

How to Measure a DC Motor for use as a DC Generator

MTM Scientific, Inc. PO Box 522, Clinton, MI 49236 USA

A common challenge for experimenters building a windmill or water turbine is finding an inexpensive DC power generator which has high power output at low RPM. One option is to use a regular permanent magnet DC motor as a DC generator. Most people know a DC motor can be driven at the shaft to become a DC generator, but they don't know how much power to expect. Here we describe a simple technique for measuring a DC motor for use as a DC generator.



Figure 1. DC Motor working as a generator, driven at the shaft by a drill press.

The best way to measure the performance of a motor as a generator is to create a simple test setup on your workbench. Three pieces of equipment are needed to perform the test: A digital multimeter capable of measuring DC voltage, an assortment of load resistors or shunt, and a source of constant speed RPM such as a drill press. Figure 1 shows a typical test setup. In our example we are measuring the performance of a gear head motor. The gear head increases the motor RPM. In

our setup note that the drill chuck is directly gripping the motor shaft, and that the DC motor is securely held with clamps. *It is important to have a secure setup because the motor will have a strong reaction torque during parts of the test.*

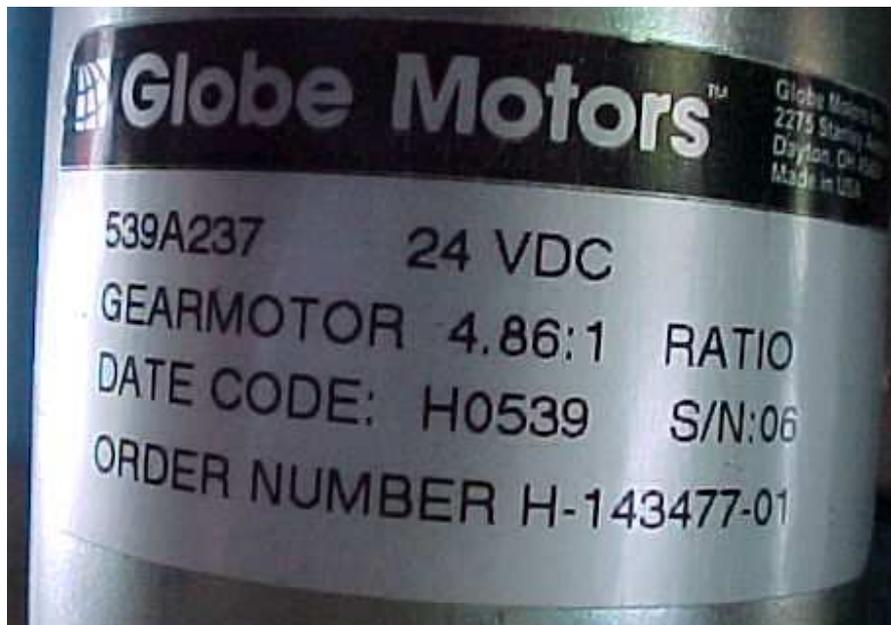


Figure 2. Nameplate information from DC Motor/Generator used on this test.

In our example the drill press RPM is taken from a legend table printed on the cover for the V-belt settings. We arranged the belts for the slowest speed available, which is 220 RPM.

With the motor spinning at 220 RPM we can proceed to collect the data. The measurement process involves connecting the output leads of the motor to various load resistors and measuring the generated voltage. Our results are shown in Table 1. Note that we began by measuring the output voltage with no load attached, which gives the open circuit output voltage at 220 RPM. Also, we ended the test by measuring the short circuit current through a current shunt. This is the short circuit output current at 220 RPM.

LOAD OHMS	VOLTAGE	CURRENT	WATTS
OPEN	8.37	0	0
200	8.2	0.041	0.34
100	8.08	0.081	0.65
50	7.93	0.159	1.26
25	7.72	0.31	2.38
10	7.23	0.72	5.23
5	6.61	1.32	8.72
2	5.16	2.58	13.3
1	3.67	3.67	13.5
0.5	2.4	4.8	11.5
SHUNT	0	6.5	0

Table 1. Output of the Motor/Generator

Table 1 also has an entry for the power developed. This is calculated from the equation: DC Power equals voltage multiplied by current ($P=V \times I$) From the results we see that the maximum power developed was in the range of 13Watts at an output voltage between 2 and 5 Volts.

The test results become more meaningful when we plot them on a graph, as shown in Figure 3.

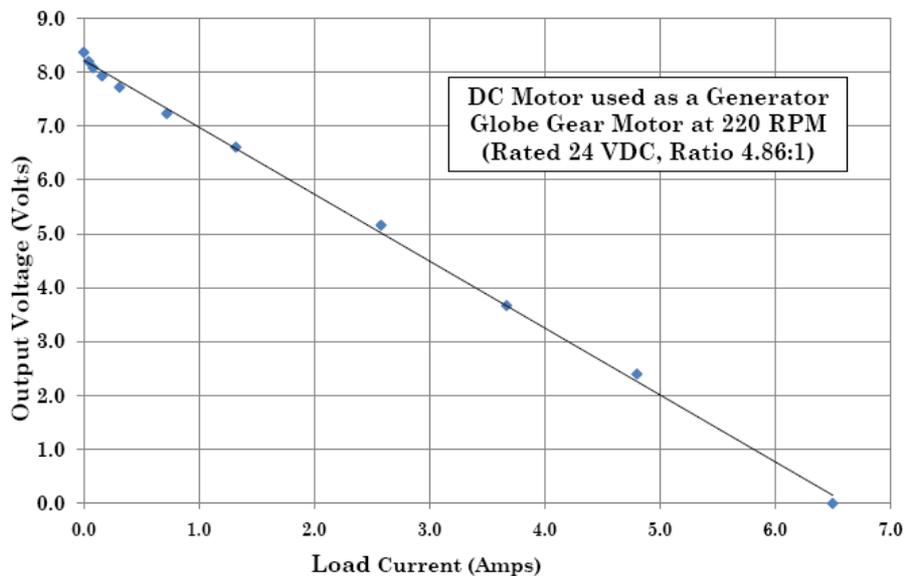


Figure 3. Output Voltage of Generator versus Load Current

The relationship between the output voltage and load current is a straight line. The graph can be used to predict the power output at any voltage. For example, suppose we want to use this motor to provide 5 Volt DC power. Using the graph we find the output current would be 2.5 Amps. Since the DC power output is voltage multiplied by current (Power = Voltage x Current), we can expect a power of 12.5 Watts at 5 volts with this motor spinning at 220 RPM.

It was not necessary to collect so many data points to create the graph. The straight line graph could have been created from 2 simple measurements at the end points: The open circuit output voltage ($V_{oc} = 8.4V$), and the short circuit output current ($I_{sc} = 6.5A$). If those 2 measurements are made correctly, we can plot them and draw a straight line to predict generator performance.

The open circuit output voltage is easily measured with a digital multimeter, but the short circuit output current has the potential to cause damage to your meter. The safest approach is to measure the short circuit current with the use of a current shunt. A typical current shunt is rated for 100 Amps of current and will provide a voltage output of 50 millivolts at rated current. The main load current flows through the shunt and a multimeter is simply used to measure the voltage signal across the shunt. This is sometimes referred to as a 4-wire measurement.

What about other speeds?

It is possible to predict the generator output performance at other speeds from these same measurements. The straight line graph of output voltage versus current has a slope determined by the effective resistance of the motor. The equation for motor resistance is $R_m = V_{oc} / I_{sc}$, where R_m is the motor resistance in ohms, V_{oc} is the open circuit voltage, and I_{sc} is the short circuit current. In the example above we calculate $R_m = 8.4 \text{ Volts} / 6.5 \text{ Amps} = 1.3 \text{ ohms}$

The open circuit output voltage from the motor used as a generator is directly proportional to the speed in RPM. For example, doubling the speed will double the open circuit output voltage. Our original measurement was made with the motor turning at 220 RPM. We can predict the new output voltage (for example at 430 RPM) with the formula $V = (430/220) \times 8.4 = 16.4 \text{ Volts}$.

Next, we can calculate the new short circuit current by dividing the new open circuit voltage by the effective resistance of the motor. In our case, $I = 16.4 / 1.3 = 12.6$ Amps

We therefore have the two points we need to plot the graph for 430 RPM: $V_{oc} = 16.4$ V and $I_{sc} = 12.6$ Amps. Figure 4 is a graph of the predicted generator performance plotted with some data points that were taken of the actual performance. The predicted and actual performance are in good agreement.

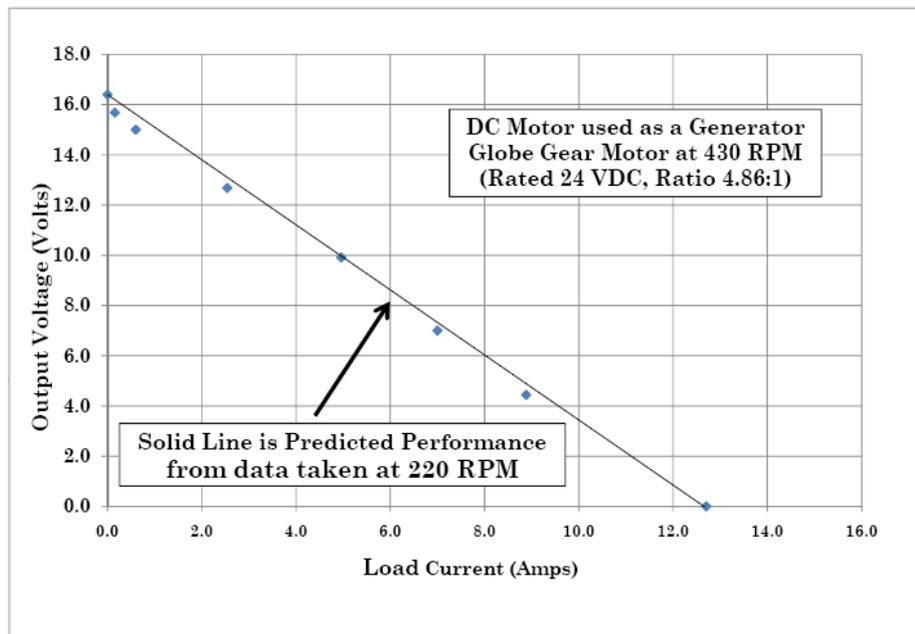


Figure 4. Predicted versus measured performance at a higher speed

Cookbook Method to do this Motor/Generator Test

Here is a cookbook method to apply this test to your motor/generator:

1. Attach the motor/generator to a source of rotation at a known RPM.
2. Measure the DC Voltage output using a multimeter. This is V_{oc} .
3. Use a shunt to measure the short circuit current. This is I_{sc} .
4. Draw the load line on a sheet of graph paper using V_{oc} and I_{sc} .
5. Use the load line to predict power at any voltage or current at this RPM.

Here is the procedure to extend the results from above to a New RPM.

6. Calculate the motor/generator resistance by $R_m = V_{oc} / I_{sc}$ (from above)
7. Calculate RPM Ratio = New RPM / Old RPM
8. Calculate New V_{oc} (New $V_{oc} = \text{RPM Ratio} \times \text{Old } V_{oc}$)
9. Calculate New I_{sc} (New $I_{sc} = \text{New } V_{oc} / R_m$)
10. Graph the New I_{sc} and New V_{oc} to obtain the load line at the New RPM.

Calculating Peak Power

The output voltage versus current output of a DC generator, such as shown in Figure 3 has an interesting feature that may not be immediately obvious. There is a point on the performance line that will generate peak power. Since DC power output is the product of voltage and current, we find that there is actually a point where peak power is generated. This peak power point corresponds to the largest rectangle which can be drawn under the output line, as shown in Figure 5.

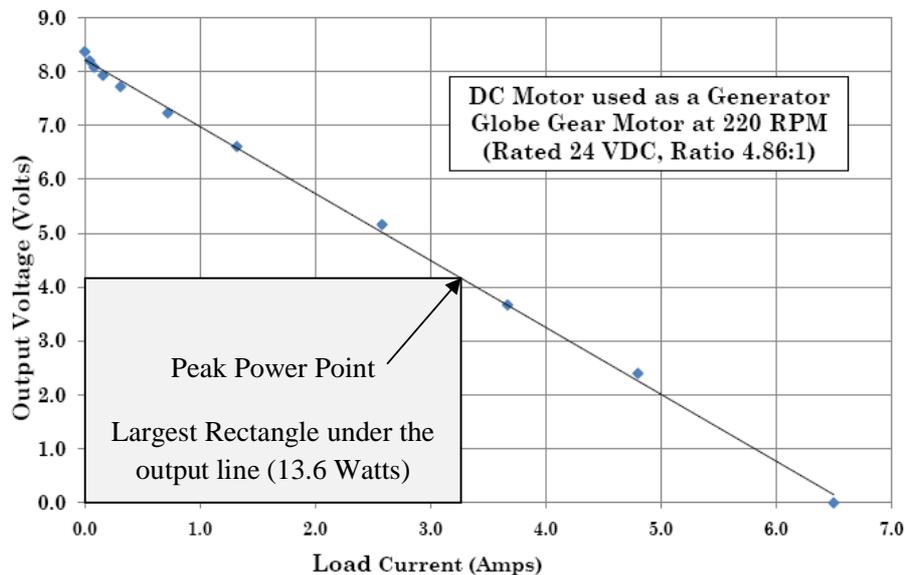


Figure 5. Every DC generator has a Peak Power Output Point for any given RPM.

From a mathematical perspective, we see that the Peak Power Point is simply given by the following equation:

$$\text{Peak Power (Watts)} = \frac{1}{4} \times V_{oc} \times I_{sc}$$

Where, V_{oc} = Open Circuit Voltage and I_{sc} = Short Circuit Current, as before. The Peak Power Point is also a concept which applies to measuring the power output of solar panels. These same concepts can also be developed mathematically.

What power output is practical?

Common sense tells us the power output from any generator must have a limit as the RPM increases. What is the limit? The limit is usually the DC motor's temperature rise from self-heating. If the motor becomes too hot it will burn out. This explains why larger DC motors are able to continuously generate more power. Larger motors are able to dissipate more heat than smaller motors. The temperature of a DC motor used as a generator should be monitored during operation to make sure it does not become too hot. If the case of the motor becomes hot-to-the-touch the power limit has been reached.

If your motor has a power rating stamped on the frame in Horsepower (HP) you already have a good indication of the generator capacity, since 1 HP equal 746 Watts (0.75 KW). For example, a $\frac{1}{4}$ HP motor would have about 186 Watts capacity as a generator.

DC motors work best as generators when the power source is nearly constant in speed. That's because the voltage output of a DC generator will change with RPM. One great advantage of an alternator is the ability to control the voltage output using a control current sent to the field windings. This is why, for example, alternators are used in automobile power systems.

DC motors used as generators do have their advantages however. DC gearhead motors are especially useful in low RPM applications as explained in our Handcranked Generator Booklet. A significant advantage of using a DC motor as a generator is design simplicity. For example, some riding lawn mowers use a DC motor for starting the engine, and the same motor doubles as the DC generator for charging the battery.

24 VDC Gearmotors



• New, TRW Globe compact inline gearmotors. Spur gear reducer, permanent magnet motor.

- SPECIFICATIONS**
- Voltage 24 DC
 - Amperage 0.40 Amps
 - Rotation reversible
 - Duty continuous
 - Mount three #4-40 tapped hole on face, 1.062" B.C.
 - Shaft 3/16" dia. x 7/16" w/flat
 - Size 1 7/16" dia. x 2 1/2"
 - Shpg. 3/4 lb.

ITEM 5-1728
SPECIFICATIONS

- Model 415A6113
- Speed 210 RPM

\$13.95

- Torque 30 oz.in.
- Gear ratio 24:1

ITEM 5-1729
SPECIFICATIONS

- Model 415A6016
- Speed 22 RPM

\$13.95

- Torque 100 oz.in. in - lbs.
- Gear ratio 240:1



20 RPM, 12 VDC Inline Gearmotor

ITEM 5-1726
\$49.95

• New, T & L INTERNATIONAL permanent magnet inline gearmotor.

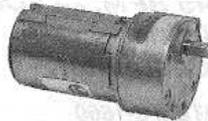
- SPECIFICATIONS**
- Enclosure TENV
 - Mount 4 bolt on 2 3/4" x 3 3/8" centers
 - Shaft 1/2" diam. x 7/8" w/dual flats
 - Size 7 3/4" x 3 1/8" x 3 3/8"
 - Shpg. 8 lbs.
 - Speed 20 RPM
 - Voltage 12 DC
 - Amperage 13 Amps
 - Torque 16.75 in - lbs.
 - Rotation reversible
 - Duty intermittent

380 RPM, 12 DC

ITEM 5-1430
\$14.99

• BUEHLER. Compact inline gearmotor.

- SPECIFICATIONS**
- Duty continuous
 - RPM 380 no load
 - Voltage 12
 - Amps 0.07
 - Rotation reversible
 - Shaft 5 mm x 9/16" w/flat
 - Mnt. 5 tapped holes on face
 - Size 1 3/8" diam. x 2 1/2"
 - Shpg. 1 lb.



500 RPM, 12 VDC

**Inline
Gearmotor**

ITEM 5-1727
\$13.95

• New, TRW GLOBE Model 317A1093. In-line permanent magnet gearmotor. Heat treated gears and ball bearing on motor shaft.

- SPECIFICATIONS**
- Speed 500 RPM
 - Voltage 12 DC
 - Amperage 1.2 Amps max.
 - Torque 32 in. oz.
 - Gear ratio 30:1
 - Rotation reversible
 - Duty continuous
 - Mount 4 hole face
 - Shaft 5/16" dia. x 1/2" smooth
 - Size 1 1/2" x 1 1/2" x 3.11"
 - Shpg. 1 lb.



1/4 HP, 24 VDC Motor

ITEM 10-2518
\$36.99

• New, PROTECH continuous duty permanent magnet motor. Rigid welded base. Externally accessible brushes.

SPECIFICATIONS

- Power 1/4 HP
- Voltage 24 DC
- Amperage 10 Amps
- Speed 2040
- Rotation reversible
- Duty continuous
- Enclosure TENV
- Frame 34
- Mount 4 bolt 3 3/4" x 2"
- Shaft 1/2" dia. x 1 3/8" w/flat
- Size 7 3/4" x 4" x 4 5/8"
- Shpg. 12 lbs.



www.surpluscenter.com

68 RPM, 24 VDC

ITEM 5-1447
\$18.99

• New BUEHLER.

- SPECIFICATIONS**
- RPM 68
 - Voltage 24 DC
 - Amps 50 mA
 - Watts 1.2
 - Torque 14 in. oz.
 - Rotation reversible
 - Duty intermittent
 - Shaft 0.2" dia. x 3/8" w/flat
 - Mount face
 - Size 1 3/8" diam. x 2 5/8"
 - Shpg. 3/4 lb.



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Smaller Type Motors

24V @ 360RPM MOTOR

MFG: BUEHLER
P/N: 1.61.046.526.03
COIL: 24VDC continuous
Gearhead DC motor rated:
360RPM @ 24V, .07A NL, 1.2A Stall
170RPM @ 12V, .06A NL, .7A Stall
5mm dia. X 16mm flattened steel shaft. 3 metric (M3) threaded mounting holes. 10' leads.

L: 2-7/8"(Body) DIA: 1-3/8" WT: .4

STOCK #	DESC.	1EA	10EA
17726-MD	360RPM/24V Gearhead Motor	\$12.95	



12V @ 225RPM GEARHEAD MOTOR

MFG: BUEHLER
P/N: 1.61.046.514.01
COIL: 12-24VDC
USED, Gearhead DC motor rated:
450RPM @ 24V, .07A NL, 1.5A Stall
225RPM @ 12V, .06A NL, .6A Stall
5mm dia. X 13mm flattened steel shaft. 3 metric (M3) threaded mounting holes. 3' leads.

L: 2-3/4"(Body) DIA: 1-3/8" WT: .4

STOCK #	DESC.	1EA	10EA
17131-MD	225RPM/12V Motor	\$14.95	\$12.95



24VDC/400RPM GEAR MOTOR

MFG: PITTMAN
P/N: GM8513E658
COIL: 24V
USED, gear motor rated: 400 RPM @ 24VDC/163mA No Load/2A Stall, 6mm dia. X 18mm, flattened steel shaft. Three 4-40 threaded mounting holes in front. Solder pin terminals

L: 3-1/8" (Body) Dia: 1-3/8" WT: .49

STOCK #	DESC.	1EA	5+EA
17047-MD	24V 400RPM Motor	\$18.95	\$16.95



www.allelectronics.com
800-826-5432

70 RPM GEARHEAD MOTOR, USED

Namiki #22CL-3501PG80:1
Small, fairly powerful, precision gearhead motor. Operates smoothly between 3-15 Vdc. No load measurements: 70 RPM @ 6 Vdc @ 50 mA. 22 mm diameter motor. Length of motor and gearbox, 60mm. 4mm dia. x 20mm long shaft. Shaft at rear of motor extends 10mm and has fan blades. 3" long wire leads. Used, very good condition.



CAT# DCM-282 \$12.00 each

Ideas for Supplying Constant RPM

The testing example shown here used a drill press for supplying the constant RPM speed. Most drill presses will have a legend printed on them giving the RPM speed versus arrangement of the drive belts. Figure 6 shows a typical drill press legend. Note that the slowest speed choice available was 220 RPM.

The drill press drive method works well for motor/generator testing, but there are other options if a drill press is not available. One option is to turn the motor manually using a handle. With care it is possible to approximate constant RPM, especially if the handle is large in diameter and the speed is slow. The RPM is calculated by counting the number of rotations in a minute.

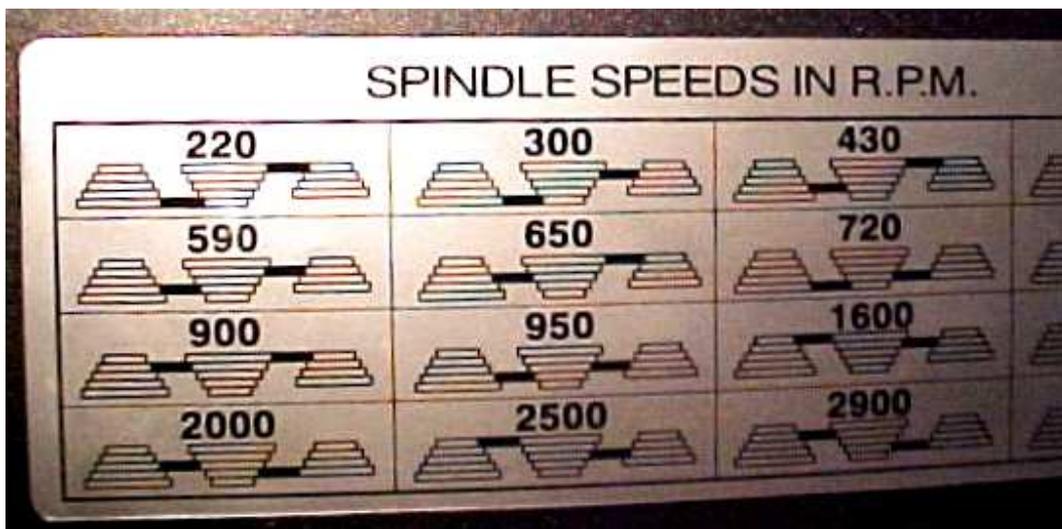


Figure 6. Spindle Speeds in RPM for different drive belt arrangements.

Another option is to use an AC induction type motor with a mechanical drive arrangement to reduce the RPM to something workable. A very common speed for AC induction motors is 1800 RPM. (Look at the nameplate for the speed rating.) It is fairly easy to construct a speed reduction of 3X to 6X using ordinary V-Belt pulleys which is quite satisfactory.

You may encounter a situation where the driving RPM is not known. A contact type tachometer can be used to measure RPM if necessary. These devices measure RPM directly, and are available for about \$25 from tool supply stores like Harbor

Freight. With a tachometer it is possible to use a DC motor for the driving power and simply vary the applied DC voltage to measure and attain a target RPM.

How to Choose Power Resistors

Power resistors are used to provide a controlled resistive load to the motor/generator being tested. Although we have described a technique for measuring motor performance using only 2 data points (Open Circuit Voltage, Closed Circuit Current) you may have an interest in measuring additional power points, such as were shown in Figure 3. Also, taking a few data points to verify they are on the predicted performance line will give you additional confidence the measurements are correct.

One challenge you may have is finding power resistors of sufficient variety and power handling capacity to make the measurements. One option to consider is using a high power variable resistor known as a rheostat, such as shown in Figure 7. The rheostat shown in Figure 7 is capable of 225 Watts power dissipation. Rheostats are very convenient for testing, but they tend to be expensive, even in used condition. A good source for rheostats is amateur radio swapfests.

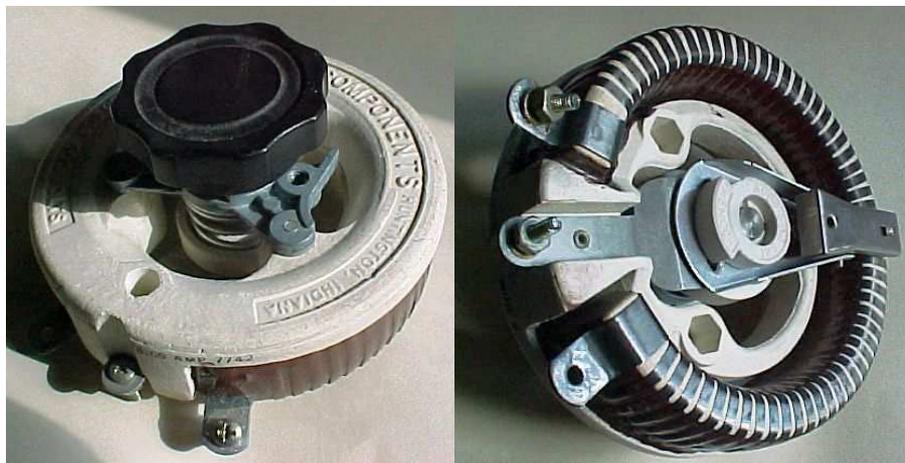


Figure 7. View of an adjustable power resistor, or rheostat.

Another option for power resistors is to build a switchable load resistor bank. This is actually quite easy to do and creates a very useful item for testing. The basic idea is to use 9 power resistors of equal value and size and connect the resistors into an array with 8 toggle switches as shown in Figure 8. With this arrangement

you can create 3 different values of resistance using the same resistors. For example, by using 10 ohm resistors you can create an array of 1.11 ohms, 10 ohms, and 90 ohms. The real advantage comes with the power rating though. Since all resistors are used at the same time your power rating is 9 times greater. By using 10 watt resistors you can create an array with 90 watts power capacity!

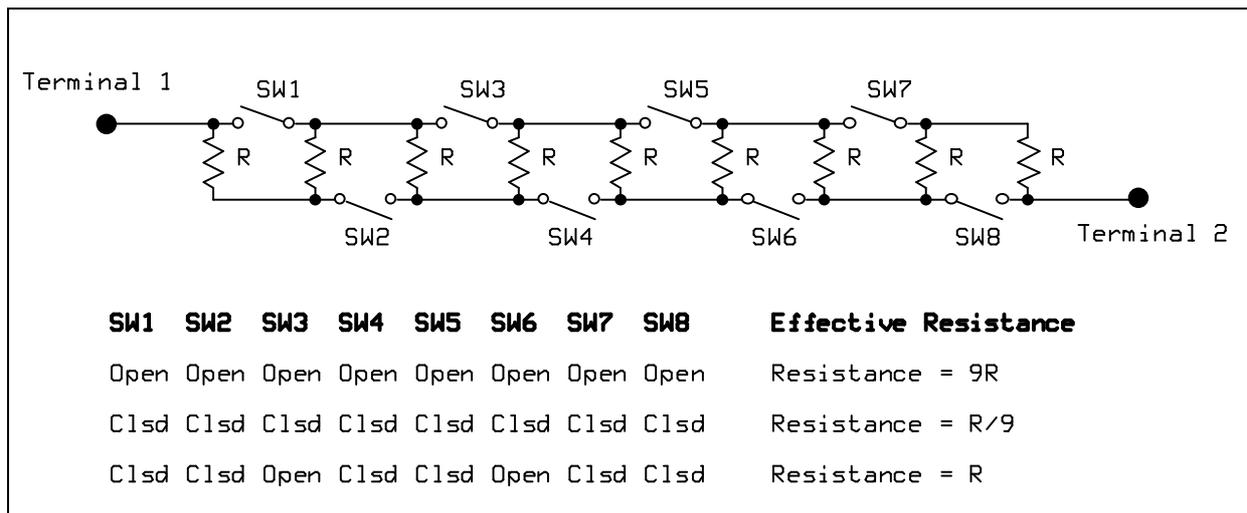


Figure 8. Method to build an adjustable load resistor array.

Basic Operation and Use of a Current Shunt

A current shunt is a device for measuring large DC currents, which is especially useful for measuring the short circuit current as described here. A current shunt is useful because most multimeters have a current limit of about 10 amps, and they will blow a fuse (or be damaged) by higher currents. Figure 9 is a view of a typical 100 Amp/50 mV current shunt that is available from MTM Scientific, Inc.

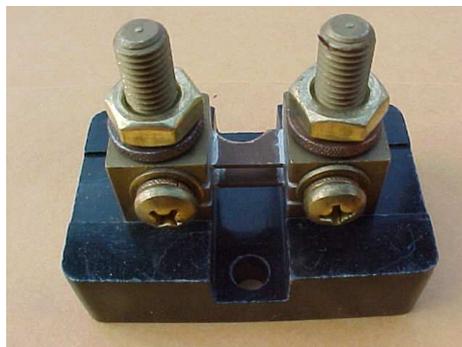


Figure 9. View of a typical 100 Amp Current Shunt

A current shunt is used to measure large DC electrical currents. A typical shunt can measure up to 100 amps of DC current. The current should flow directly through the shunt using the bolted top connections. The shunt output is measured using a multimeter set on the volts or millivolts setting connected to the small side screws. The voltage reading on the multimeter is directly proportional to the current flow. For example, at 100 amps current the meter indicates 50 mV (0.050 Volts)

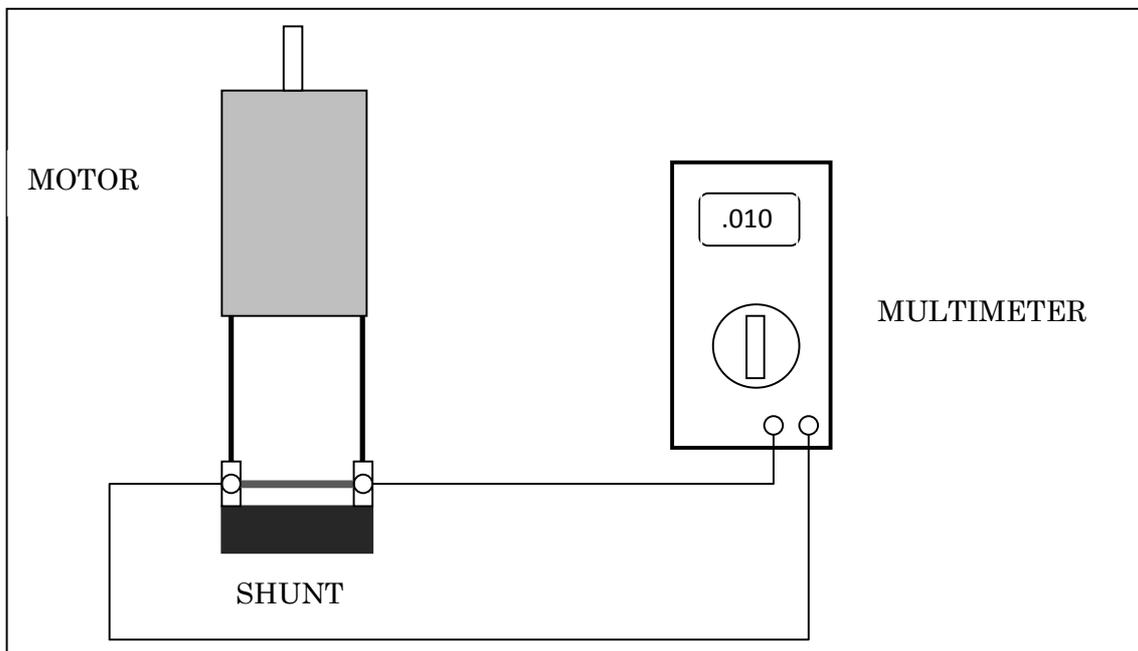


Figure 10. Typical setup for measuring current using a shunt.

The shunt current flow is calculated using the formula:

$$\text{Current (in Amps)} = 2.0 \times \text{Voltage Reading (in mV)}$$

If your multimeter only reads in units of Volts, you can convert the reading by moving the decimal point over 3 places. For example, 0.015 Volts equals 15 millivolts, which is $15 \times 2 = 30$ amps current flow.