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Prototyping Using a Custom, AC-Powered Test Bench

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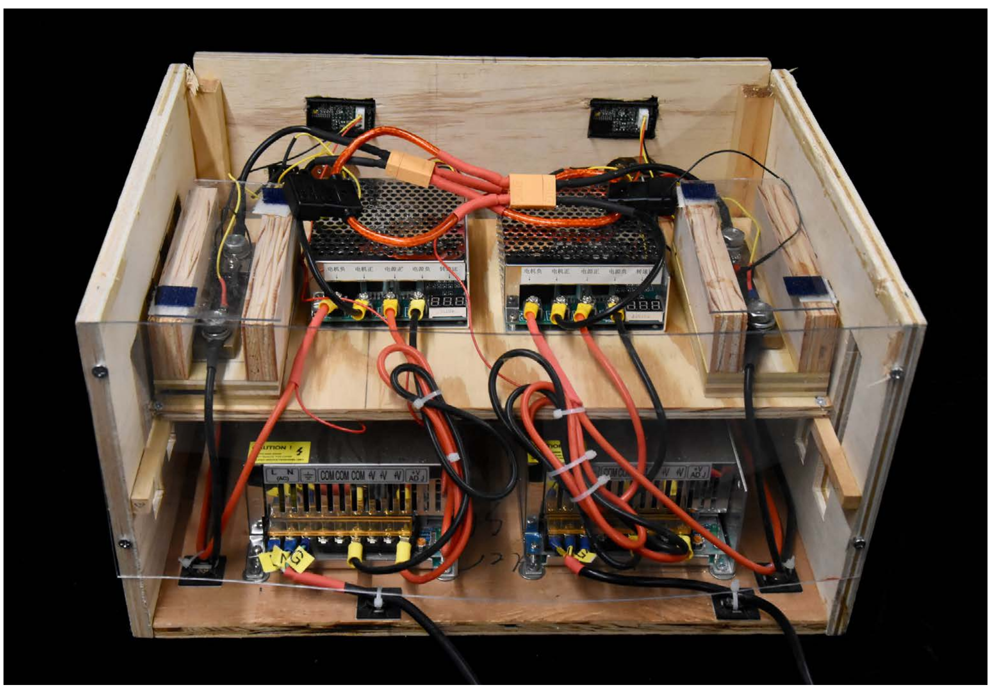

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1 Abstract

In an FRC build season, it's often necessary to build prototypes to test ideas, validate assumptions, and rapidly iterate a design. For these prototypes, it's often desirable to test under similar conditions to a full-fledged robot by controlling the motion with electricity.

In the past, the LigerBots have tried several methods to power prototypes, but found each to be lacking due to issues with bulk, convenience, and safety. We designed a test bench that is powered by a wall outlet and has consistent, variable speed control with parameter readouts.

This paper will provide an overview of common prototyping methods, present the features of our design, the components we used, and a rough guide for assembling a test bench.

2 Background

There are many solutions for powering prototypes in the FRC community. Some of the most common are: motors directly connected to a battery, a cordless drill, a full robot control system, a servo tester, and a commercial benchtop power supply. While these systems have utility, we will explain why we chose to develop our own solution. Many of these will reference the downside of using batteries for prototyping. While people are prototyping, they often get carried away and forget to pay attention to the charge level of a battery. Not only is deeply discharging a battery bad for its health and longevity, mechanisms powered by an undercharged battery will have different performance characteristics.

2.1 Motors directly connected to a battery

Connecting motors to the battery is the quickest way to power a motor. However, there are numerous obvious disadvantages to this approach:

- It uses a battery.
- It's impossible to control the speed of the motor.
- It's dangerous without a fuse between the battery and the motor.
- FRC batteries are crimped with SB50 connectors. Since motors probably don't have the same connectors, an interface cable is needed. In the past, the LigerBots had melted wires when untrained students put alligator clips with undersized wires between the battery connector and the motor.

2.2 Cordless drill

A standard drill can be easily coupled to a shaft using an adapter collet. Drills provide variable speed and direction. However, the speed is not a consistent value nor is it precisely measurable as it relies on someone having a steady trigger finger. Drills also output a completely different power wattage from an FRC motor, which might deliver misleading results. Finally, like motor batteries, drill batteries must be continually monitored and recharged which disrupts the flow and output consistency of testing.

2.3 Drill trigger

One method of adapting the drill speed control to FRC characteristics is to disassemble a cordless drill, removing the battery and gearbox assembly. Where the battery was, attaching a circuit breaker and an Anderson SB50 connector will allow the input to be connected to a robot battery. Adding motor connectors to the drill output (where the motor was) let the trigger transfer power to a motor of choice.

This method involves making a custom device, which takes time and effort. It's still dependent on a battery, as well as having a steady trigger finger for consistency.

2.4 Full robot control system

A control system is bulky, and setting it up requires effort and time from electrical and programming students that could be used on other tasks. It's a lot of expensive components, of which teams have a limited number, to set aside for testing a quick prototype. This also requires a drive computer, running actual robot code, to control the speed of the motor in the prototype.

2.5 Servo tester

A servo tester is a PWM signal generator that can be connected to a motor controller in lieu of programming. This eliminates the need for a roboRIO or any code, and also produces a consistent, known motor output. However, this method still requires the use of a PDP and a battery to power the motor controller.

2.6 Commercial benchtop power supply

FRC motors can consume large amounts of power. By reading the driver station logs or using tools like the JVN Calculator, we know that mechanisms can have short, high current draws upwards of 30-50A and drivetrain motors can pull current spikes up to 60-80A. Benchtop variable power supplies that can provide a maximum of 40-60A at 12V were hard to find on a budget. For example, the CSI1560SW power supply can output up to 60A, but costs $277.13 just to supply power for a single motor. (www.circuitspecialists.com/csi1560sw.html)

3 Custom Testbench Objectives

We decided to build a custom, safe, all-in-one system that would provide variable speed control to make the prototyping process during build season more efficient. Our requirements included the following features:

1. Change the the speed of the motor
   (a) To change the speed, the voltage a motor receives needs to be adjustable
   (b) Measure voltage going to the motor during prototyping
   (c) Maintain a consistent and measurable voltage display output
2. Create a safe testing environment
3. An all-in-one system that requires minimal set-up, "plug-and-play" to use
4. Be able to supply a maximum current draw of 40-60A to approximate actual robot conditions
5. Be able to supply 12V to approximate actual robot conditions

4 Design Decisions

1. 12V 50A power supply

    (a) Motors can pull up to 80A during extreme spikes, e.g. CIM motors in a drive train when accelerating. However, this is an extreme case that usually happens under adverse conditions and risks brownouts. Our driver stations logs show that 50-60A is a more typical high current spike, and most mechanisms pull much less, so a 50A supply is sufficient for prototyping.

    (b) The power supply must provide 12V to match FRC-legal battery specifications so that prototyping results will map to robot performance.

    (c) We added an in-line fuse between the power supply and the motor controller for safety. We used 40A fuses in the fuse holder to simulate the 40A ports on the PDP. Different sized fuses like 20A or 30A can also be used to simulate different ports on the PDP.

2. 10-55V, 60-100A speed controller

    (a) A speed controller adjusts the power supplied to the motor.

    (b) The speed controller must be rated for the maximum current that the power supply can provide.

    (c) The voltage range must include 12V. Our 10-55V range is based on the available parts we found online.

3. 12V, 50A readout with voltage and current measurements

    (a) A readout is necessary to provide detailed performance metrics for quantitative testing and evaluation.

    (b) Our readout came with a shunt resistor. We isolated it in a subcompartment within the box so when people are handling the test bench the shunt does not shock them or short.

4. Powered via standard AC wall outlet

    (a) Always available. While it makes the testing rig slightly less mobile many people tend to drop batteries and motors in the shop and keeping it tethered to a wall keeps the electrical components safer from being dropped by students running throughout the shop. Sometimes a sufficient amount of charged batteries are not available due to outreach events, software testing of chassis, and other projects, so not having to rely on batteries to test is extremely helpful in speeding up the testing process.

5. Contained in a box
   (a) Makes it easy to transport.
   (b) Protects users from dangerous power. 12V & 50A is a significant amount of power and proper precautions need to be taken.
6. Two complete power circuits in one box
   (a) Prototyping often involves using 2 motors at once. For example, sharing a single load across 2 motors or testing integration between an intake and a scoring mechanism.

5 Components

The total cost reflects that we put 2 complete power circuits in our box per our design decisions above. We used many components (wire, crimps, wood, polycarbonate sheeting) that we use regularly as a team. We expect that many teams will also have these supplies readily to hand, so we count their cost at $0.

Figure 1: Materials and Costs

Part	**Unit Cost**	**Total Cost**
Eyeboot 12V 50A DC Universal Regulated Switching Power Supply 600w	$ 55.00	$ 110.00
(2) GEREE 0.28" Digital LED Voltmeter Ammeter Multimeter DC 4.5-30V 100A	$ 26.99	$ 53.98
(2) SenMod 12V 24V 36V 48V 60A Stepless DC Motor Speed Controllers	$ 13.51	$ 27.02
12 AWG wire (red and black)	$ 24 for 25 feet at AndyMark	$0 Had on hand from robot
22 AWG wire (red, black, and yellow)	$ 3.97 for 25ft from local shop (You Do It Electronics)	$ 11.91
22 AWG spade wire crimps	$ 1.57 from local shop (You Do It Electronics)	$ 1.57
12 AWG ring wire crimps	$ 7.86 on Amazon	$ 7.86
12 AWG spade wire crimps	$ 9.99 on Amazon	$9.99
PC Power cord (2)	$ 4- $10 online	$8- $20
Inline fuse holder (2)	$ 6.40	$ 12.80
40A Fuses	$5.56	$5.56
Scrap wood	had in shop	$ 0
Scrap Polycarb	had in shop	$ 0
Wood Glue	had in shop	$ 0
Wood screws	had in shop	$ 0
Mesh	recommended improvement	recommended improvement
Heat Shrink	had in shop	$ 0
Adhesive Velcro	$ 2.98 on amazon	$ 2.98

Total budget: $ 263.67

For comparison, an equivalent setup to our DIY test bench can be made using two 15 Volt DC 60.0 Amp Switch Mode Power Supplies from Circuit Specialists for a total cost of $554.26. Link to alternative power supply: https://www.circuitspecialists.com/csi1560sw.html

6 Tools needed for Manufacture

These are common tools, other than the pneumatic nail gun. We assume teams have these or equivalent tools on hand, so we are not including costs for these. The pneumatic nail gun can be substituted by a hammer or by a cordless drill and screws.

- Band saw or jig saw
- Drill
- Soldering iron
- Heat gun
- Wire strippers for 22 AWG and 12 AWG
- Crimpers for 12 AWG and 22 AWG
- Wrenches
- Screw drivers
- Drill press or cordless drill
- Circular drill bit
- Hack saw
- Pneumatic nail gun and air compressor

7 Assembly

Below are instructions for wiring the testbench components. A wire diagram is included. We do not include specific instructions on how to build a box. The box should have air vents to prevent parts from overheating. We also suggest putting walls around the shunt resistor to help prevent anything from shorting across it.

Figure 2: A wiring diagram for one circuit.

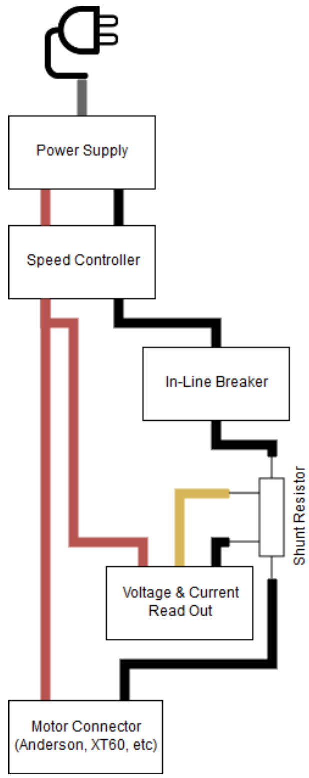


Figure 3: Left: The front of the testbench box with readout, speed control dial, and connector pigtail. Center: Air vents for cooling. We recommend covering these with mesh to prevent loose items from falling into the test bench. Right: The back of the box with its lid on and polycarbonate sheet across the back for protection. We chose polycarbonate instead of wood for the back so we could see the status LEDs on the components for rapid diagnosis and debugging if necessary.

1. Construct a box using wood. The thickness of the wood does not matter much, just keep in mind that the box is likely to be dropped and should be durable. (Note: Measure the size of the components and make sure to add room for crimp connectors and wires when designing your box.)

2. Cut venting holes. To cut a hole in a piece of wood, drill a hole in a corner and then use a jig saw or hack saw to cut the rest of the hole. We reccomend covering your vent holes with a mesh material to prevent stray items or metal shavings from falling into the box and causing electrical shorts or mechanical damage.

3. Cut holes for readouts, speed controller dials, and holes where the motor controller pigtails will exit the box.

4. If using a shelf, place in the box. You may want to leave a gap between the shelf and the front of the box for wires to pass through.

5. Place the components in the box

6. Construct a container to isolate the shunt, leaving room for wires to enter and exit.

7. Cut the IEC female connector end off a standard computer power cable. Strip the cable to expose the 3 wires inside and separate the three wires.

8. Strip the three wires and crimp a connector on each.

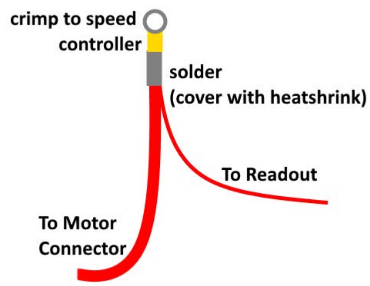
9. Screw the three crimped wires into the screw terminals of the power supplies. Power wire to L ("Live"), ground to ground, and the third wire to N ("neutral"). Attach the cable to the box to provide strain relief and protect the crimp-to-screw-terminal connection. The A/C wall outlet end of the cable will extend outside the box so they can be plugged into a wall outlet or extension cord.

10. Cut **red 12 AWG wire** to go between the power supply and the speed controller. Crimp both ends and connect one end to the power supply V+ terminal and the other to the voltage input of the speed controller.

11. Cut **black 12 AWG wire** to go between a ground terminal on the power supply and a ground terminal of the speed controller. Use spade or ring crimps to connect to screw terminals.

12. Cut **red 12 AWG wire** to go from the speed controller out the exit hole on the outside of your box. Solder one end to the **22 AWG red wire** and crimp as shown in the figure below. This end connects to the motor controller. The other end of the **22 AWG red wire** runs from the controller to the readout (be sure to use heatshrink to cover the solder joint.) Use your team's standard connector (usually Anderson Powerpoles, we use XT60s) at the other end of the **red 12 AWG wire**. We recommend that these do not extend far outside the box to make for storage easier. You can make extension pigtails as necessary to reach your motors when prototyping.

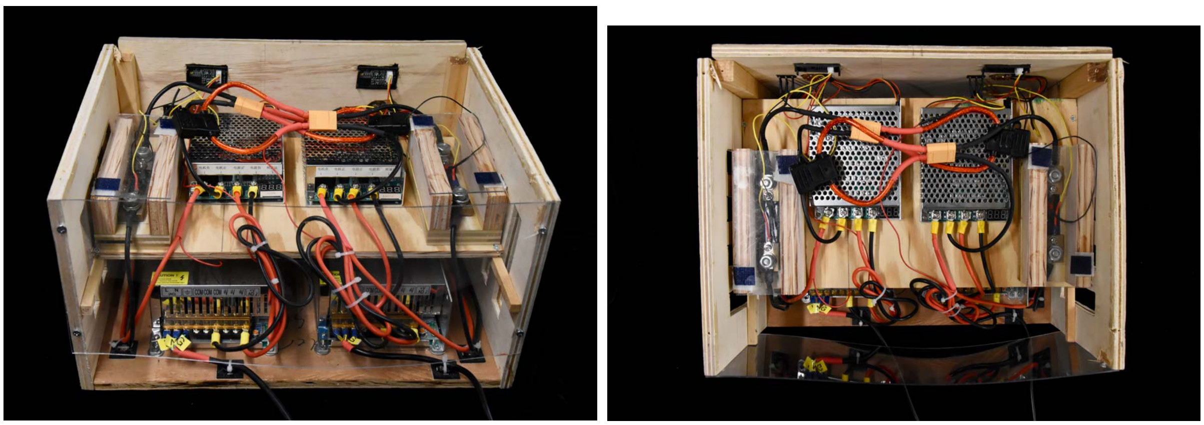
Figure 4: How to make the power wire from power supply to motor controller, with a branch for the readout.



13. Use the inline fuse holder to connect the ground terminal of the speed controller to a ground terminal of the shunt resistor. Solder and heatshrink **black 12 AWG wire** to ends as necessary for length. Crimp ends with ring or spade connectors to attach to screw terminals of controller and shunt. Place a fuse in the fuse holder.

14. Cut another **black 12 AWG wire** to go from the other end of the shunt to the exit hole in the front of the box. Connect to shunt with crimp connector to screw terminal. The other end will exit the box to interface with the motor. Use your team's standard connector (usually Anderson Powerpoles, we use XT60s) at the end. Again, we recommend that these do not extend far outside the box to make for storage easier.

Figure 5: The inside of our finished box with 2 circuits in it. You can see the shunt resistors on the far left and the far right on the top shelf. The power supplies sit on the bottom shelf.



15. Crimp ring or spade terminals to the **22 AWG yellow and black wires** from the voltage readout and connect to the corresponding screw terminals on the shunt resistor.

16. Provide strain relief on the motor connector cables exiting the box.

17. Close up the back of the box, leaving room for the power cables to exit.

8 Lessons Learned

While the test bench has been a great success supporting our prototyping efforts, there are some improvements we would make to our original design. In general, team members were rougher with the box than we had anticipated: they pulled the wires, sometimes grabbed the test bench thinking it was unplugged and ripped the cord out of the wall, and left it sitting next to the metal chop saw in a pile of metal shavings. Below is a short list of what we discovered and how we recommend fixing these problems:

- The more strain relief the better because otherwise the connectors will be severely pulled on which can break the crimps or the screw terminals on the components.

- The air vents on the sides should be covered with mesh to avoid metal shavings entering the box and causing electrical shorts.

- The motor connector pigtails that exit the test bench should be kept short and connector-to-connector extensions should be used to connect to motors. Making short, medium, and long extensions makes it easy to choose the right wire length for your prototyping application while avoiding tangles or having stray loops of wire vulnerable to being caught in gears of sprockets.

- The top or back of the box should be hinged with a latch, instead of screwed down, to make fuse replacement easier.

9 Conclusions

We used the test bench frequently in our 2018 and 2019 build seasons to test our different mechanisms and make iterations. It made prototyping easier because it eliminates the need for someone to rig up a whole control system and write a code to test. Any student, including rookie members, was able to quickly learn how to use the testbench due to its simple interface and contained design. It has also greatly reduced the load on our batteries during our prototyping phase of design development. In general it meets all our design criteria and works effectively.

Figure 6: Our test bench in action!