

Clough42 Electronic Leadscrew

Implementation for

Precision Matthews PM-1030V & PM-1022

By Dan Groninger, March 2021

Introduction and Thanks

This is one hobbyist's implementation of the Clough42 open-source electronic leadscrew design. Thank you to James, and thank you to other YouTube presenters, especially Physics Anonymous, Blondihacks, Tubalcain and This Old Tony. They have given me many hours of great instruction and motivation to get into the shop and be creative. I have been an electronic and software engineer in my career and have tinkered with mechanics and woodworking in my shop for forty years, but machining on the mill and lathe has been a recent addition. Quinn's content at Blondihacks has been especially helpful since she has almost identical machines to mine, and James's machines are close as well.

I also found postings on Thingiverse and GitHub from other builders immensely helpful. Pictures from mac651955 on GitHub (<https://github.com/clough42/electronic-leadscrew/issues/130>) were an inspiration, and I ended up using the encoder mount posted by Nick Stahl on Thingiverse (<https://www.thingiverse.com/thing:4732492>) exactly as posted. Thank you!

Goals

My primary goal when starting this project was to move from change gears to the ELS, and to learn something in the process. I watched James's entire playlist (<https://youtube.com/playlist?list=PLDIWKv7KIlr90ZZ7Zqt-ge5nVVdS3WVgg>) from start to end, some of the episodes several times. I particularly like how he started from the very beginning by stepping through the calculations on paper and discussing the trade-offs of various approaches to handling the calculations and timing in software. Getting my head around that early in the process helped later in working through the gear ratios between the feed and thread mechanisms on the Precision Matthews lathe. There is much good content on GitHub in addition to the code for this project. Be sure to read through the wiki and the issues discussion at <https://github.com/clough42/electronic-leadscrew>.

My other major goal was to make no permanent changes to the lathe, and to be able to switch back to the change gears quickly and easily in case of failure of the ELS. With the setup shown here, the encoder can be removed, and the regular change gear stack returned to the lathe as quickly as any other change of the gears. The stepper motor does not need to come off to use the gears – just take off the belt and remove the pulley to put on the regular lead screw gear.

Encoder and Mount

I used the encoder that James recommended in his postings, an Omron E6B2-CWZ6C. Note that there are many versions of this basic encoder available, but this one is 1024P/R 6000r/min 5-24v. The important part there is 1024 pulses per revolution, and that matches up with James's assumptions in the code. You can edit the code to adjust for other pulse rates by editing this line in configuration.h:

```
#define ENCODER_RESOLUTION 4096
```

The 4096 comes from this being a quadrature encoder, so there are effectively four edges to each pulse, so $4 \times 1024 \text{ P/R} = 4096$. If your encoder ends up being 1000 P/R or something else, simply adjust this setting in the code. For example, if your encoder is 512 P/R, then set this to 2048.

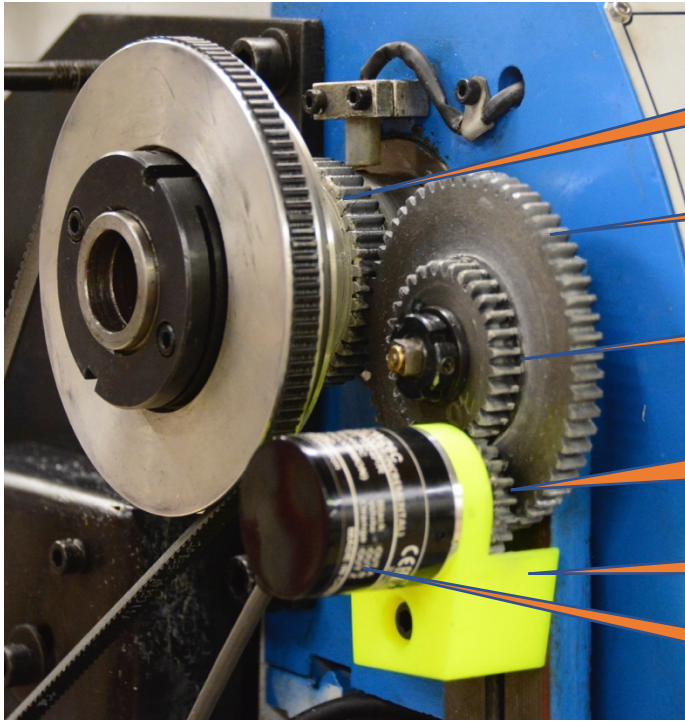
As mentioned before, I used the encoder mount posted by Nick Stahl at Thingiverse: <https://www.thingiverse.com/thing:4732492>. He has both the mount and an adapter posted. His adapter fits the shaft of the encoder and the bore of the Precision Matthews change gears. I made these on a 3D printer with simple PLA filament. Neither of these parts takes any real load in use, unless something is wrong, and then they would be a cheap failure point. I printed the mount as sized, but I found that I got a bit better fit of the adapter at 101.5% scaling. You may need to print a couple in different sizes to find your best fit.

The encoder attaches to the mount with 3x M3-10 flat heads screws. Choose the orientation so that the cord comes out of the encoder in a convenient direction to clear other parts when it's placed on the lathe's banjo. Put the 20 tooth change gear on the adapter and that onto the encoder shaft. Locate the 60 and 30 tooth change gears and put those together with the 60 tooth in back and 30 in front, then put that on the top of the banjo. Make sure that it's far enough down the banjo so that everything clears the gear guard and adjust the gear lash as directed in the lathe manual. Avoid engaging the gears too tightly as they will be noisy and wear unnecessarily quickly. Done correctly, there will be almost no load on the encoder shaft and minimal but noticeable play in the gears. An M6 socket head machine screw is used to mount the encoder mount to the banjo using the same T-nut that would be used with the change gears.

A little math – the gear on the spindle of the PM lathe is 40 tooth (thanks again to Nick Stahl for that bit of info), engaging the 60 tooth, which shares the shaft with the 30, driving the 20.

$$40/60 \times 30/20 = 4/6 \times 3/2 = 2/3 \times 3/2 = 1$$

So, one turn of the spindle equals one turn of the encoder. That turns into 4096 pulses seen by the electronics for each turn of the spindle.



Spindle Gear, 40 tooth

Change Gear, 60 tooth

Change Gear, 30 tooth

Change Gear, 20 tooth, on
encoder shaft adapter

Nick Stahl's Encoder Mount

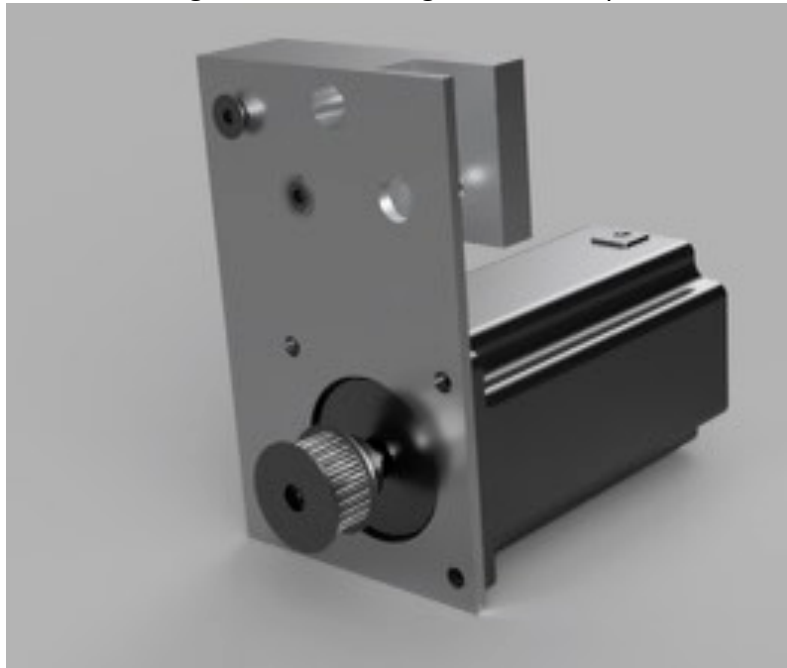
Omron Encoder

Stepper Motor Mount

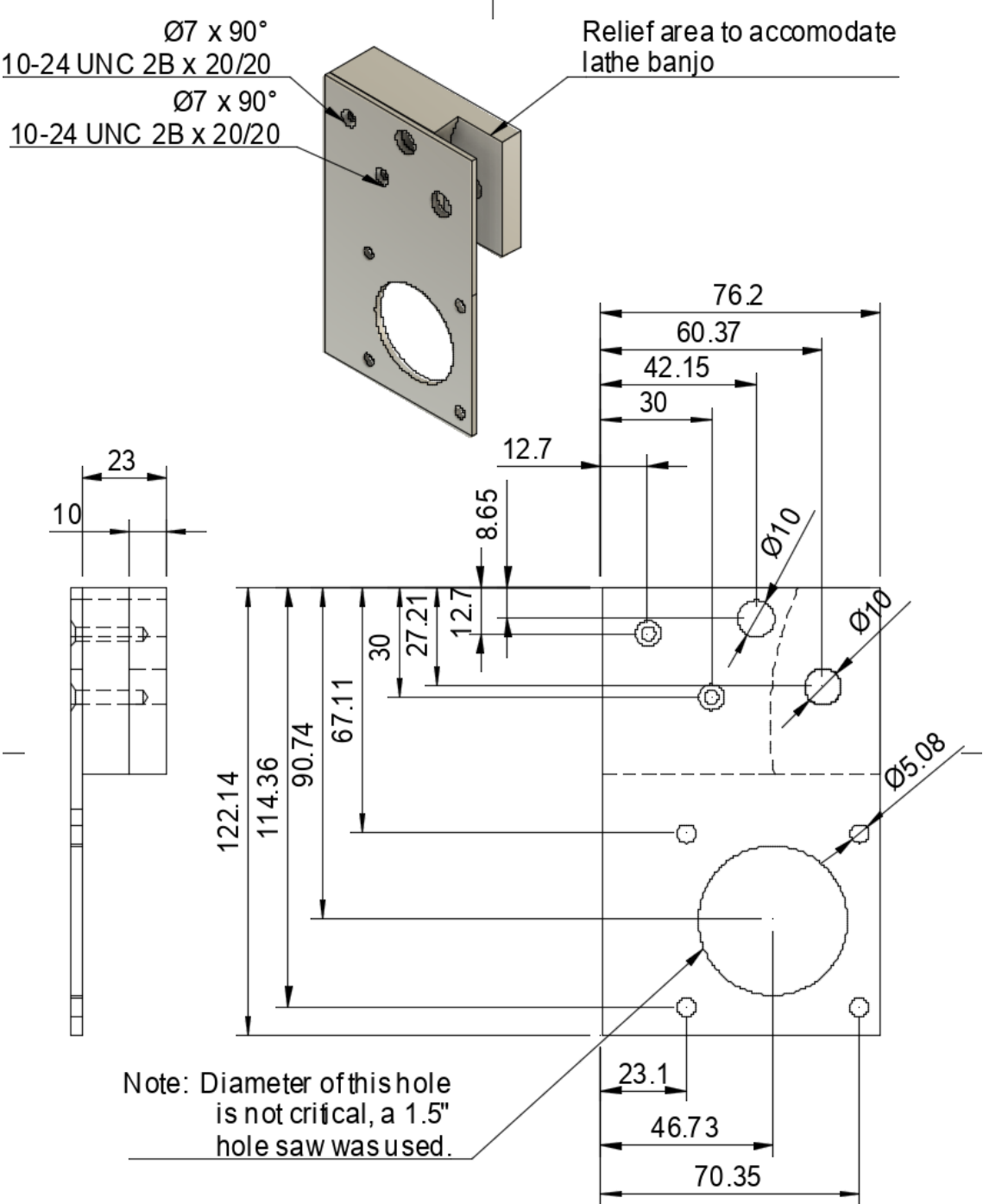
Seeing the mounts that mac161955 and nstahl posted, it was clear that the opening in the lower frame of the lathe was an ideal place to put the stepper. I did swap out the endmost lathe holddown bolt for a carriage bolt to maximize the available height in that opening. There's not a lot of extra space, but the motor does fit with some room for adjustment of belt tension. From there, it was a matter of looking at mac's mount and materials that I had on hand. I also wanted to use the banjo, so my design is a result of having 1/8" aluminum sheet and 1"x2" aluminum bar on hand.

The mount is two parts, a block and a plate. These are held together by two 10-24 flat head hex machine screws. There are two holes provided for mounting to the lathe frame using the long stud that is normally just a standoff for the gear shield and the M8 screw that holds the banjo slot. The mount's block is relieved at one end to allow the arc of the banjo to pass between the plate and block.

Designing this was an exercise in learning Fusion360 techniques. A pro would likely laugh at the complexity of the process I needed to get to this simple end product, but I did learn better ways to do things along the way. I started with a picture of the end of the lathe with the guard and gears off, taken from as square as possible from the end and at the height of the opening. I included a ruler in the picture against the frame, so it was easy to scale the picture when importing it to Fusion as a canvas. I then sketched the basic shape and holes of the mount block using the canvas for placement. I extruded that, then started on the plate. I used the import function from McMaster Carr to get the model for the NEMA23 motor, then used the mount end of the motor to design in the mounting holes to the plate. Here's the result:

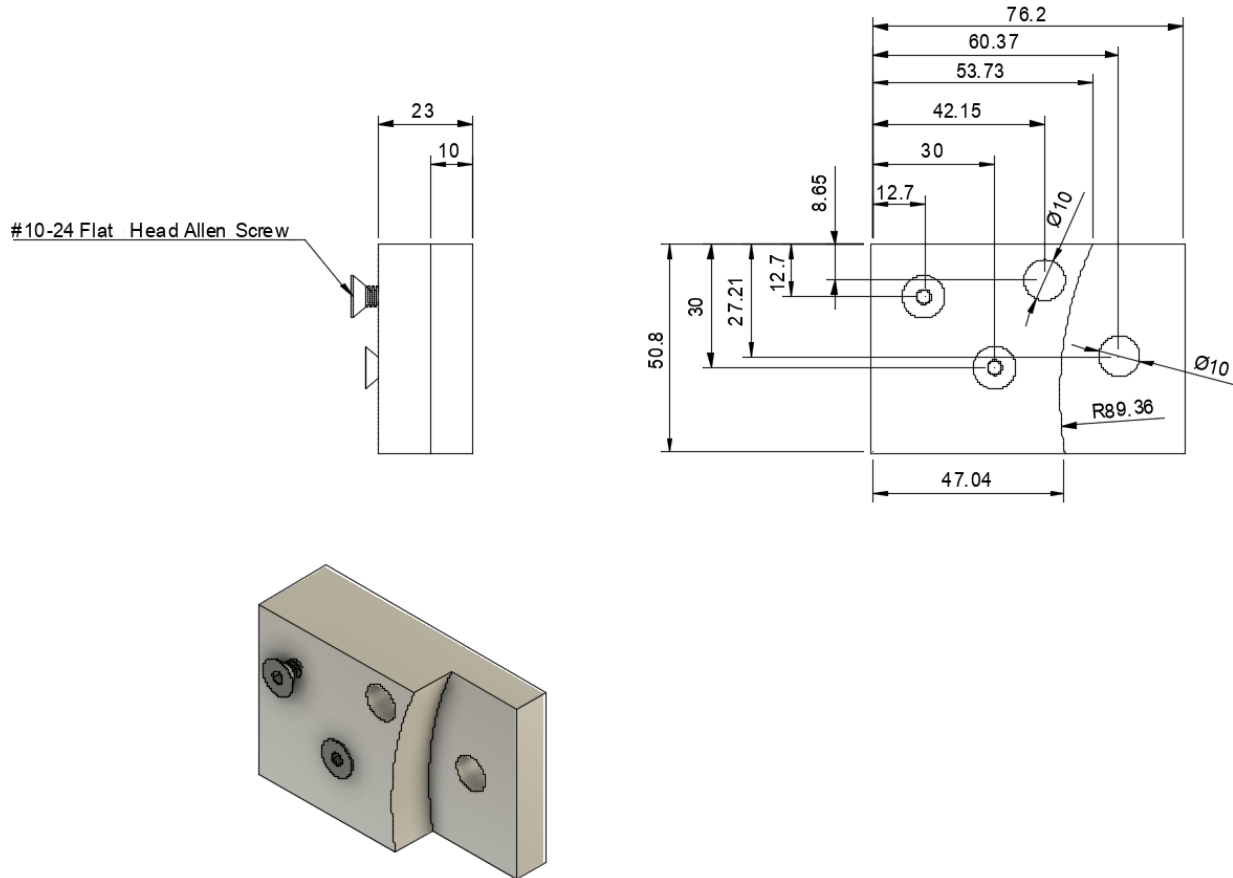


I found that the easiest way to size the 1/8" plate was to cut it on my table saw using a fine-tooth carbide plywood blade and a cutoff sled. I deburred that, set it up on parallels in the mill vise and drilled all the holes according to the dimensioned drawing below. The large center hole for the motor came in nicely with an inch and a half Milwaukee Hole Dozer hole saw. I thought I'd need to clean it up and enlarge slightly with a boring head, but it made a neat hole just a tad oversize. The motor mounts to the plate with four M5 x 20 hex cap screws with nylock nuts.



Milling of the block involved cutting a piece of the 1x2 bar a bit over 3" long, then squaring it all up in the mill. I took the overall thickness down to 23 mm and the length to 76.2 mm (3").

I then marked off the banjo relief end of the block and used a 1/2" end mill to take the thickness down to 10 mm in that area. I didn't get a rotary table in time to do a really neat job of the end of the relief area, so I just did a rough approximation of the curve freehand with the mill table wheels. I ended up with an ugly, but functional, job on that feature.

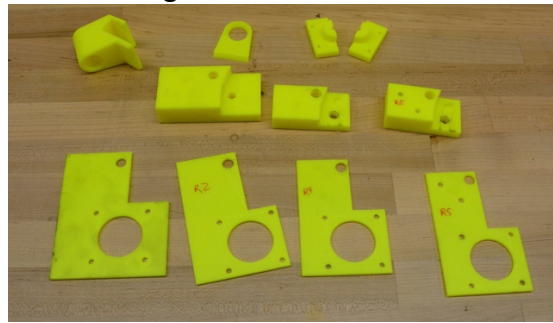


Once both pieces were milled, I assembled them with 2x #10-24 x 3/4" flat head machines screws, added the motor and installed it in the lathe. At this point, the leadscrew gear was removed, the banjo was swung away and the block put in place with the long 10 mm stud. The banjo was swung back, and the M8 bolt installed, all bolts loosely in place.

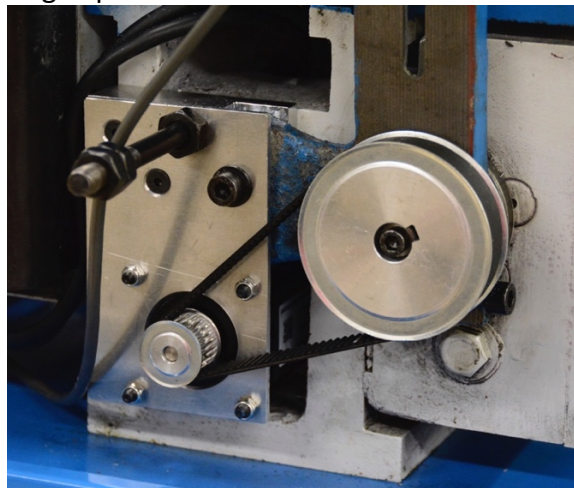
I used the 24 and 72 tooth pulleys recommended by James. The 72 tooth pulley was installed on the leadscrew, belt put in place and tensioned, then the stud and banjo bolt snugged up. You will need to broach the key slot in the leadscrew pulley – it comes with a smooth bore. I held the pulley in the three jaw chuck and used a sharpened bar of 5 mm high speed steel in the tool holder, kept the chuck in one position, and worked the slot down 0.001" at a pass by manually cranking the saddle. Some mind numbing number of passes later, I had a neat slot broached at the correct depth.

I tried several belts, and for me, the **354 mm, 118 tooth belt** was the perfect length. There was enough swing in the mount to go up or down a couple of teeth with the belt, but 118 teeth had the mount hanging plumb. I found PolyTech in New Jersey who stocks a huge selection of belts: https://shop.polybelt.com/3M-15-15mm-Wide-Belt-Rubber_c59.htm They have a \$25 minimum, but if you want to try a variety of lengths, they can supply that and ship quickly.

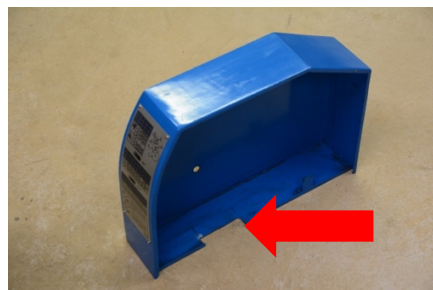
I went through a series of 3D printed bracket parts to confirm all the dimensions, and it took me five iterations till I was satisfied – I guess I'm a slow learner.



Here's a picture of everything in place:



One minor issue when putting the guard back on – the mount sticks down about $\frac{3}{4}$ " too far, so I needed to trim a small area of the bottom of the guard to clear. I think that there might have been room to take the mount up enough to clear, but I had the mount together and a belt to fit, so trimming the guard was the path of least resistance. Hacksaw blade and a jigsaw was used.

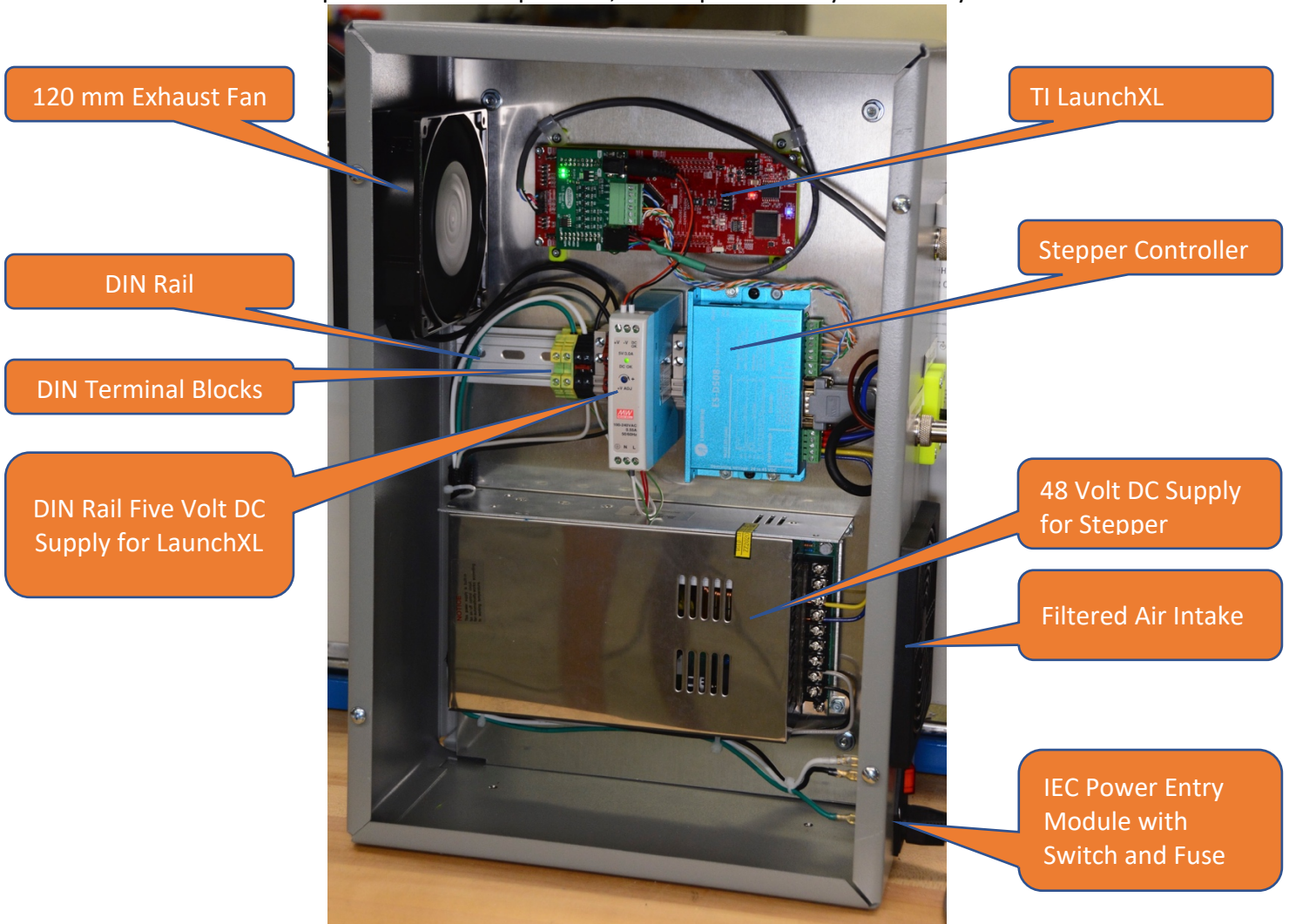


Electronics Assembly

For the electronics, I followed James's design closely. I chose a box that was 12" x 18" x 6" from Wiegmann, their SC121806NK. I found that at Automation Direct (https://www.automationdirect.com/adc/shopping/catalog/enclosures_-_subpanels_-_thermal_management_-_lighting/enclosures/junction_boxes/sc121806nk). This was a nice size, but I'm not sure that I'd use this particular box again. The build quality isn't quite as nice as a Hoffman, but I had trouble finding what I wanted in their line. Automation Direct was great to work with, good pricing and quick to deliver.

The Wiegmann box did not come with standoffs or an interior mounting panel, but I made one up from 1/8" aluminum plate. It's much easier to assemble all the electronics on the bench on a flat and open plate, then set the plate inside the box when the wiring is done.

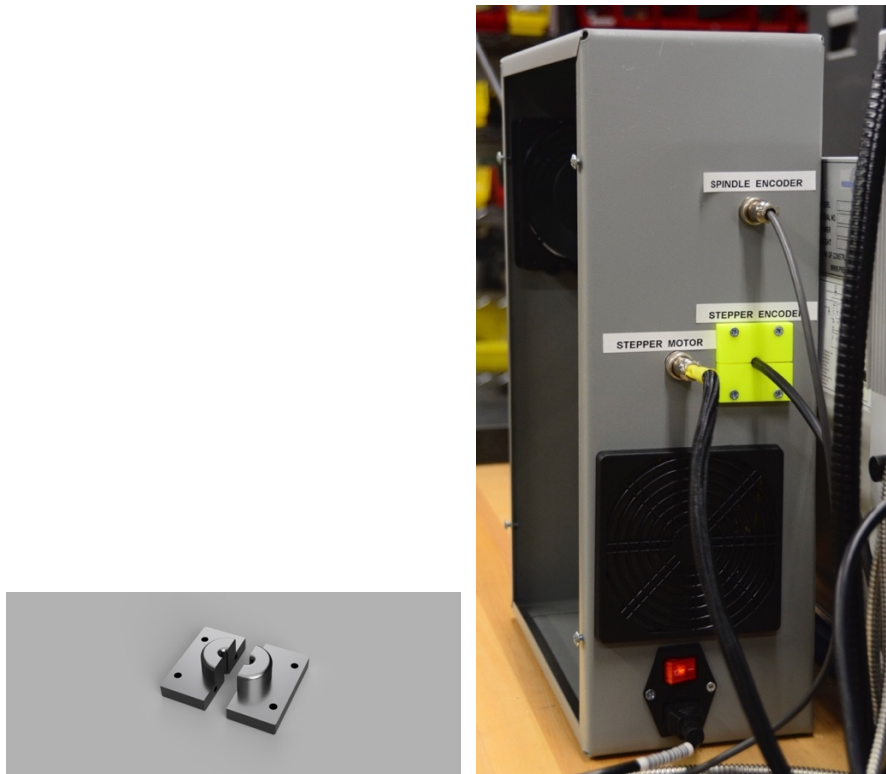
I was careful to separate the stepper parts of the circuit as well as I could from the logic. I kept separate grounds for the motor supply and step controller from the digital ground. I kept the cable to the control panel as short as possible, and kept that away from noisy stuff.



I have the lathe on a bench large enough that I had space to stand the box on end behind the lathe, and it extended a couple of inches above the splash shield – perfect height to mount the control panel right on the back of the electronics box using the C124 Bud box recommended.



I passed all the cables for the motor and encoder through the side of the box, again trying to keep cables as short as possible and paying attention to shields and grounds where appropriate. Cable shields were connected to the case ground or connector shells to the case, never to digital or motor power ground. The spindle encoder got a five pin metal shell pass through connector on the box, and the motor drive got a three pin. The motor's encoder had a 15 pin cable with an adapter cable, and rather than cut into that, I made a large opening and designed a custom strain relief and hole cover in Fusion and 3D printed in PLA. Be sure to use that extra cable on the motor encoder – it's not just an extension, it also switches pins on some signals. If that cable is skipped, the motor encoder won't work and the motor won't turn.



All wiring was done following the schematics that James has posted at <https://github.com/clough42/electronic-leadscrew/wiki/Wiring-Everything-Together>. One substitution that I made was using a DIN rail mount 5 VDC power supply in place of the wall wart. I was already using the rail and terminal blocks, and this made a nice fit. The connector for the Launch board was taken from a pack of 9 volt battery adapters that I had on hand for Arduinos.

Note: I thought that the five pin single row connections to James's level shifter board and the encoder to the Launch were a loose fit and might come off with vibration, so I added a little dab of hot glue to help hold the connectors on the headers, and provided strain relief clips to hold the cables a couple of inches out from the connectors. James used some very nice raceways in his build, but I didn't find those in time and thought that the wiring was simple enough to skip those.

Programming and Editing configuration.h

I won't go into details here on downloading the TI Code Composer tools, getting the source code or programming the Launch board through USB. James has an outstanding step-by-step video (https://youtu.be/2A4LH1Q_b_w) and that's what I followed. He does note that this is all designed for Code Composer 9.1, and TI makes that available along with many older and newer versions. Be careful to get that version, although some folks with newer Macs may need 10 or later to run.

There are a couple of changes needed in configuration.h to match things up with our Precision Matthews lathe. Since I used the encoder and pulleys that James called out, I had a close start. I programmed my stepper controller to use 1000 pulses per revolution, and with the 3:1 (72 to 24 teeth) pulley ratio, microsteps are set to 3 for threading. Here are the key lines for that:

```
// Steps and microsteps
#define STEPPER_MICROSTEPS 3
#define STEPPER_RESOLUTION 1000

// Encoder resolution (counts per revolution)
#define ENCODER_RESOLUTION 4096
```

The lead screw is 8 threads per inch on the PM-1022 and PM1030, so we set that line in configuration.h appropriately:

```
// For Imperial leadscrews: pitch in Threads Per Inch (TPI)
#define LEADSCREW_TPI 8
```

The one item where the PM lathes depart a bit from the basic design is that they have a separate gearbox driven feed system from the half-nut threading feed. This is due to the PM lathe having power feed for both saddle travel and cross-feed. From careful measurement with the saddle feed engaged and turning the leadscrew by hand, I found that one turn of the screw moved the saddle 0.0375" per turn.

Since the leadscrew is 8 TPI, that would be 0.125" per turn in thread mode with the half-nuts engaged, so the gear ratio for feed is 0.125/0.0375, or 3.33 to 1. James has provided a place in configuration.h to deal with this. We need to set the value for STEPPER_MICROSTEPS_FEED to 10. Why 10? Well, the standard microsteps are 3 to handle the pulley ratio. We need to turn 3.33 times faster for feed, and very conveniently, $3 \times 3.333 = 10$. I love it when real math turns out an integer result, very handy in this application.

Anyway, find these lines...

```
// Separate step and microstep settings for feed rates. Redefine these if your
// lathe has a separate feed drive train with a different ratio.
#define STEPPER_MICROSTEPS_FEED STEPPER_MICROSTEPS
#define STEPPER_RESOLUTION_FEED STEPPER_RESOLUTION
```

.... and change the microsteps line to:

```
#define STEPPER_MICROSTEPS_FEED 10
```

Those are all the needed changes in configuration.h, and no other changes are needed to the code to get everything working and moving correctly.

Note: James added code in version 1.4 to detect situations where the stepper would be clocked faster than 100 kHz. With this setup, that will happen at about 900 RPM on the spindle at 0.040" per turn of feed. This is a much more aggressive combination than Precision Matthews had in mind for these lathes. The standard coarse feed gear setup in the PM manual has a max feed rate of 0.015" per turn, not 0.040". I plan to not use the most aggressive couple of feed settings on my lathe, and can tell you that 0.040" per turn and 900 RPM has the leadscrew spinning fast enough to be scary, and it's whining in protest. 0.015" is my limit for feed.

Settings Changes to Stepper Controller

The default factory settings on my hybrid servo controller were not set for 1000 steps per revolution. I needed the programming cable and software from the controller manufacturer to change the settings. I bought a complete kit from Automation Technologies, and their page has links to all the documentation for the motor and controller.

Kit: <https://www.automationtechnologiesinc.com/products-page/nema23-closed-loop-stepper-motor-system-hybrid-servo-kit/hybrid-servo-drive-kl-5080h>

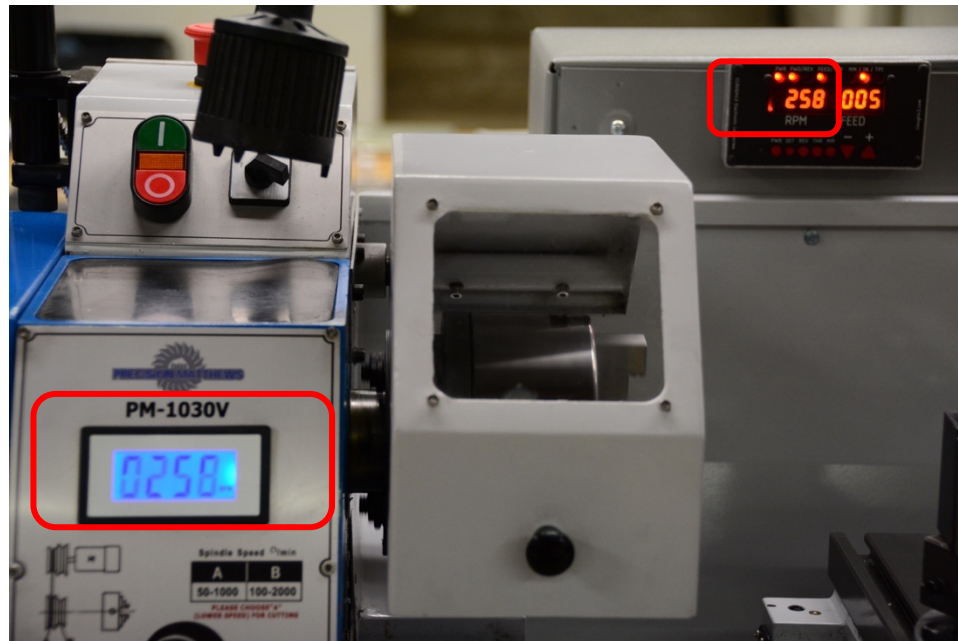
Programming cable: <https://www.automationtechnologiesinc.com/products-page/nema23-closed-loop-stepper-motor-system-hybrid-servo-kit/calibration-cabel>

My kit came with a slightly different but equivalent controller to the one pictured at Automation Technologies. It was this controller: <http://www.leadshine.com/productdetail.aspx?type=products&category=easy-servo-products&producttype=easy-servo-drives&series=es-d&model=es-d508> The PC software utility for programming the controller (ProTuner) can be gotten from the Downloads tab of that page.

James has a screen shot of the software with the **correct change to the settings to get 1000 pulses per rev** at: <https://github.com/clough42/electronic-leadscrew/issues/140> I also lowered my Holding Current setting to 20%. In our application, there isn't much hold needed if the motor isn't spinning.

Testing

The first test when everything was assembled and checked mechanically was to confirm that the LaunchXL was able to read the spindle encoder correctly and that the tachometer on the ELS was accurate. Here's a picture showing both the factory tach on the lathe and the ELS control panel:







They agree perfectly, so that indicates that I have all of that section wired correctly and that the encoder settings in configuration.h in the code are correct.




Once that was confirmed, I connected the motor and checked that feed and thread rates. For that, I used the DRO to check saddle movement, and simply turned the chuck by hand to count turns. Both feed and thread rates checked out as accurate.

Parts List

Here are the parts that I used, and sources.

Required

Item	Description	Source
TI LaunchXL-F280049C	Main processor board from TI. 	These are available from several electronics distributors, but I got mine at DigiKey: Launch at Digikey
Interface Board		James has these on eBay as a kit with all the connectors. Some assembly required – basic soldering. eBay: https://ebay.to/2WuLa7m
Control Panel Kit		You can get the panel alone, but save time and support Clough42 and get the kit from him at: https://ebay.to/31VMbKw Assemble and drop right into the Bud Box C124. Assembly video: https://youtu.be/HObYiK3c-QA
Hybrid Servo Stepper Motor & Controller	NEMA 23 Closed Loop Stepper Motor System-Hybrid Servo Kit, 32 bit DSP Based: 282 oz-in Item# 1602 	I purchased this as a kit from Automation Technology: Hybrid Servo Kit I did receive a different controller from the one pictured here and on their page, but it was functionally identical. You will need the programming cable to go with the controller: Programming Cable
48 Volt Power Supply	HobbyUnlimited 48V 12.5A 600W Universal Regulated Switching Power Supply 	Amazon: https://www.amazon.com/gp/product/B0822L99C2/ref=ppx_yo_dt_b_asin_image_o09_s00?ie=UTF8&psc=1


Bud C124 Box		eBay: https://www.ebay.com/itm/Bud-Industries-CU-124-Metal-Enclosure-Econobox-Diecast-LOT-OF-2/324287145158?ssPageName=STRK%3AMEBIDX%3AIT&trksid=p2060353.m2749.l2649
72 Tooth Pulley	72 tooth, 3M, 15 mm pulley with 14 mm bore. This will need to have a keyway broached.	eBay: https://www.ebay.com/itm/3M-Timing-Belt-Pulley-12T-120T-Tooth-Width-15mm-Pitch-3mm-Synchronous-Wheel-Gear/163542838348?ssPageName=STRK%3AMEBIDX%3AIT&var=462917666602&trksid=p2060353.m2749.l2649 Note that you must specify bore, width, etc.
24 Tooth Pulley	24 tooth, 3M, 15 mm pulley with ¼" bore.	See same link as above. I bought these together and note that this vendor ships direct from China. Mine arrive in a little over two weeks.
Timing Belt	354 mm, 118 tooth belt, 3M, 15 mm	These are available from Amazon in many lengths, but I got a selection from PolyTech Designs: https://shop.polybelt.com/3M-15-15mm-Wide-Belt-Rubber_c59.htm It turned out that 118 was the correct tooth count for my mount. Amazon: https://www.amazon.com/BEMONOC-Synchronous-Length-Printer-Accessories/dp/B07RVJ7RCC/ref=sr_1_5?dchild=1&keywords=3m+15mm+belt+118+teeth&qid=1616283034&sr=8-5
Large Electrical Box	Wiegmann SC121806NK 	Automation Direct: https://www.automationdirect.com/adc/shopping/catalog/enclosures-z-subpanels-z-thermal-management-z-lighting/enclosures/junction-boxes/sc121806nk
IEC Power Entry Module		Amazon: https://www.amazon.com/gp/product/B07RQV2NPN/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1 Provides a lighted switch and fuse. Makes a very neat entry into the electrical box.
Five Volt Power Supply	MEAN WELL MDR-20-5 AC to DC DIN-Rail Power Supply 5V 3 Amp 15W	Amazon: https://www.amazon.com/gp/product/B005T6RBSO/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1
Cooling Fan	AC Infinity AXIAL 1238W, Muffin Fan, 120V AC 120mm x 38mm High Speed, UL-Certified for DIY Cooling Ventilation Exhaust Projects	Amazon: https://www.amazon.com/gp/product/B004YTSB7C/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1 Might want to consider a smaller fan than I used – this sounds like a jet engine and could cool a small nuclear reactor.

Fan Guards With Filters	coolerguys 120mm 3 Part Fan Filter Grill with Screws (2 Pack)	Amazon: https://www.amazon.com/gp/product/B00V8ZVH4O/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1 These are matched to the fan above. If you go with a smaller fan, looks for matching size for these.
DIN Rail Kit	Dinkle UL Listed DIN Rail Terminal Block Kit #1 Red/Black Dinkle 20 DK2.5N 12 AWG Gauge 20A 600V Ground DK4N-PE Jumper DSS2.5N-10P End Covers End Brackets	Amazon: https://www.amazon.com/gp/product/B07NVVP9X7/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1 Note that this comes with long jumper bars. I ordered some short, two position jumpers to go with it: https://www.amazon.com/gp/product/B07SVG5ZJ/ref=ppx_yo_dt_b_asin_title_o07_s00?ie=UTF8&psc=1

Optional Parts

I used these, but you may want different connector arrangements to suit your overall installation.



Item	Description	Source
Metal Shell Connector Kit	<p>Hilitchi 40-Pieces 2 3 4 5 Pin 16mm Thread Male Female Panel Metal Aviation Wire Wire Connector Plug Assortment Kit (2 Pin / 3 Pin / 4 Pin / 5Pin)</p> 	<p>Amazon: https://www.amazon.com/gp/product/B07F5B5LLX/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1</p> <p>You'll only need two sets for the ELS, but you're all set for the next project!</p>

Connector Kit for Cables to Fit Pin Headers on PCBs

CHENBO 620pcs
2.54mm/0.1" Connectors
Wire Jumper Cable Pin
Header Connector Housing
Assortment Kit Male Female
Crimp Pin Connector
Terminal Pitch With Plastic
Box



Amazon:

https://www.amazon.com/gp/product/B077X8XV2J/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&psc=1

You may need a crimp tool for the pins if you don't already have one: https://www.amazon.com/IWISS-Professional-Compression-Ratcheting-Wire-electrode/dp/B000MM4YUY/ref=pd_bxgy_img_2/135-2232498-3601669?encoding=UTF8&pd_rd_i=B000MM4YUY&pd_rd_r=5e7b19c2-ab6a-47eb-9d83-36cff8392c66&pd_rd_w=7llaP&pd_rd_wg=ohTld&pf_rd_p=f325d01c-4658-4593-be83-3e12ca663f0e&pf_rd_r=ZZN36QECY01TQTF09NX5&psc=1&refRID=ZZN36QECY01TQTF09NX5

Get the correct crimper – it will save lots of aggravation.

Flat Spade Terminal Kit

Wire Terminal
Crimping Tool Kit,
Qibaok Ratcheting
Wire Crimper AWG 22-
16(0.5-1.5mm²) with
500PCS Female Male
Spade Connectors &
Bullet Connectors
Terminals



Amazon, crimper included:

https://www.amazon.com/gp/product/B07RZSSTSJ/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1

Ferrule Crimp Kit	<p>Ferrule Crimping Tool Kit - Sopoby Ferrule Crimper Plier (AWG 28-7) w/ 1800pcs Wire Ferrules Kit Wire Ends Terminals(AWG 22-8)</p> 	<p>Amazon, crimper included: https://www.amazon.com/gp/product/B07PJK2VNT/ref=ppx_yo_dt_b_asin_title_o07_s00?ie=UTF8&psc=1</p> <p>These are to apply to stranded wire ends when used with terminal blocks and strip to avoid stray strands shorting to adjacent points. If you've never used these, give them a try. The really neaten up an assembly.</p>
Chip Tray	<p>Winware ALXP-1622 16-Inch by 22-Inch Aluminum Sheet Pan, Pack of 1</p> 	<p>Amazon: https://www.amazon.com/gp/product/B001CIEJQU/ref=ppx_yo_dt_b_asin_title_o08_s00?ie=UTF8&psc=1</p> <p>It's just a baking sheet, but it's a perfect fit for the PM-1030 lathe for a removable chip tray. Exact fit front to back and about 2/3 of the length of the bed.</p>
Multi-conductor Shielded Cable	<p>25' West Penn 3270 6 Conductor 22 Gauge Shielded Cable ~ 6C 22AWG CMR</p> 	<p>eBay: https://www.ebay.com/itm/25-West-Penn-3270-6-Conductor-22-Gauge-Shielded-Cable-6C-22AWG-CMR/264312330784?ssPageName=STRK%3AMEBIDX%3AIT&trksid=p2060353.m2749.l2649</p>
Multicolor Stranded Wire	<p>BNTECHGO 16 Gauge Silicone Wire Kit 10 Color Each 5 ft Flexible 16 AWG Stranded Tinned Copper Wire</p> 	<p>Amazon, 16 AWG 5 ft: https://www.amazon.com/gp/product/B01M7NWX7A/ref=ppx_yo_dt_b_asin_title_o08_s00?ie=UTF8&psc=1</p> <p>20 AWG, 10 foot: https://www.amazon.com/gp/product/B01LZ4CGXL/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&psc=1</p>