Other planned control methods including control by audio signal may be added once they are perfected. The control board should be mounted on a solid surface so it does not flex when the RJ11 connectors are plugged and unplugged. There are 6 mounting holes which will accommodate a number 4 sheet metal or machine screw. Not all 6 holes need to be used for mounting. Use non metallic spacers under the board to prevent bending component leads that go through the board as this may cause shorts. Use a non metallic washer under the screw head of the screw that goes through the hole between the knob control connector and the sync output connector. This is because there are circuit board traces close to this hole. A washer on the other holes is not necessary. Wires need to be run from the Gecko to the stepper motor and from the Shagmatic board to the Gecko. Wires need to be run from the limit switches to the Shagmatic board. Hall effect switches require logic voltage (5 volts) as well as ground and output connections but reed switch types (recommended) only require a ground connection and connection to the shagmatic board limit switch connectors. The diagram below shows all connections. If you are using reed type limit switches, ignore the 5 volt connections as they are only needed for hall effect switches. One caution is that if the limit switch wires are run in the same cable harness as the wires to the stepper motor, they should either be in a separate shielded cable and a ferrite installed on the wire at the controller end. It is really best to avoid problems by keeping the limit switches close to the control board as in the current design example. Electrical noise introduced in these lines can be very difficult to eliminate. Clip on ferrite noise suppressors are highly recommended although they will not be required with the reed type limit switch unless the wires to them are long and or pass by switched motor leads or other sources of interference. There is a shunt pre-installed on the board next to the sync connector. It is used to select 5 or 3.3 volts to the joystick encoder. Five volts should work for most encoders. If 3.3 volts is required, move the shunt one pin space away from its pre-installed position. The other two pins in this location are for future possible uses of the sync output connector and are not used in the current configuration.

There are two jumpers or "shunts" on the side of the board opposite the microcontroller. The three pin group is toward the front of the board and the two pin group is toward the middle of the board. The three pin shunt chooses 3.3 or 5 volts to be supplied to the joystick encoder and add on devices. With the shunt on the two pins closest to the front of the board, 3.3 volts is chosen. In the other position, 5 volts is chosen. Try the 3.3 volt position first and use the 5 volt position only if you know the encoder you are using is rated for 5 volts. Even a 5 volt encoder is likely to work fine on 3.3 volts. The two pin shunt allows the selected voltage to be provided on position four of the slave output connector. It is not necessary for use of this connector as a slave output, only necessary for add on devices such as the audio record/playback board.

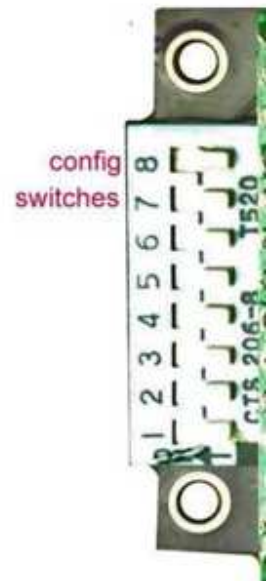
The 8 position configuration switch is used to select various options that will be added to the firmware over time. The chart below shows the function of each switch.

### 5.8.1.1 SHAGMATIC CONTROLLER BOARD CONFIGURATION SWITCHES

All switches default to off position They are read at power restore only. Changing switch positions while power on will not change configuration switch parameters.

1. Reserved
2. Run test program at startup (see below)
3. Reserved
4. De-select "seek home at boot". Turn on to disable "seek home"
5. Force joystick speed to low
6. Divider bit 1 see below for details
7. Divider bit 0
8. Select 8 wire controller if on, 6 wire if off

If switch number 2 is set on, the controller will run in test mode. This can be useful for testing limit switches and input devices without having a motor controller or other hardware. See the section below that describes the test mode. Switches 6 and 7 may be used to set a divide factor of the joystick encoder count. this may be used to adjust for microstep implementations used by different stepper controllers. it may also be used to compensate for higher count encoders. The default value is 1 with both switches in the off position. Switch 7 on alone produces a divide factor of 2. Switch 6 on alone produces a divide factor of 3 and both on together produces a divide factor of 4



### 5.8.1.2 TEST MODE

If configuration switch number 2 is on at startup the machine will run in test mode. It is not recommended to run the machine in test mode, it is only for checking the limit switches, input controls and general system operation. When the machine is started in test mode, the motor will start moving (or not if not connected) until the rear limit switch is triggered either by having one connected or just by shorting the inputs. and blinks the LED rapidly. when you trigger the rear limit switch it pauses a little and then runs to the front limit switch blinking again. when you hit the second limit switch, it turns the LED off. After the front limit switch is triggered it will respond to the joystick and the three knob controller if connected by both moving the motor and also flashing the LED. This allows the testing of the sockets and the limit switches without installing the Shagmatic board in a working machine. The only thing this does not test is whether there are motor control signals at the appropriate connection points. These may be tested by putting a 5 volt LED across the motor step and direction pins and see that they blink appropriately. An LED with a 220 ohm current limiting resistor may be connected between the step and direction connections and logic ground.



## 5.9. POWER SUPPLIES

The Shagmatic machine has two power supplies. One for the electronics, the other for the motor.

### 5.9.1 CONTROLLER BOARD SUPPLY



A separate small power supply is needed for the 5 volt logic supply. This powers the controller board, the limit switches and the various encoders. Almost any small 5 volt regulated switching supply may be used. Any USB phone charging supply will work as long as it provides 5 volts at a minimum of 500 milliamps.

### 5.9.1 MOTOR POWER SUPPLY:



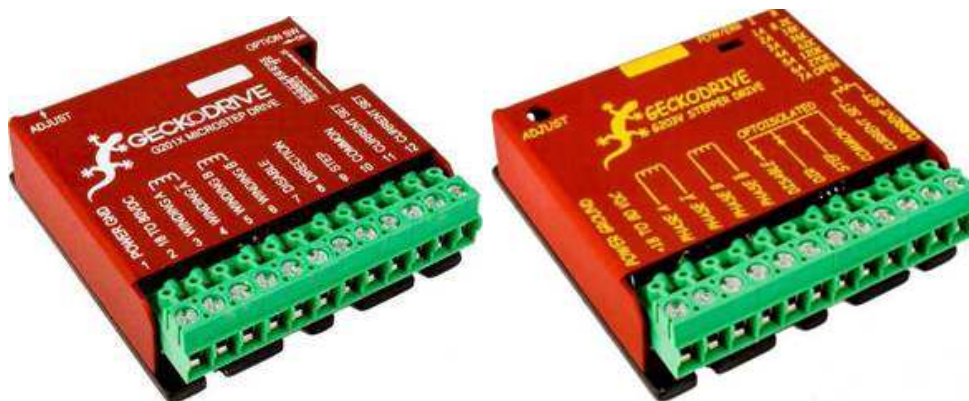
The best power supply for inductive motor loads is a simple transformer / rectifier / filter capacitor design built from the parts in the list. It is also necessary to provide a power cord and fuse. The chassis of the machine must be grounded. or all components carrying high voltage DC current must be isolated from the rest of the machine and the transformer enclosed in a grounded metal enclosure. For this reason the best approach is to use a metal chassis to mount the transformer and other AC components. Various current /voltage combinations have been tried. It is possible to get by with a 200 VA transformer but a 300 VA will insure maximum power from the recommended motor. For maximum performance a supply that provides a DC voltage right at the recommended max for the chosen motor and that does not exceed the limit of the stepper drive. The recommended 300 VA transformer meets these requirements as well as providing more than enough torque at the motor. It is probably adequate to power two machines working in tandem. [This page](#) on the Gecko site is where I got my design parameters and formulae. The motor controller and control board should be mounted close to the motor assembly so this should be considered when choosing a support assembly design especially if an external power supply is used. Best to mount the motor controller and the control board close to the motor and only remote the power supplies if necessary.

### 5.9.1.1 MOTOR WIRING

Connect the stepper motor to the controller according to the instructions provided with the controller. Four wire steppers are the easiest to connect. Just connect the two wires of each phase to the marked terminals on the controller. A multimeter or continuity tested should be used to determine which pairs of wires connect to the same phase coil. Low resistance will indicate pairs of wires connected to the same coil. If the motor runs backwards, switch the wires of just one of the phases. Motors with 6 require that you determine which wire are the common center connection of each center tapped coil. These wires will not be used and should be insulated so they do not contact anything else in the system. Eight wire motors generally require consulting the data sheet and also choosing the way you are going to wire them, series or parallel. Motors with 8 wires will have two pairs connected to the other two, resulting in a 4 wire motor. Check the instructions delivered with the motor or search for the motor part number online for assistance.

Wires from the controller to the motor should be kept as short as possible. If you are using a separate power supply/control box, try to keep the motor wires away from other wiring or components. You may shield the cable that houses the motor wires but **do not ground** it anywhere or you will cause interference to the Shagmatic board or joystick controller.

## 5.10. GECKO MOTOR CONTROLLER BOARD



The Gecko stepper motor controller is highly recommended. Others will work and have been tried but the Gecko allows for much faster acceleration and smoother motion in general. This is because of the clever design that morphs from variable microstepping at low speeds to full step at higher speeds. This largely eliminates low speed resonance problems which are inherent in stepper motors. You can use a less sophisticated controller but performance will suffer and the firmware will also have to be modified. The recommended Gecko drive (G203V) is a little more expensive than some of their less expensive models but this one is virtually indestructible which is good for building your first machine. If you are experienced and careful you can save a little money buying the less protected version of the controller (G201X). The controller is connected to the control board with just three wires, common and step and direction. The photograph of the controller shows these connections. The power and motor connections are shown on the controller. It is highly recommended that you download the manual for the controller you are using and that you read it thoroughly. Instructions on setting current limit and other options are very well described. Additional tips will be added to this manual. The G201X has the option of setting the current limit with DIP switches whereas the G203V requires a resistor to set the limit. If you feel confident that you are not going to wire the controller improperly or subject it to any severe abuse, the G201X is a reasonable choice especially since it is easier to change the current limit setting. If you have little experience and tend to destroy electronic stuff the G203V is recommended.

### 5.11. SUPPORT ASSEMBLY



Below is shown an older style of support. This worked very well but is a significant project. It was used with a two piece design consisting of a motor unit and power supply/electronics unit. It allowed for adjustment to a wide range of heights and angular positions. The current box or channel designs can have bolts fitted to allow mounting on such a support. Other possibilities are to mount to a floor standing tripod or to mount to a bed frame or other furniture. The limit is your imagination. I purchased a very heavy tripod at a thrift store and converted it to a Shagmatic stand. I will a a picture of it soon. There are also heavy tripods used in the stage lighting industry and other industries as well. These may often be found surplus and may be adapted to this purpose.

## PART 6. INPUT DEVICES, HMI CONTROLLERS

The input devices plug into the electronics assembly and allow the user or operator control of the machine when in use.

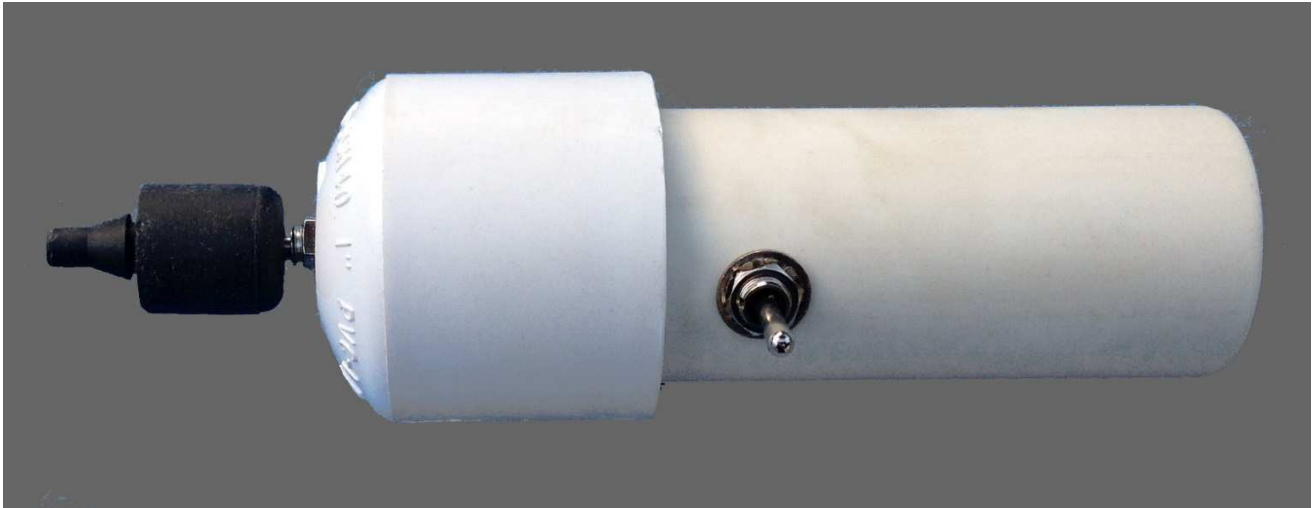
### 6.1. CONTROLLER TYPE 1, THE THREE KNOB



The three knob is very inexpensive to build using just three \$4 mechanical encoders. These allow for the control of speed stroke length and offset. The offset control may be used to completely control position when stroke is turned to minimum setting. It may also be used in combination with the automatic mode. Three mechanical encoders are mounted in a suitable box. An 8 wire RJ45 is needed for the three knob controller. Stroke offset can also be used in a manner similar to the joystick control but the resolution of the encoders is much less and performance is degraded. Wiring for the three

knob controller is as follows and a diagram will be forthcoming. Wire a standard RJ45 punch down connector following the color chart of the T568B specification. Use an 8 inch length of CAT 5 or 6 wire with standard color codes. The three encoders have their common leads connected together and also to the green/white wire. The A and B phase terminals are connected as follows. If once connected, a knob works backwards (eg clockwise lowers speed) switch the A and B phase wires on that encoder. The speed encoder has the A phase connected to the solid green wire and the B phase connected to the brown/white wire. The stroke encoder has A phase connected to the solid brown wire and the B phase connected to the solid blue wire. The stroke offset encoder has its A phase connected to the orange/white wire and the B phase connected to the solid orange wire. If you are wiring different sockets of your choice, the following pin assignments should be made as traced through the connected wiring. Speed encoder phase A goes to microcontroller pin 18 phase B to pin 20. Stroke encoder phase A to pin 7, phase B to pin 17. Stroke offset encoder phase A to pin 15 and phase B to pin 21. A normally closed pushbutton switch is also installed in the three knob controller. It provides two functions. First it is used to set maximums for speed and stroke by invoking parameter setup mode at boot time. Secondly it acts as an emergency stop switch when the machine is running in automatic mode. Pressing the button stops all motion, clears all operation parameters and returns the machine to the retracted position. Since the switch is normally closed it also serves to defeat three knob control if the cable should become disconnected. The blue/white wire is connected to one terminal of the e-stop switch and the other terminal is connected to the ground or common wire of the encoders, where the green/white wire is also connected.

## 6.2. CONTROLLER TYPE 2, THE JOYSTICK

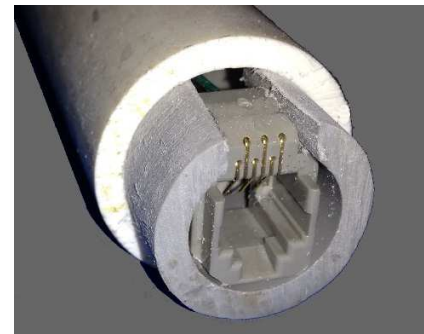
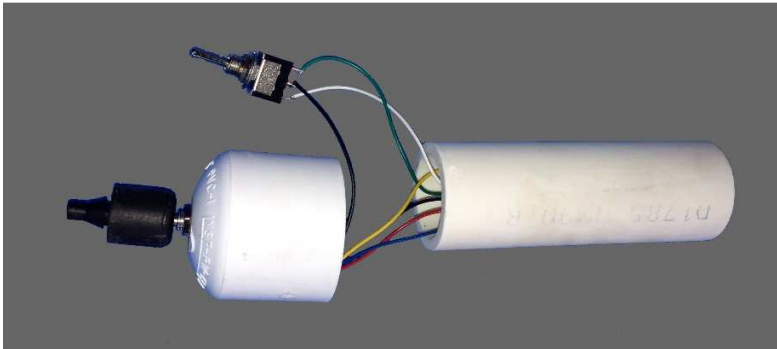


The best input device for precise control requires a more expensive encoder. If you want the highest resolution and ability to perform quick thrusting motion, this controller is recommended. The two knob encoder has a resolution of 24 steps per revolution whereas the higher quality encoder has 256 steps.

The "joystick" controller is simple a rotary encoder wired to an RJ11 socket and both mounted in a piece of PVC pipe with a pipe cap on one end. See the photograph for details. The latest design also has a miniature toggle switch that allows selection of "speed" from the controller. It really is the ratio of joystick motion to machine motion that is varied but the effect is similar to a change in speed. See the wiring chart in the diagram section for information. If using the RJ11 plug listed in the parts list, the wire color codes apply. If using an encoder different from the recommended one, its phase A and B connections may need to be reversed if the motor goes the wrong way in the initialization phase of the program loading process. Any quadrature encoder with suitable counts per inch that works from a 5-volt supply should work. The firmware is designed for an encoder with 128 to 256 counts per revolution.

Firmware modification will be necessary for encoders with higher or lower counts per revolution. The speed selection switch is a SPDT center off switch with momentary on one side. This allows for switching on either medium or high speed but requires holding the switch in the third position for high speed. This is a safety feature to prevent accidental switching on of high-speed mode. If this is not a concern a standard, SPDT center off switch may be used.

A better choice of material is to use schedule 40 1" PVC pipe and cap. This allows more room for installing the encoder and switch. Ideally a flat top cap should be used but they are difficult to find. If a domed cap is used it is good idea to flatten the top a little and to use a spacer or a couple of washers on the encoder shaft inside the cap so the plastic housing of the encoder is not against the cap and the metal only is bearing the load. If the housing is against the cap and the shaft nut tightened too much it could break the plastic encoder housing. It is also easier to install the switch if the 1" pipe is used. A split bushing made of 3/4" schedule 40 PVC pipe is used to hold the 6 pin socket in place. The OD needs to be sanded a little to produce a perfect tight press fit. No glue is needed if the fit is right.



The joystick is made with a short length of 3/4" schedule 40 PVC plumbing pipe and a PVC pipe cap. It is best if you can find a cap with a flat top as opposed to a domed one as this will allow the end=coder to fit better. The hole for the encoder shaft is centered and then made oval with a round file so the offset shaft will fit better. Schedule 40 pipe is used because this allows the socket to be held in a press fit. Squeeze the pipe out of round in a vise to allow the socket to fit. Alternately thinwall pipe may be used and the socket glued in place. Thinwall allows more room for the encoder pins and also for the switch. Drill hole closer to the encoder end for the switch. It will be necessary to fiddle around with the switch to get it to fit into the hole but it is possible. Be sure to solder the wires on the switch before inserting it as it will be very difficult to solder to it once in place. You may have to move the switch lever to one extreme position to allow it to snake into the hole. Once the assembly is made and tested, it is a good idea to use PVC glue to cement the cap to the pipe so the pipe will not move around and damage the encoder pins or case. Use a very small amount of cement, just enough to bond the parts and not get on the delicate encoder. You may also cut away some of the pipe to allow space for the pins.

## PART 7. BUILD THE SHAGMATIC – STEP BY STEP

Update 04/19/16 – The first builder has made a machine work – guide here coming soon!

(This will be the hard part. Find out what the a-z steps are. Ensure they are in correct order. Be sure to explain so any idiot can follow your instructions. TEST THIS on some builders; they will get stuck all over the place where you were sure no confusion could be found. REDO those steps with tiny baby steps. Force feed the fine print into their eager builder's hands. Add detail pictures for the steps, crop away a bit less than you feel is needed to allow the builders to see where on the machine they are to be fiddling)

1. Putting in a few points here so I don't forget  
when building the wooden box model it is a good idea to pre-assemble the wooden parts but not glue them. Verify the location of all parts and mark any needed screw holes. This will allow fasteners to be entirely internal and not mar the finished outside surface. Then disassemble the temporary assembly and drill the holes being careful to not drill through to the outside of the case. It is much easier to drill the holes on a flat surface with nothing in the way. If you have a drill press you can limit the depth to prevent drilling through. If you are drilling by hand, mark the drill bit with a piece of tape to prevent drilling too deep.

The way the controller board is mounted requires careful planning to line up the 7/8" holes for the sockets. Mark the centers of the sockets with the board held in place and standing off the wood wall the required amount on spacers the same thickness as the standoffs you are going to use. Be sure that the USB socket will not touch the top plate once it is screwed in place. There are two possible ways to access this connector. You can drill a hole similar to the ones for the other sockets and will then be able to re-program the control board without opening the case. You may also open the case and remove the teensy board in order to program which will offer a little



more protection of the board. If you drill an access hole, it is recommended that you plug the hole when not in use to keep debris out of the connector and the sensitive board.

2. Add step two
3. (...)
4. Add step forty-five

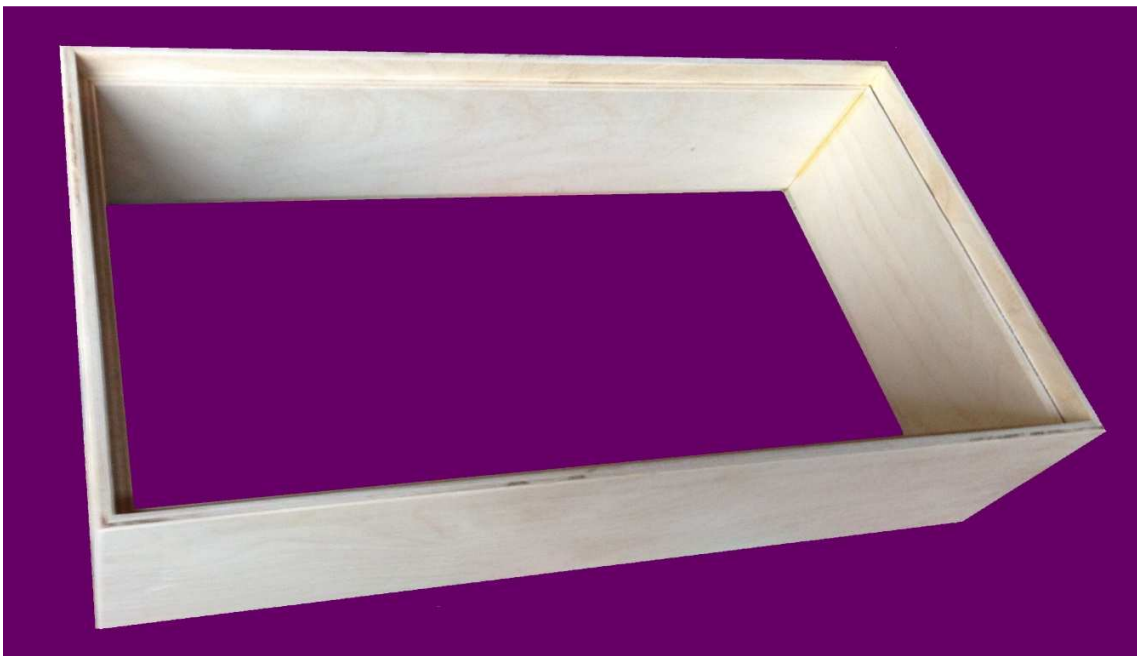
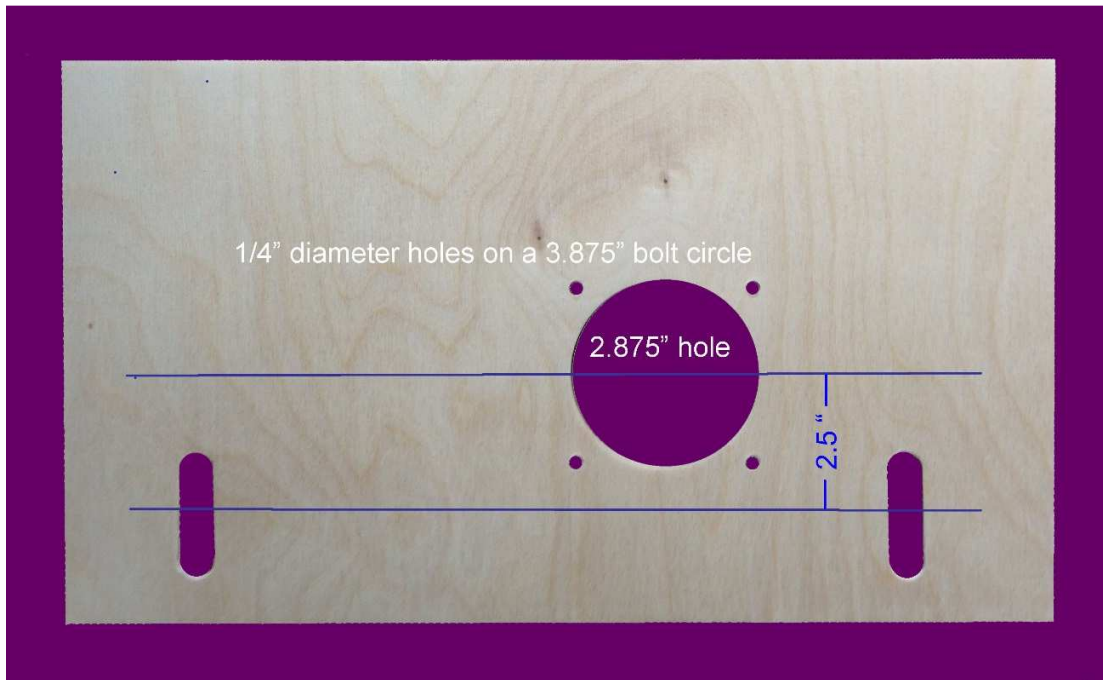
## PART 8. CUTTING TEMPLATES

There are only a few critical dimensions in the entire machine. The size of box chosen will be influenced by the type and size of the power supply and also the stepper motor driver used. The design pictured below will hold all of the recommended components including the torroidal transformer and a Gecko stepper motor driver. It will not be large enough for most other stepper motor drivers.

The relationship between the motor mounting holes and the slots for the idler wheels is critical. There must be the enough space for the ram tube to fit properly and be adjusted for a range of idler tensions. The dimensions shown will allow this but it is possible to use other arrangements as long as the tube will fit and can have adequate tension applied. Also consider that there needs to be space between the idler wheel shaft nuts and the inside walls of the box. Before cutting holes and slots draw their tentative positions and lay the parts on top of the plate to be sure all will fit properly. Do not glue the plate to the rest of the box before cutting the holes as it will be difficult to remove if you find you have made a mistake in the layout. Mark all holes with respect to the center of the motor mounting holes. The four screw holes must be on the specified circle and must be evenly spaced.

Oversized holes may be used for the idler wheels if cutting slots is difficult. This may be the case if you use metal and do not have tools for making slots in metal. If the layout is done carefully it is possible to have enough room for adjustment with oversized holes. Be sure to consider that the urethane tire on the drive wheel will compress some when proper tension is set.

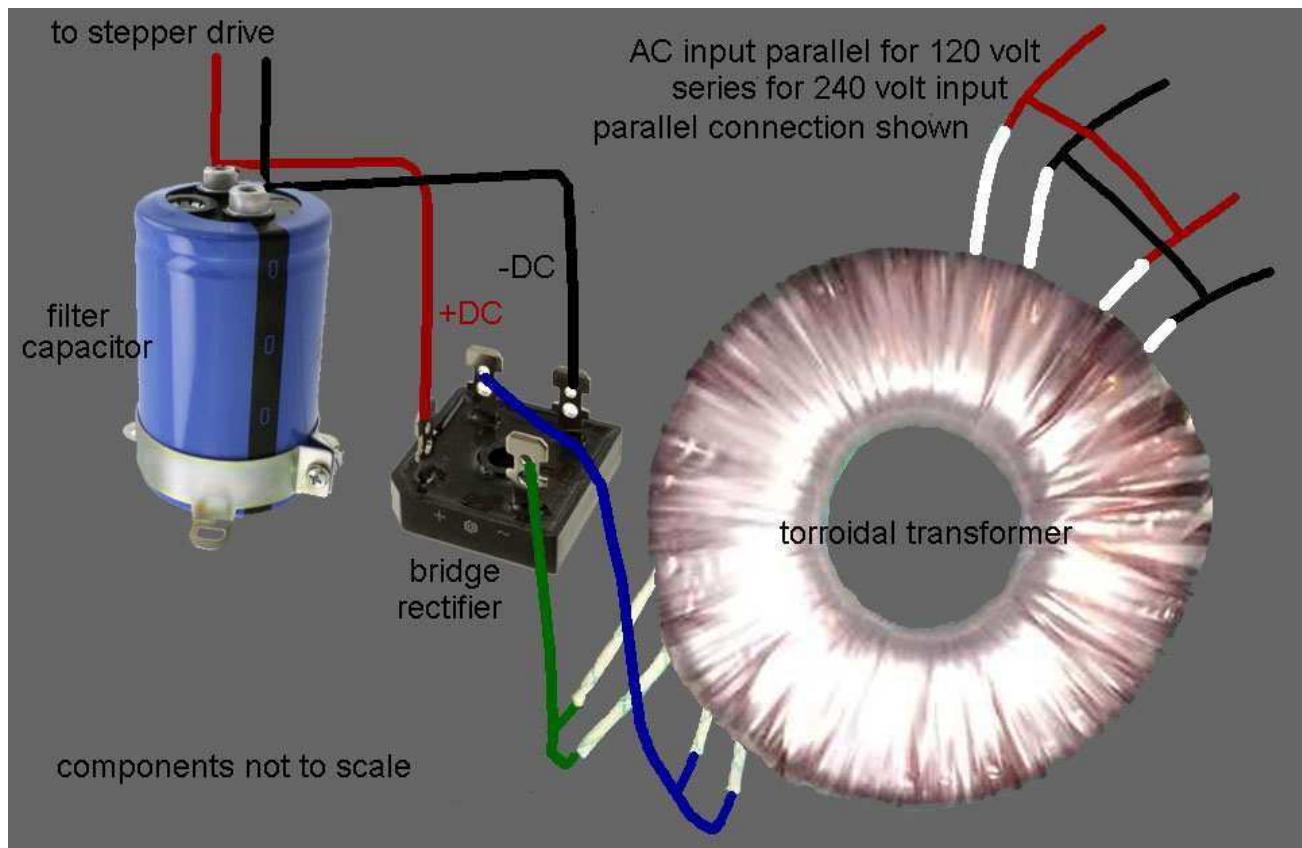
As shown in the picture below, the most critical dimension is the distance between a line running through the centers of the idler wheel slots (or oversized holes) and the center of the motor mounting holes. this distance should be 2.5" if the recommended stock drive wheel and idlers are used. The box is made of 1/2" Baltic Birch plywood. The overall dimensions are 9" x 16" x 4.5". This will accommodate the larger of the recommended motors. If using the smaller motor, the box height may be reduced to 4".





## PART 9. ELECTRICAL WIRING DIAGRAMS

### 9.1. DIAGRAM 1 – MOTOR POWER SUPPLY CONNECTIONS

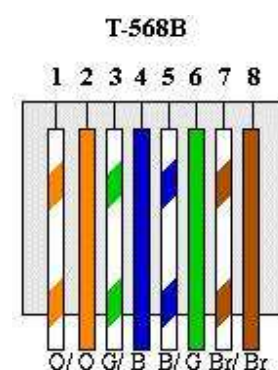
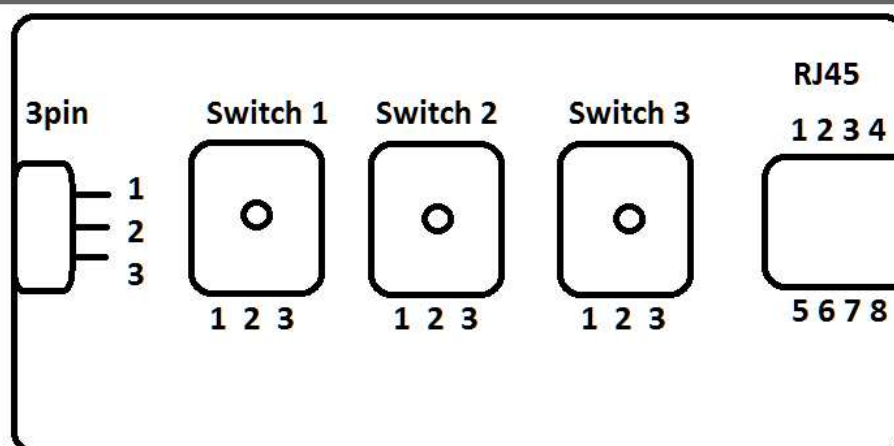
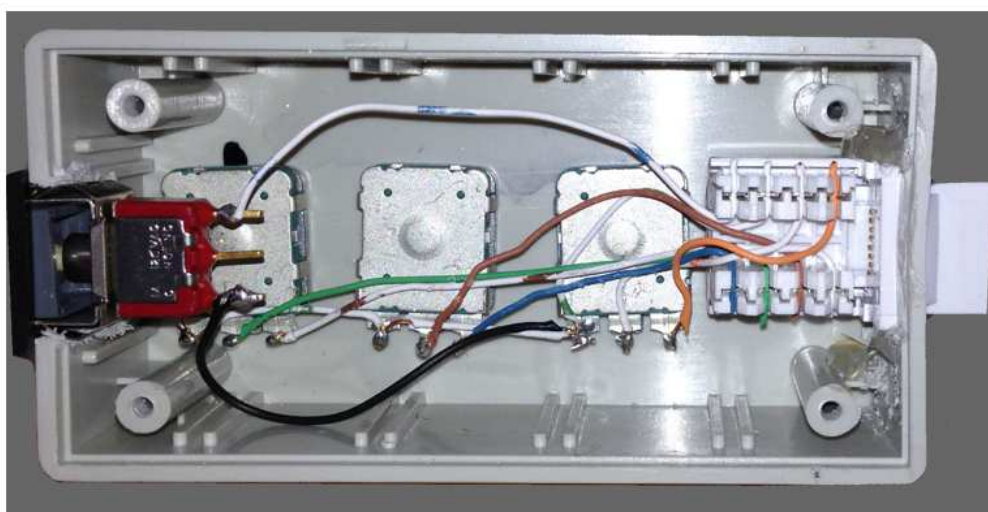


## 9.2. DIAGRAM 2 – JOYSTICK CONTROLLER CONNECTION

Note that the switch pin linked to GND is opposite of the direction of the switch movement, see step-by-step Joystick part.

RJ11 Wire Color	Function	Connection Switch	Connection Encoder
Red wire	+5v	-	Encoder pin 4
Black Wire	GND	Center	Encoder Pin 1
Blue wire	Phase A	-	Encoder pin 3
Yellow wire	Phase B	-	Encoder pin 5
Green wire	Slow	-	NO switch pole (slow)
White wire	Fast	-	NO switch pole (fast)

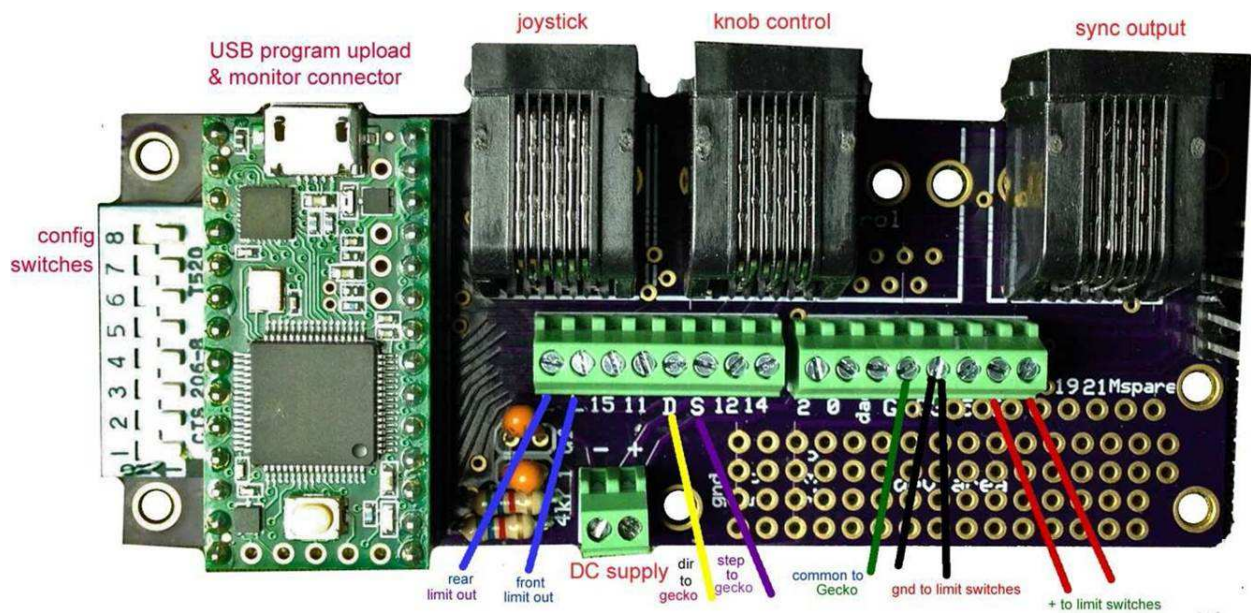
## 9.3. DIAGRAM 3 – THREE KNOB CONNECTION



Wire Color	RJ45 – female connector	Connection 1	Connection 2	Connection 3
White/Orange	3	SW3-2	-	-
Orange	4	SW3-3	-	-
White/Green	2	SW3-1	SW2-1	SW1-1
Blue	5	SW2-3	-	-
White/Blue	1	3pin-1	-	-
Green	6	SW1-2	-	-
White/Brown	8	SW1-3	-	-
Brown	7	SW2-2	-	-
Latch 1 (Black)	-	3pin-3	SW3-1	-



## 9.4. DIAGRAM 4 – SHAGMATIC CONTROLLER CARD CONNECTIONS



Wire Color	Function	Connection 1	Connection 2
<b>Blue1</b>	Limit switch rear, output	Smatic 17	Limit SW rear
<b>Blue2</b>	Limit switch front, output	Smatic 16	Limit SW front
<b>Yellow</b>	Dir to controller card	Smatic D	Controller Dir
<b>Purple</b>	Step to controller card	Smatic S	Controller Step
<b>Green</b>	Common ground to controller card	Smatic G	Controller Com GND
<b>Black1</b>	Limit switch grounding front	Smatic GND	Limit SW front
<b>Black2</b>	Limit switch grounding rear	Smatic GND	Limit SW rear

## PART 10. TROUBLESHOOTING

1. Motor does not come on and initialize at power on  
Wires between Shagmatic board and stepper driver are not connected or connected incorrectly.
2. Ram tube is run out of machine during initialization routine  
Limit switches not connected or front and rear switches are reversed. Check connections for proper location and tightness. Try switching the front and rear switch connections. The ground wire does not need to be changed, only the wires connected to the L positions on the first terminal block.
3. Ram tube slips on drive wheel.  
Inadequate tension. Move idler wheel(s) closer to the drive wheel. Do this a small amount at a time. It is good to allow slippage under heavy load as a safety measure.
4. Motor skips under heavy load instead of turning  
Inadequate current setting. Try higher setting.  
Binding of drive wheel. Move idler wheel(s) away from drive wheel a small amount and check again.
5. Joystick controller not responsive  
Joystick plugged into the wrong socket. The socket closest to the Teensy microcontroller is for the joystick. The middle connector is for the knob controller and the last one is for slave signal out.  
Wired incorrectly or bad cable.
6. Knob controller not responsive  
Plugged into the wrong socket.  
Wired incorrectly or bad cable.
7. Erratic behavior, motor jumps or goes only one way  
**Connections Connections Connections!!!** 99% of all strange behavior problems are caused by bad connections. Pull on wires in screw terminals and make sure they are not loose. Screw terminals must be loosened completely before inserting wire and then tightened completely. If you only loosen the terminal partly you may put the wire on the wrong side of the internal clamp and it will possibly sort of work but not reliably. Check the step direction and common connections on the Shagmatic board and the stepper driver. Also check the 4 wires from the stepper driver to the motor. Loose connections here will cause very erratic behavior.
8. Motor makes random moves with no joystick or controller instructions. This is most likely caused by interference on the inputs. Most likely cause is ground problem, especially ground loops. The AC line ground should not be connected to the DC ground, either the stepper supply or the Shagmatic board ground. Ground connections to the Shagmatic board and its power supply should only be made as indicated in wiring diagrams. Long signal wires should be shielded with the shield connected to ground only at the Shagmatic board. Ferrites on signal wires can also help but should not be necessary under most conditions. Phase wires to the stepper motor may be run in shielded cable but the shield must not be connected to ground anywhere. The fast high current switching within the cable will cause interference everywhere and may be very difficult to diagnose

## 10.1. FIRMWARE UPGRADE

The custom controller board containing firmware written by me controls the Shagmatic. The firmware may be updated in the future, allowing increased performance, safety measures or new functions. To perform a firmware upgrade, follow the below steps.

1. Download Teensy.exe, serial install.exe and the firmware file <versionname>.hex from [here](#)(add link).
2. Start serial install.exe and allow it to install. Run as admin. In >WinXP ensure installing unsigned drivers is allowed.
3. After successful install, start Teensy.exe. Click "File" and select the hex file (the firmware) wanted.  
Before connecting the USB cable, unplug the machine from the AC line and wait at least two minutes before connecting the USB cable. If the Teensy is powered by both the internal power supply and the USB port, one of them may be damaged. After two minutes connect the USB cable from your PC to the Shagmatic and proceed . Press the upload button and watch the status move to "Programming" and then "Reboot OK".

## PART 11. PHOTOS OF COMPLETE MACHINES

