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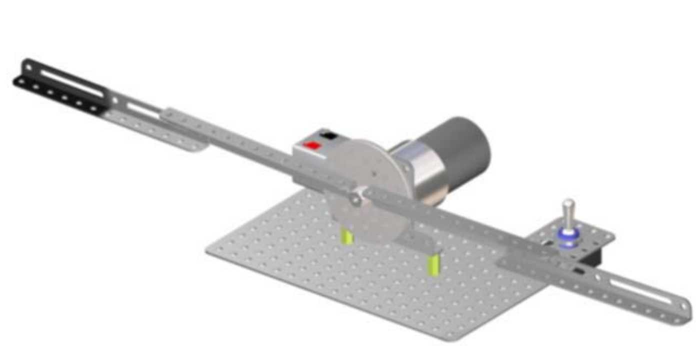
GEARS-EDS . . . technology education in a box

Build a GEARS-IDS Dynamometer

Build and Use the Dynamometer to Explore These Engineering and Physics Principles:



DESIGN/BUILD/TEST/ PLAY

Use The GEARS-IDS™ Invention and Design System to build a dynamometer and analyze the performance of a fixed magnet direct current electric motor.

DC electric motors are found in many of the products we use daily. Some of these include; CD players, tape players, computer printers and scanners, cell phones and pagers, computer drives and countless other applications.

Designing, building and using the GEARS-IDS™ dynamometer is an excellent engineering or physics activity that involves:

- Mechanical Construction
- Voltage Measurement
- Current Measurement
- Torque Measurement
- Graphing, Analysis and Performance Assessment

Mechanical Principles

- Levers

Science and Engineering Principles

- Torque
- Work and Power
- Volts vs. RPM
- Amperes vs. Torque
- Testing and analysis
- FMDC electric motor performance
- Electromagnetic force
- Motors and generators

Mathematics

- Create and use basic mathematical models to evaluate and predict motor performance
- Assess performance
- Graphing and graphical analysis

History of Science and Technology

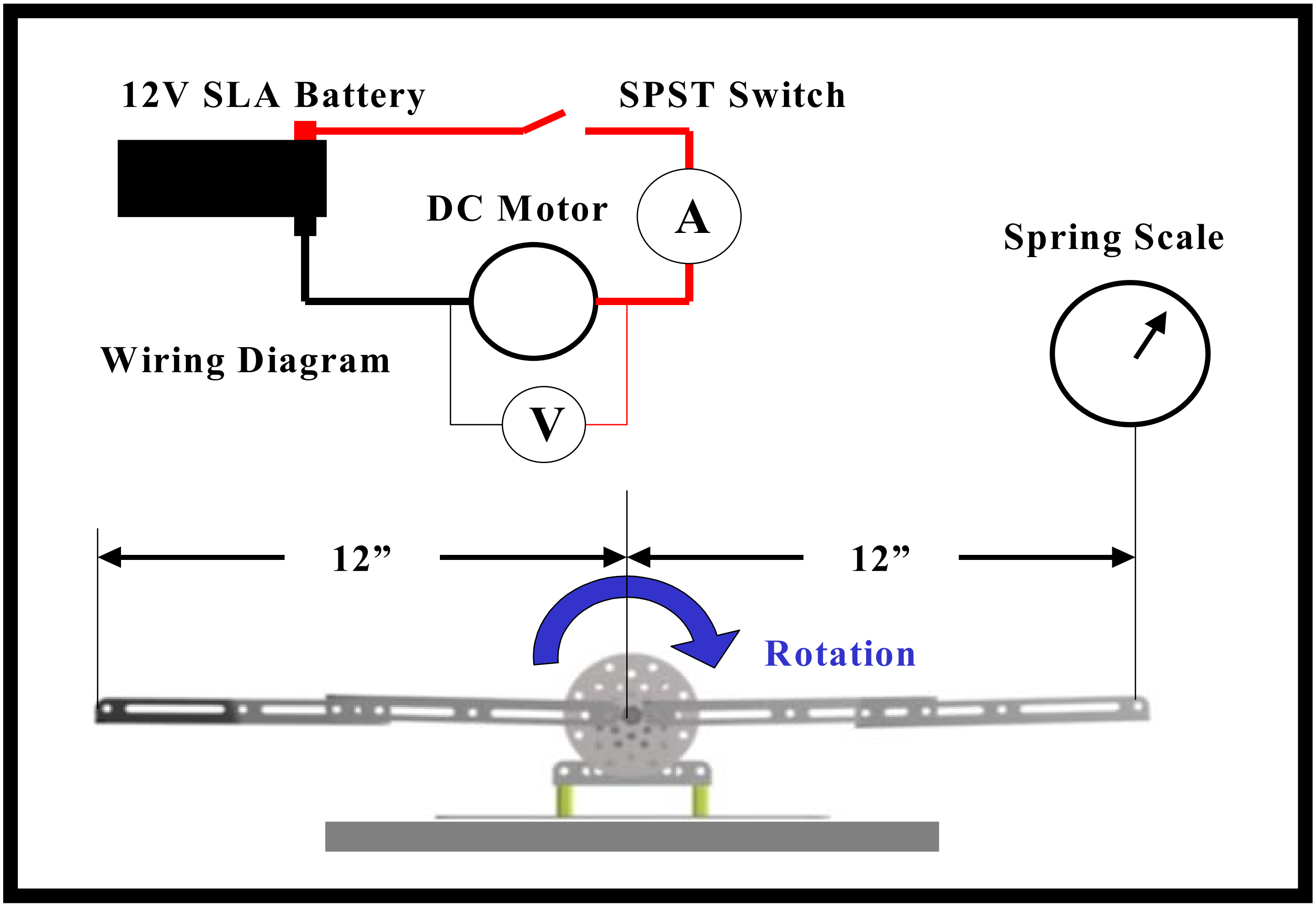
- The Development of electricity and motors
- The relationship between electricity and magnetism

Personal and Interpersonal Skills

- Self directed learning

NOTE: GEARS-IDS Components can be used to construct mechanisms that demonstrate physical science principles. These mechanisms allow students to experiment with simple machines, investigate work power and energy or construct devices that demonstrate the effects of force and motion.

DESIGN – BUILD – TEST - PLAY



Performance Tip. Before beginning any project, it helps to have a sense of what the beginning, middle and end of the project looks like. For **Best Results Read the Entire Document Before Beginning**

1 person can build the Dynamometer in less than 45 min..

Performance Tip. Assembling engineering projects can be less frustrating and more fun if you think about the entire project as a system of subassemblies called modules. This project has the lever system module, the motor and test stand module and the electrical system or module. These guidelines will help you to complete your dynamometer quickly and correctly, the first time.

1. **Obtain and organize the Tools and Materials** *(Listed below)*
2. **Build one or more of the subassemblies or modules** *(Illustrated in this document)*
3. **Integrate the subassemblies into a working dynamometer.**
4. **Perform the tests, and obtain the measurements described in this document.**

Caution: Always wear safety glasses when working on, testing or using the dynamometer.

Organize the Tools and Materials

The dynamometer can be completed quickly and with minimal frustration and mistakes by taking the time to read through the directions and readying the necessary tools and materials before beginning the assembly.

Required Tools

Safety Glasses
2-3 Phillips Head Screwdrivers
5/16" Combination Wrench *(For the Stand Offs)*
3/8" Combination Wrench
6" Needle Nose Pliers
5/64, 6/32 Allen Wrenches or Hex Keys
Dial Calipers and Tape Measures
Wire stripping and crimping tool
Multimeter *(10 ampere capacity)*
Test Leads

Materials

Use the GEARS-IDS online catalog of parts and components to identify the following components.

Structural Components

1 6x9 Flat Plates GIDS-SC-10002
4 13 Hole Angles GIDS-SC-10006
1 7 Hole Angles GIDS-SC-10007
1 1/4" Hex Adapter GIDS-SC-10013-1875
1 ½" Shaft Collar
1 M15 Motor Mount GIDS-SC-10009
1 M13 Motor Mount GIDS-SC-10008

Hardware

1 ½" Shaft Collar
20+/- #10-24 x 3/8" PH Machine Screws
2 #10-32 x ¾ PH Machine Screws *(Motor Mounting)*
20+/- #10 Nuts, flat washers and star lock washers
2 #10-24 hex standoffs

Electrical Components

1 Gear Head Electric Motor GIDS-IM15
1 SPST toggle Switch GIDS-EC-10003TS
1 12 Volt SLA Battery GIDS-EC-10006
#14-16 ga. Insulated Wire (Approx. 30")
#14-16 ga. Insulted Male Quick Disconnects
#14-16 ga. Insulted female Quick Disconnects

Miscellaneous Supplies and Materials

Wood Mounting Base (See picture at the end of the document)
Wood screws for mounting 6x9" base plate
5-10 lb spring scale
Wire coat hanger or 1/16" welding rod
Multimeter
Photo Tachometer or Mechanical Tachometer

Performance Tip. Go to www.gearseds.com to download a complete catalog and description of **GEARS-IDS™** Invention and Design System components. This will help you locate the parts.

Construct the Dynamometer using these Subassemblies

Note: 2 assemblies are required for the right and left side frames

1. **Base Plate and Motor and Mount**
2. **Lever Arm Assembly**
3. **Electrical Circuit**

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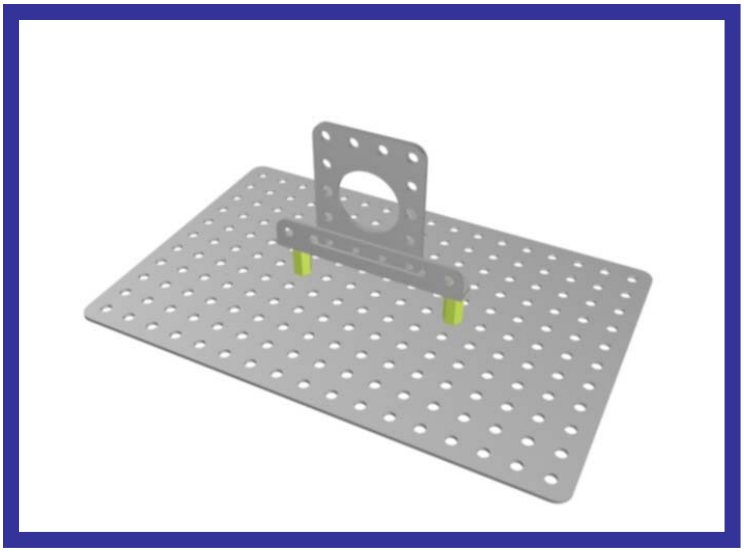
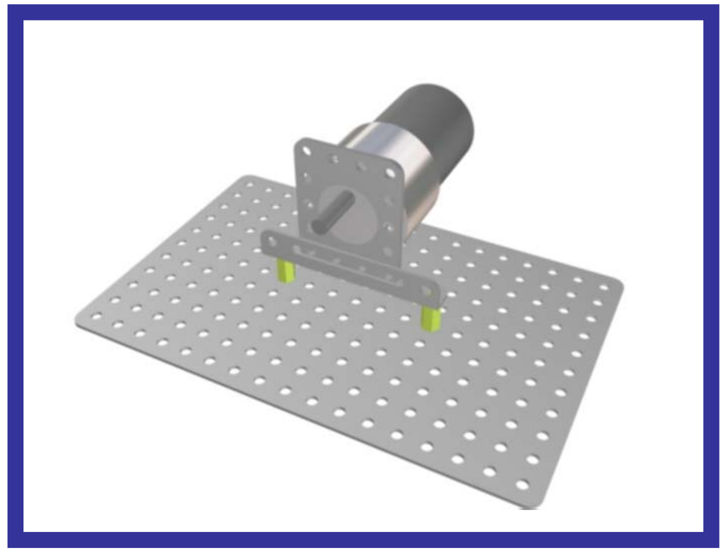




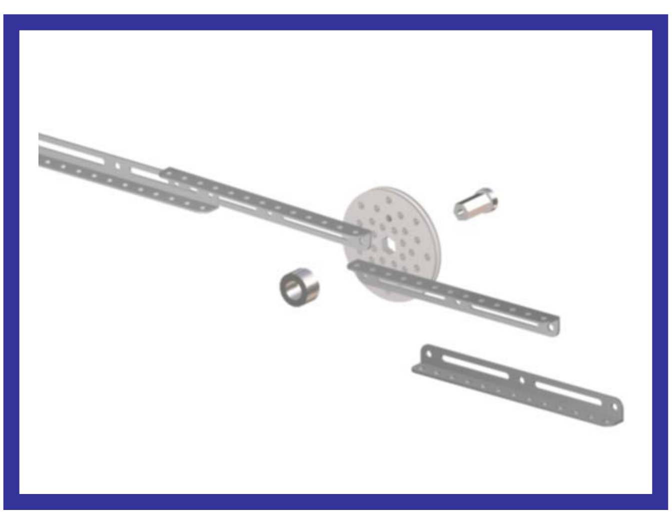
Step 1
Base Plate and Motor and Mount Assembly

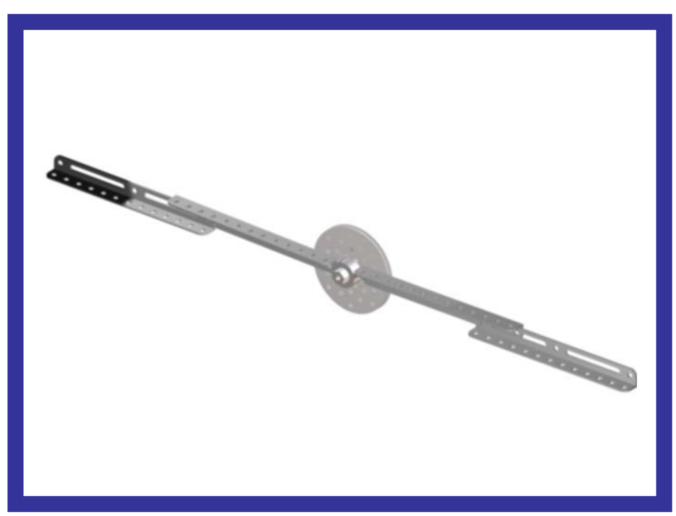
Note: Use #10-24 x 3/8” machine screws with a flat washer, star washer and #10-32 nut on every connection. Leave the setscrews loose until the final assembly.

Study the illustration and align and mount the #10-24 hex standoffs and 13-hole angle as indicated in the illustration above.

It is possible to assemble the components in several different ways and still create a working dynamometer.

Step 2
Assemble the Lever Arm





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Assemble the lever arms so that the outer most holes are approximately 12 inches *(1 foot)* from the center of the hex adapter. *(See illustration on page 2)* The lever arm assembly must be symmetrical. The reason there are two arms, is to balance the torques acting on the motor shaft. When the motor is energized and begins to turn, the force needed to lift one arm is balanced by the counter weight of the other arm. This ensures that the torque being measured is the torque developed by the motor and battery and not by the additional weight of the arm.

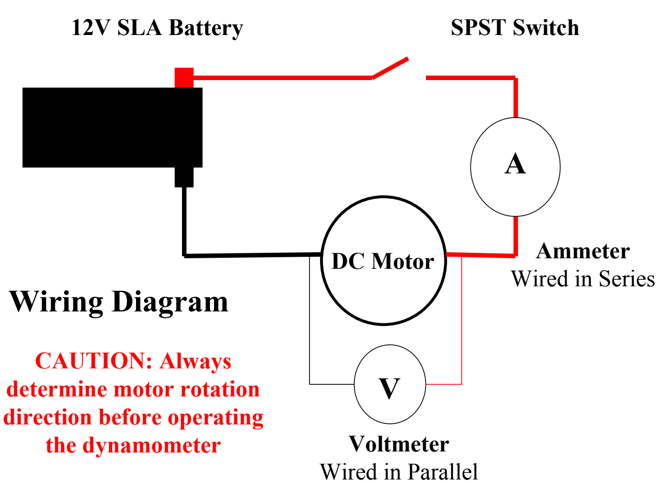
Note: The lever arms must be rigid. Rigidity prevents unwanted movement and deformation *(bending)* during testing. A loosely constructed lever arm will fail under the stress of testing. The lever will need to be strong enough to withstand the occasional "Hammering" it will receive when the motor is turned on without supporting the lever arm, Be certain to use flat washers to distribute the clamping pressures and lock washers to prevent machine screws from working loose.

Step 3
Wire the Electrical Circuit

The schematic diagram on the right illustrates how to wire the motor, battery, switch and ammeter in series. The voltmeter is attached across the motor leads as shown.

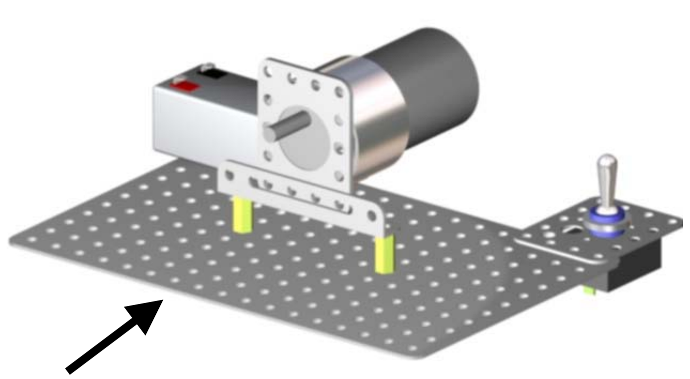
The polarity of the circuit determines the direction of motor rotation. Reversing the battery leads will cause the motor to rotate in the opposite direction.

Caution: Be certain that you experiment with the completed circuit and have determined the motor rotation BEFORE you attach the lever arm assembly



Wiring Diagram

CAUTION: Always determine motor rotation direction before operating the dynamometer



Front of 6" x9" Plate

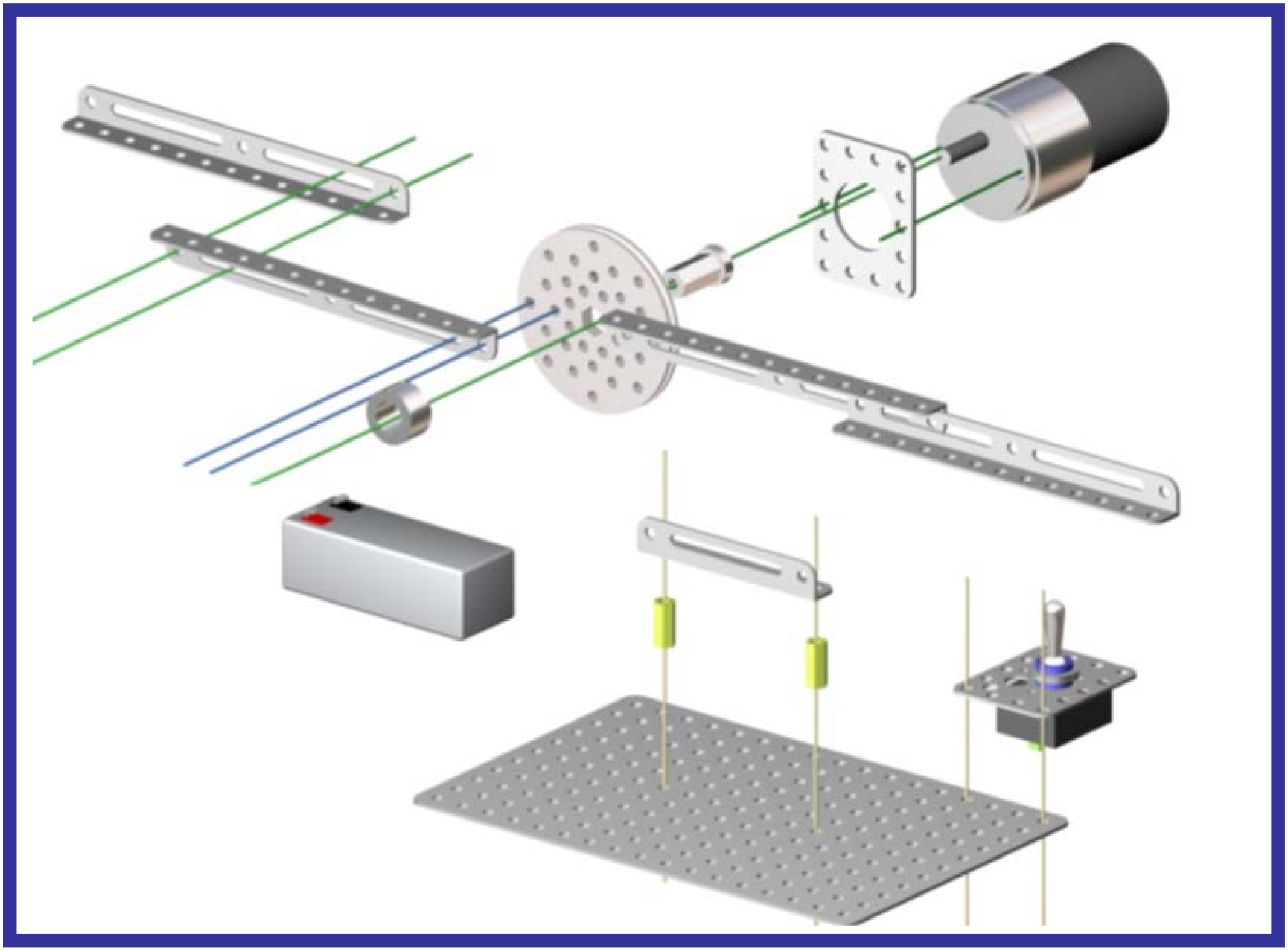
Mount the Switch as shown in the illustration on the left.

Mount the battery securely to the 6 x 9" base plate, or secure the entire assembly to a wooden platform and mount the battery to the wooden platform.

Be certain to wire and test the motor rotation direction BEFORE attaching the lever arm assembly.

If necessary, move the motor mounts and stand offs, 2 holes nearer the front of the 6"x 9" plate.

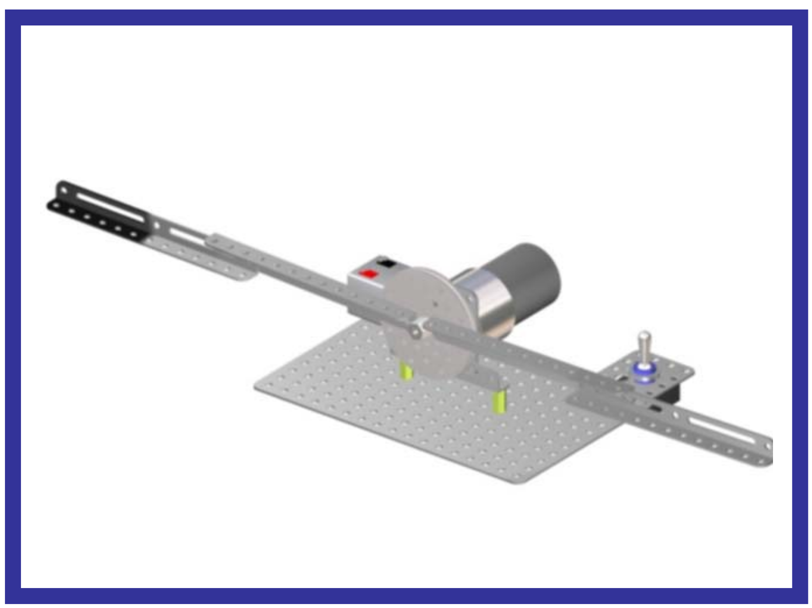
Exploded View of the Dynamometer Assembly



Complete the Dynamometer

After you have wired the dynamometer and tested the motor rotation, place a piece of tape on the motor showing the motor rotation direction.

Assemble the lever arm system to the motor shaft



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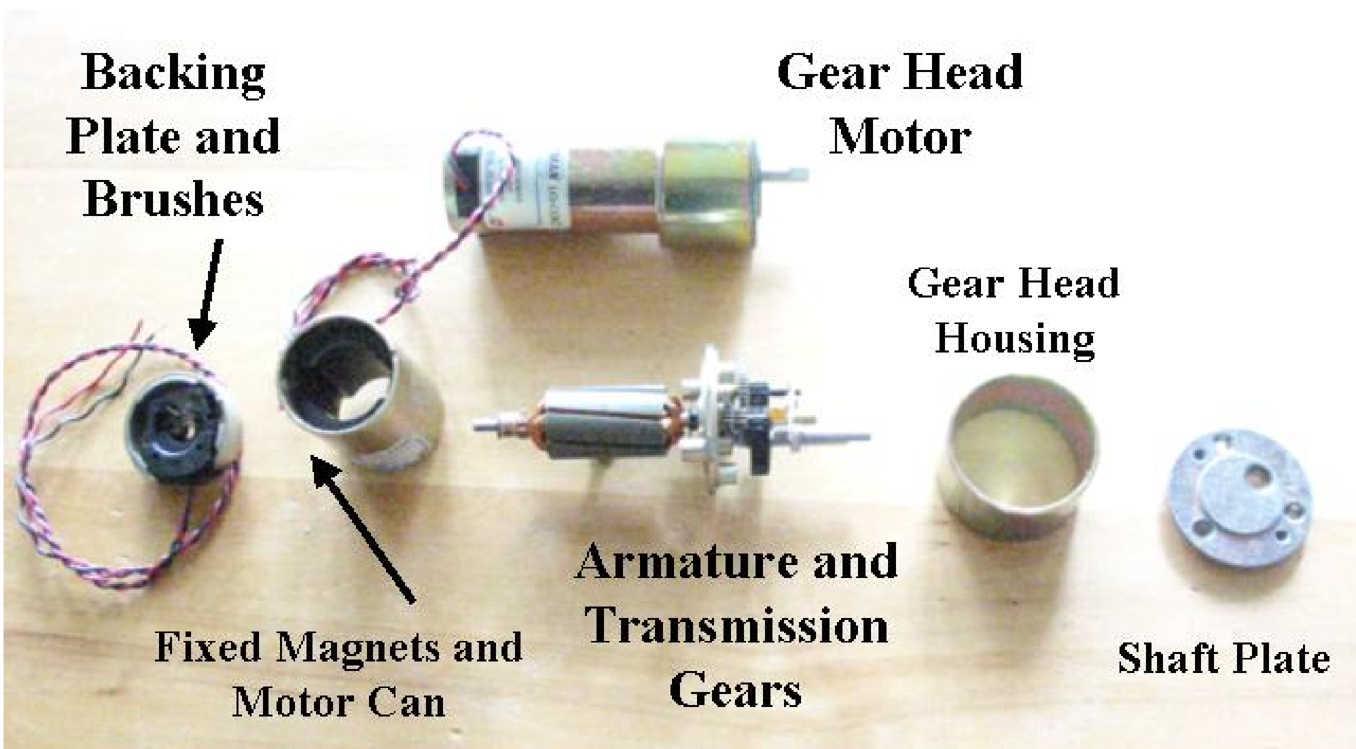
Using the GEARS-IDS™ Dynamometer

How Motors Work

Fixed magnet DC electric motors create twisting forces *(Torque)* and rotary motion *(RPM)* through the creation of unbalanced magnetic forces between the fixed magnetic fields inside the motor and the opposing electromagnetic fields developed in the rotating armature. Click here to view an interactive flash animation that illustrates the operation of a fixed magnet DC motor.

Note: Fixed magnet DC motors are also called permanent magnet DC motors.

GEARS-IDS™ Gear Head Motor Components



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Gear Head Motor used in the **GEARS-IDS™** Kit

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The Armature, Brushes and Transmission Gears

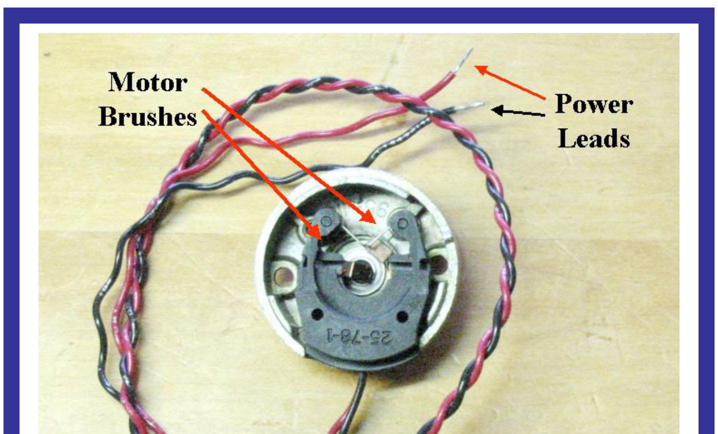
Note:

- **Whenever a current passes through a conductor *(wire),* a magnetic field is induced around the conductor.**
- **Like Poles repel and unlike poles attract.**

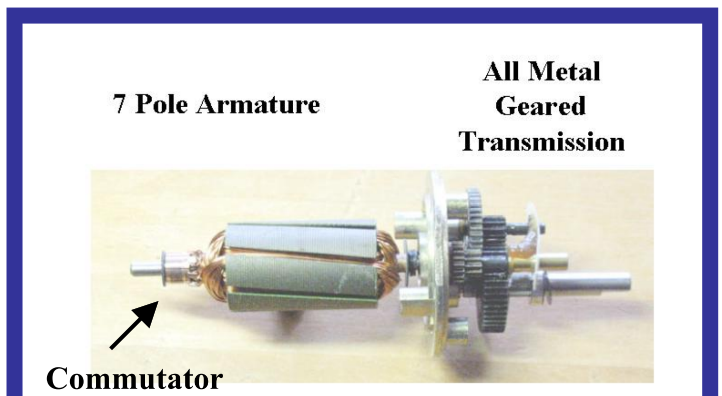
The armature of a fixed magnet DC motor is a rotating coil of wire formed around an iron core. *(See illustration below)* When the coil of wire is energized, the electric current passing through the wire creates an electro magnetic field that surrounds the coil and is focused by the iron core. This electro magnetic field is opposed by one pole of the permanent magnet formed inside the motor can, and attracted by the pole of the second permanent magnet inside the motor can.

Wouldn't you think that after a maximum of 180 degrees of rotation the opposite poles of the fixed magnets, and the electromagnetic armature field would align and stop the motor? Well, this would in fact happen if it were not for the fact that the electrical current through the armature coils is reversed every 180 degrees of rotation. When the current *(polarity)* is reversed, the magnetic fields are reversed and the attraction and repulsion forces are maintained. This is accomplished by a set of clever motor mechanisms called the brushes and the commutator.

Each coil of wire is energized as it rotates inside the motor can. The motor brushes are attached to the power leads and they ride against the commutator on the armature shaft. The brushes and the commutator maintain the electrical connection between the supply current from the battery and the rotating coil. *(See the Flash illustration link above)*



GEARS-IDS™ Brushes and Backing Plate



GEARS-IDS™ Armature and Transmission

The north and south poles of the electromagnetic field developed in the armature change positions every 180 degrees of armature revolution while the magnetic poles of the permanent magnets remain fixed. The direction of current through a conductor *(wire)* determines the direction of the magnetic field through the wire. As the commutator turns through 180 degrees of revolution, the polarity through the armature coil reverses. This reverses the magnetic field, which ensures that the electromagnetic field of the armature is always oriented in a manner that will cause the armature to keep rotating in opposition to the fixed magnetic field of the permanent magnets formed inside the motor can.

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Clearly, the strength of the turning force *(torque)* of an electric motor is proportional to the strength of the interaction between fixed magnet fields and the electromagnetic fields of the rotating armature coils.

The torque generated by the magnetic fields is proportional to the amount of current *(amperage)* passing through the armature coil.

The rotational speed of the motor is proportional to the voltage applied to the motor and the work being done by the motor *(load)*.

GEARS-IDS™ Motor Can and Fixed Magnets

Fixed Magnet DC Motor Characteristics

Torque and RPM of Fixed Magnet DC Motors

Fixed magnet DC electric motors typically turn at speeds between 2500-5000 rpm *(Revolutions per minute)*.

The motor shaft of the gear head motors used in the **GEARS-IDS™** kit turn at approximately 250 +/- rpm at 12 volts of electrical pressure. The rpm difference is due to the gear reduction of the motor transmission *(Gear head)*. The reduction ratio is approximately 20:1. This gear reduction serves to reduce output shaft rpm while increasing output shaft torque.

Torque
Torque is a force that causes a shaft or an object to turn or twist. The value or amount of torque *(Twisting or turning force)* is a product of the measured force x the distance from the point of rotation. In the example illustration below, the force *(Scale reading)* is approximately 1.125 lbs. The scale is attached at a point 12" from the center of rotation. In this case the motor Torque = 1.125 lbs x 12 in. or 13.5 lb ins. of torque.

Stall Torque
When a motor is stalled, a condition where the motor shaft is prevented from turning while the armature coil is energized, the motor will exhibit maximum torque. In this case the torque will be maximum, and the rpm will be zero.

Maximum RPM
A free spinning electric motor running at maximum rpm for a given voltage typically produces <u>little or no torque.</u> When the shaft is loaded and the motor begins working, the torque increases and the rpm drops.

Maximum Current
When a DC motor is stalled the armature coil draws the maximum amount of electrical energy. The resistance of the coil and the battery's ability to produce maximum current at 12 volts limits the amount of electrical energy or current the coil can draw. The torque produced by a DC motor is proportional to the current drawn by the armature coil. In the stall condition a DC motor produces maximum torque while drawing maximum current. The stall condition is harmful and inefficient to DC motors, since the increased current draw produces maximum heating in the coil wires. This heat will burn off the motor insulation causing short circuits within the coil wire and premature motor failure. Testing and analyzing DC motor performance requires subjecting the motor to stall conditions. Do not operate DC motors in the stall condition for more than 5-10 seconds at a time.

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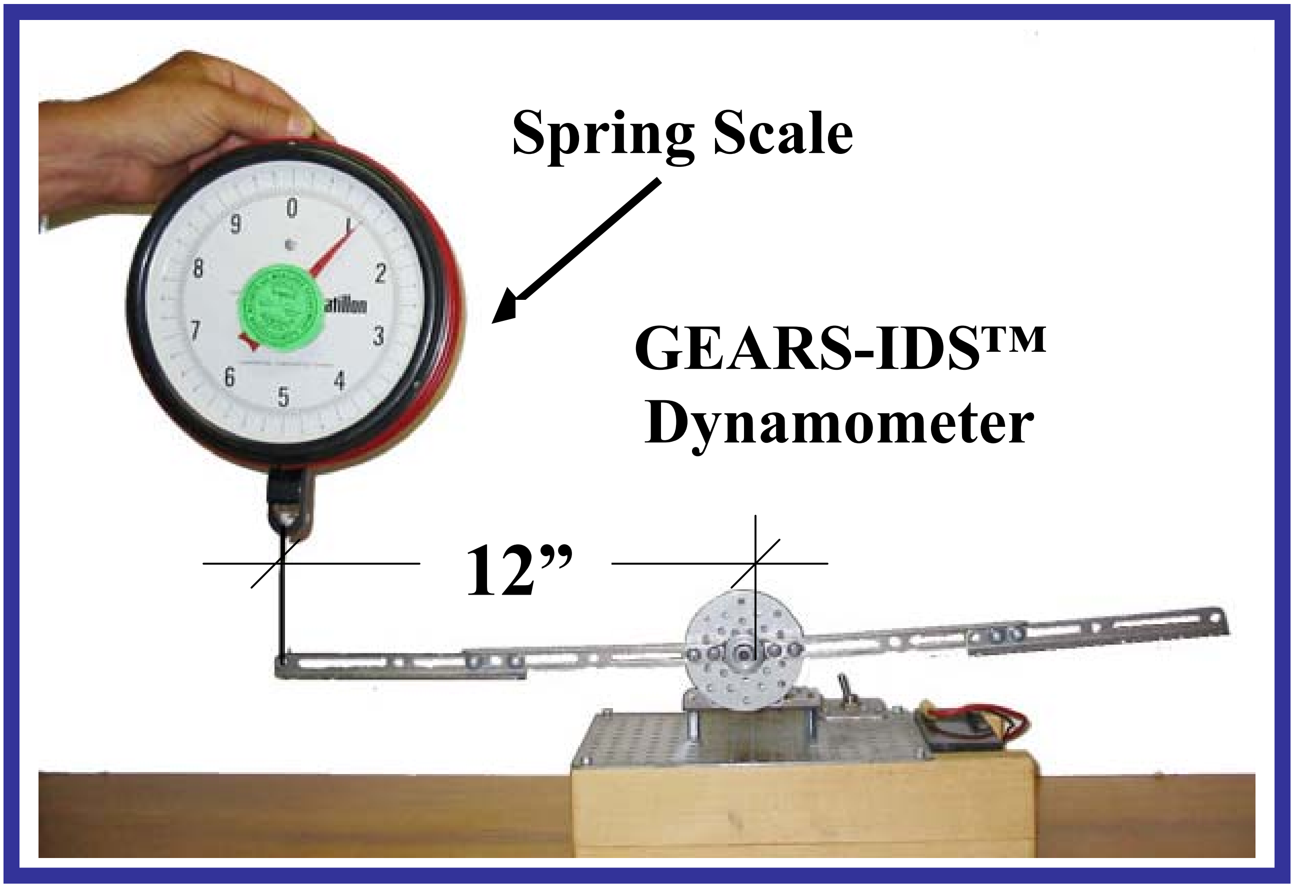
Setting Up the GEARS-IDS™ Dynamometer



Caution:

- Always clamp or affix the dynamometer securely to a table or bench top to prevent accidental tipping or rolling of the dynamometer during operation.
- The motor and lever arm will turn forcefully and rapidly when the motor is energized. Be certain that you know which way the motor will turn before attaching the lever arm or using the dynamometer.
- Keep fingers and hands clear of the rotating lever arms.

ALWAYS WEAR SAFETY GLASSES WHEN USING OR WORKING ON THE DYNAMOMETER

Hint: Place a soft foam or rubber pad under the scale side of the lever arm to prevent it from banging into the 6 x9” base plate.

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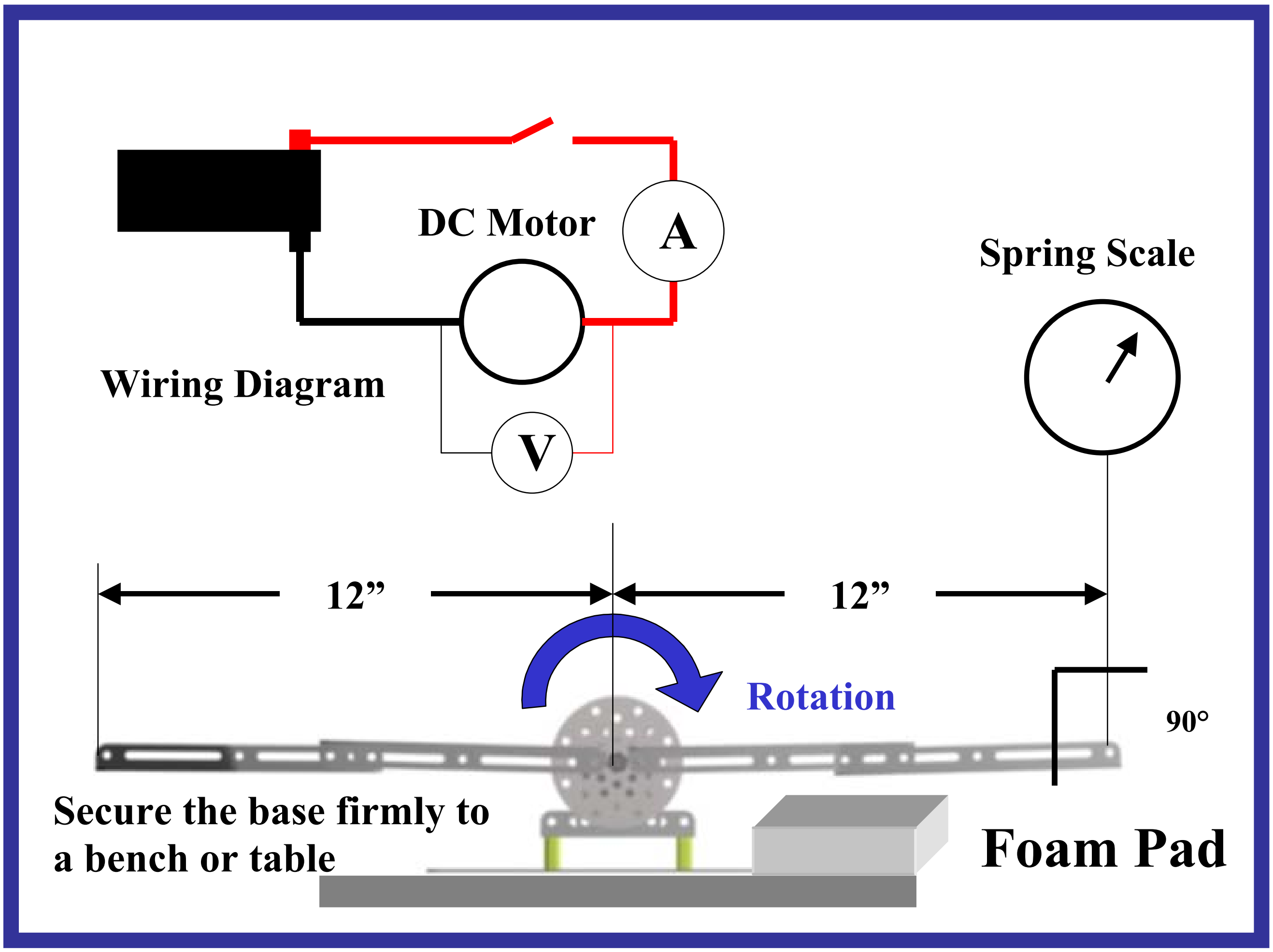
Testing Procedure

Always work in teams of two or three people when testing motor performance

1. Be certain that the battery is fully charged *(12+ volts)* and the switch is in the off position.
2. Use a tachometer to measure and record the maximum no load *(Free spinning)* motor RPM **before attaching the lever arm assembly.**
3. Secure the dynamometer firmly to a bench or tabletop. Use clamps or screws.
4. Attach a spring scale *(5-10 lb)* to the lever arm, 12 inches from the center of the rotating output shaft. Use a pair of needle nose pliers to cut and bend a coat-hanger hook or welding rod to attach the spring scale to the lever arm. Be certain that you attach the scale to the downward side of the rotating lever arm as shown.
5. Attach either or both meters as shown in the diagram below. If you use a Multimeter then perform two tests. Measure voltage during one test and amperage *(current)* on the next text.



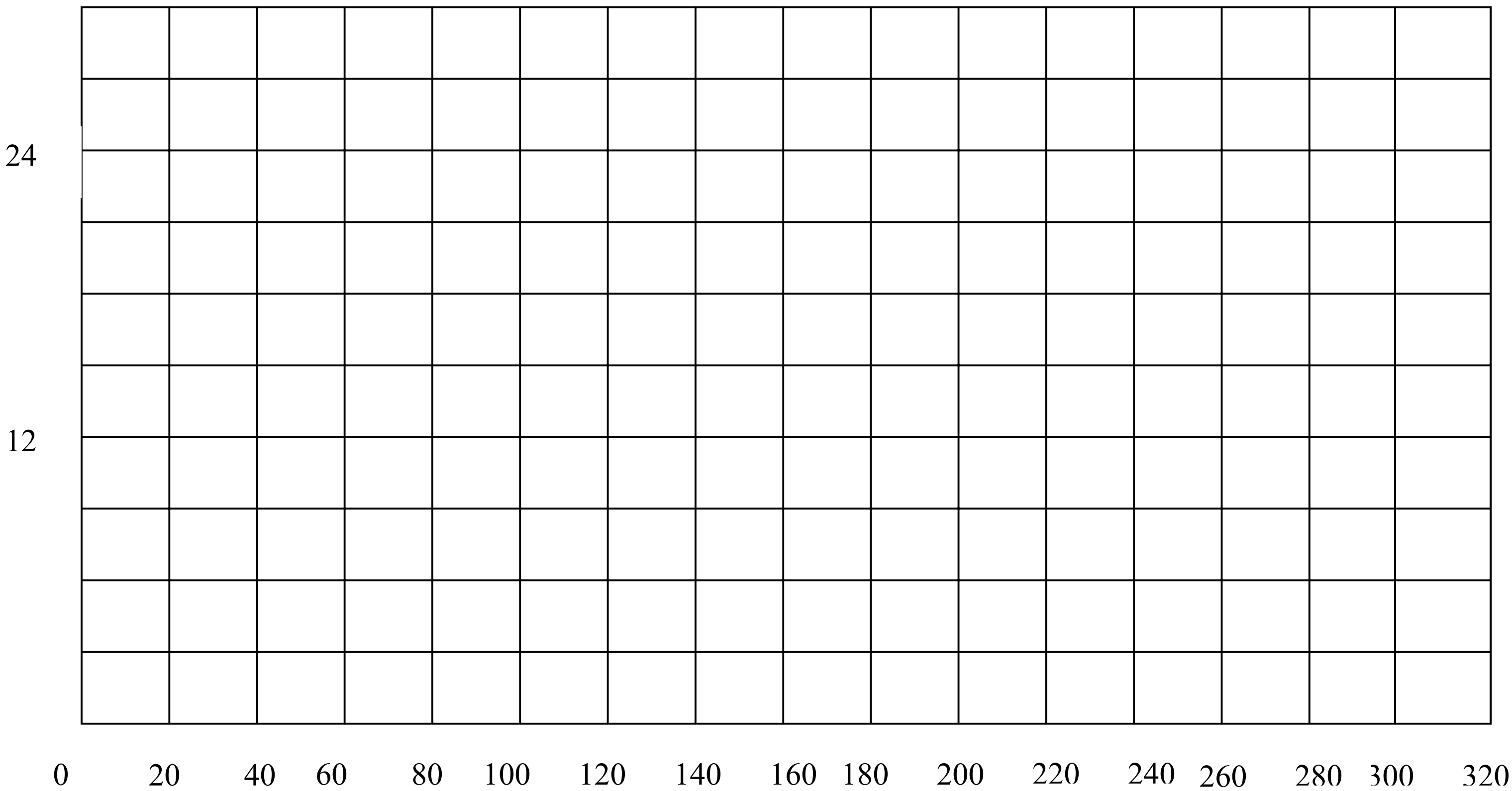
6. One person should hold the spring scale so that the lever arm is parallel to the base and the scale attachment lever is at a 90-degree angle to the lever arm. *(Note: The parallel and perpendicular orientation of the scale and lever arm is important in order to obtain reliable data)*
7. Another person should control the switch and read the meter and scale values.
8. Record these values: **Force:** The reading on the scale, **Voltage**: The electrical pressure in the circuit, **Amperage**: The current or amount of charge flowing through the circuit.

Graphing and Analyzing the Motor Performance

Use This Graph to Record and Analyze DC Motor Test Data

Torque
inch lbs

Torque and RPM Graph



RPM *Revolutions Per Minute*

Finding Design Torque and RPM
Torque is inversely proportional to RPM

Procedure

1. Record the **<u>no load RPM</u>** of the motor output shaft and mark this on the graph.
2. Record the **<u>maximum torque</u>** output and record this on the graph.
3. Connect a diagonal line between the maximum-recorded torque value and the maximum recorded “No load” RPM value.
4. Measure and mark the midpoint of the diagonal line.
5. From this midpoint point draw a vertical line perpendicular to the RPM (x axis) line. This RPM value represents a fair approximation of the design rpm of the motor.
6. From this midpoint point draw a horizontal line perpendicular to the torque (y axis) line. This torque value represents a fair approximation of the design torque of the motor.
7. The vertical (y axis) and horizontal (x axis) lines drawn from the midpoint of the diagonal line form a rectangle with respect to the Torque and RPM lines of the graph. The area of this rectangle is proportional to the power output of the motor. Calculate the area of the rectangles formed using various data points along the diagonal line. What happens to the area of the rectangle as the data points move

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away from the center of the diagonal line. What is the rate of change in the power *(area of the rectangle)* of the motor as the torque or RPM increase or decrease?

Torque x RPM = **Motor Power**. Continually operating the motor in successively higher torque ranges does not necessarily produce more power. In fact the opposite occurs. Here is an explanation of why. You can see from studying the graph that torque increases while rpm (rotational speed) decreases. In addition, requiring the motor to produce more torque also increases the current drawn through the armature windings. This increased current draw heats the motor armature windings which in turn increases their electrical resistance. *Electrical resistance of a conductor increases as the temperature of the conductor increases.*

Eventually the motor begins to loose efficiency. This loss in efficiency means the motor begins to use more current while producing less torque and speed at a given voltage. Since the amount of electrical energy available to the motor is fixed by the electrical capacity of the battery, it makes little sense to operate the motors inefficiently. That is; To require the motors to produce less power while consuming more current *(electrical energy)* It is interesting and important to note that as the motors produce more force *(torque),* the amount of power available decreases. At stall, the motors are producing maximum force *(torque)* but the motor output shaft is not turning. There

Finding Design Torque and Amperage
Torque is proportional to RPM

After finding the design torque of a motor it is useful to find the amount of current that the motor draws from the battery. This will allow you to make relatively accurate estimates of the amount of "Run time" you can expect from a battery with a known capacity.

Note: Determining the battery capacity in amp-hours is accomplished by measuring the rate of battery discharge or current output, over time. This is the subject of another ***GEARS-IDS™*** *lesson.*

Procedure
Follow the previously described testing procedure and note the following.

1. Be certain that you are using an ammeter or Multimeter with a 10-ampere capacity.
2. Connect the ammeter or Multimeter in series with the motor circuit as shown in the circuit diagram
3. If you have two meters then connect both an ammeter or Multimeter in series with the circuit and a voltmeter or additional Multimeter in parallel across the motor leads as shown in the circuit diagram
4. Create a stall condition as described above.
5. Record these values; **Force** The reading on the scale, **Voltage** *The electrical pressure in the circuit*, **Amperage**: *The current or amount of charge flowing through the circuit.*
6. Convert the force reading to inch lbs. of torque as described earlier
7. If the circuit voltage drops below 12 volts while the motor is stalled then the battery is either:
    a. Not fully charged. *Note a battery that reads 12 volts is not necessarily fully charged. A dead battery will often show a standing value of 12 volts but the voltage will drop under load. Stalling the motor puts a significant load on the battery.*
    b. Incapable of being fully charged or damaged
8. Create a graph similar to the one shown below or use this graph.
9. Mark the point on the graph that corresponds to the torque and current *(Amperage)* values that you recorded during the test.
10. Draw a diagonal line from the 0 point through the data point you recorded on the graph.
11. Locate the design torque value from the previous graph.

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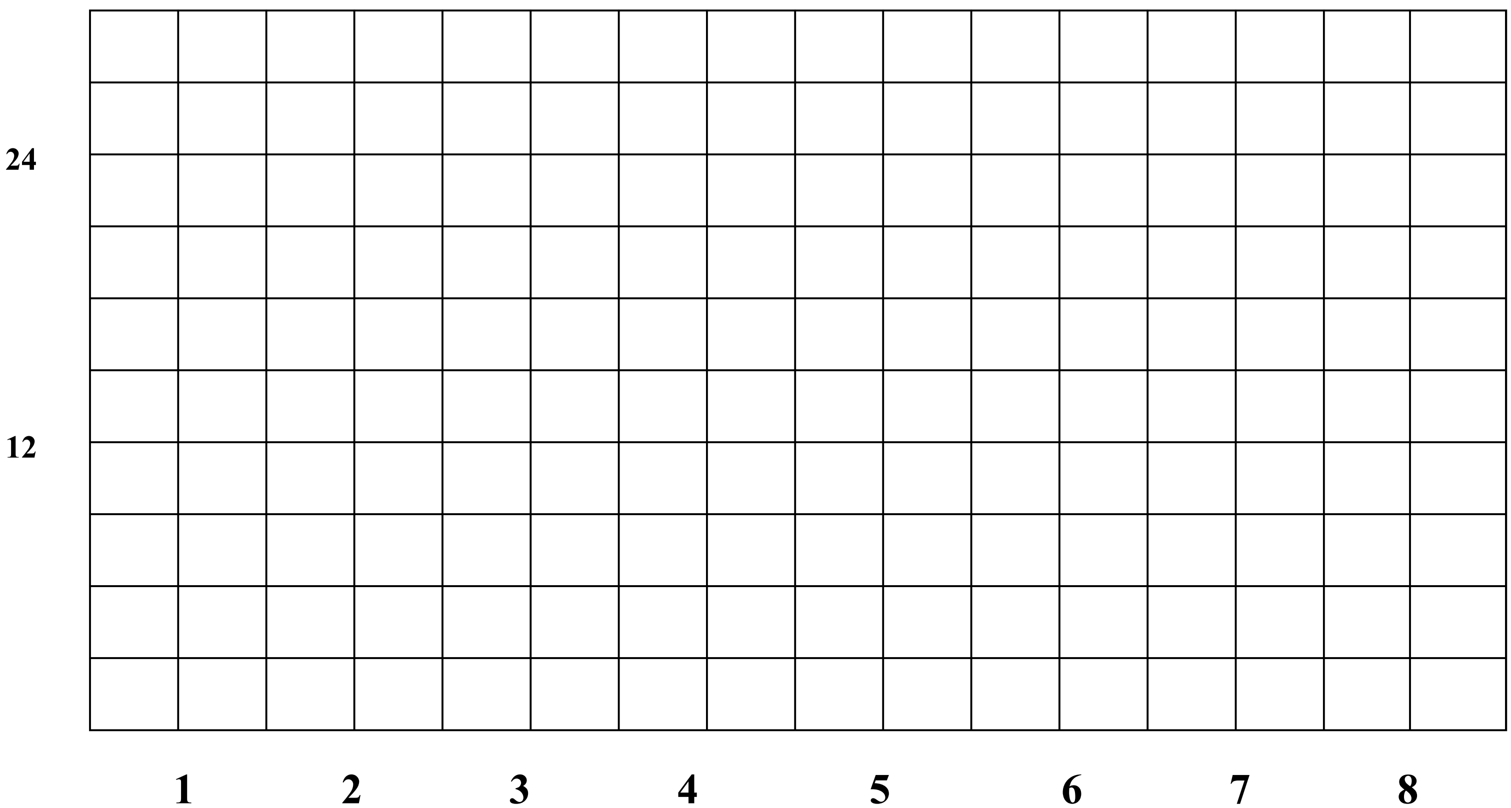
12. Draw a horizontal line from this torque value through the diagonal line of the graph.
13. From the intersection of the horizontal *(Torque)* line and the diagonal line, draw a vertical line downward through the amperage scale.
14. This amperage or current value represents the approximate current draw and torque of the motor at the design or midpoint rpm.

Torque
Inch Pounds

Torque and Amperage Graph

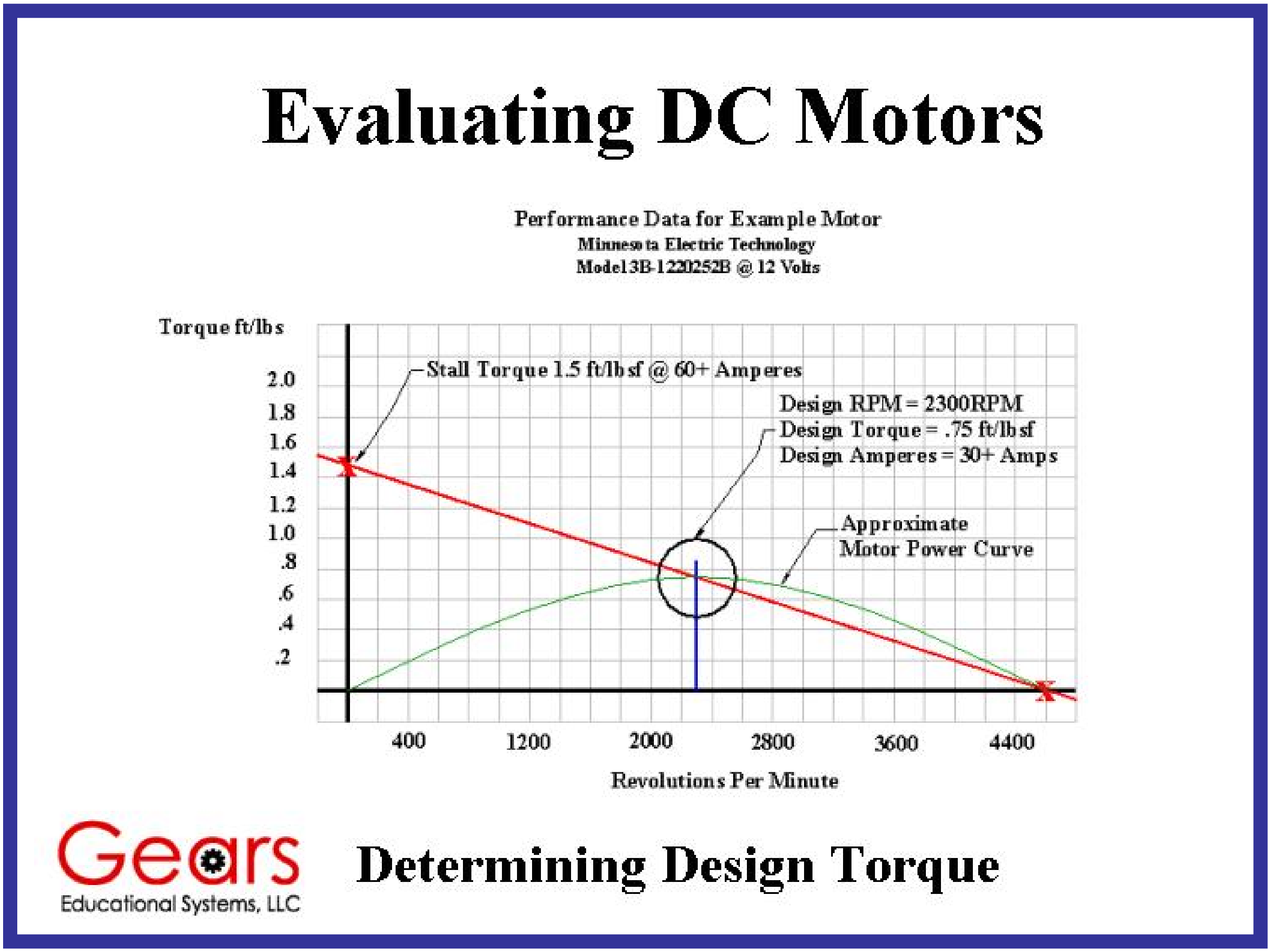


Current *in Amperes*

The data acquired from these tests can be used to approximate:

- The design motor power output
- Motor run time based on *(tested)* battery capacity
- Required speed or torque drive ratios

Here is an example of a Motor Performance Graph that was produced for a competitive robot designed and built by High School Students



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