REV ROBOTICS

MOTOR GUIDE

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1 MOTOR BASICS

Electric motors are the core power plant of most robots. This guide is intended to help users evaluate and select the correct brushed DC motor. The basic concepts of the power train design are also included.

1.1 Elements a Brushed DC Motor

The most common and important features of a Brushed DC motor are detailed in Figure 1.

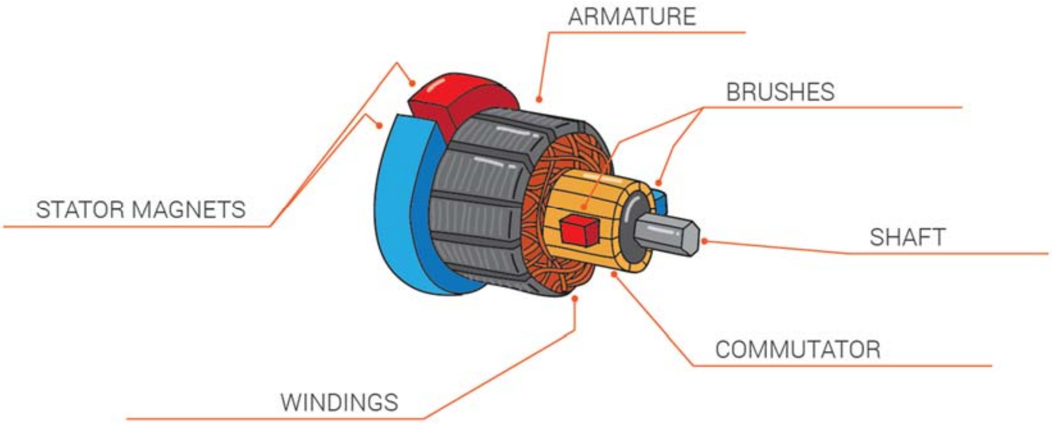


Figure 1: DC brushed motor Nomenclature

Brushed DC motors without a gear box can be estimated to be ~80% efficient, meaning if a motor is drawing 60 watts of power ~48 watts will be turned into mechanical energy and ~12 watts will become heat. Once a gear box is added the overall efficiency of the system goes down.

1.2 Key Metrics

DC brushed motors can be described by some key metrics:

Stall Torque is measured when the motors RPM is zero and the motor is drawing its full **Stall Current**. This value is the maximum torque the motor is ever capable of outputting; however, the motor is not capable of outputting this torque for an indefinite period of time. Waste energy will be released into the motor as heat. When the motor is producing more waste heat than the motor body is capable of dissipating the motor will eventually overheat and fail.

Stall Current is the maximum amount of current the motor will draw. The stall current is measured at the point when the motor enough torque that the RPM goes down to zero. This is also the point at which the most waste heat will be dissipated into the motor body.

Free Speed is the **angular velocity** that a motor will spin at when powered at the **Operating Voltage** with zero load on the motor's output shaft. This RPM is the fastest **angular velocity** the motor will ever spin at. Once the motor is under load its **angular velocity** will decrease.

Operating Voltage is the expected voltage that the motor will experience during operation. If a robot is built using a 12 volt battery the **Operating Voltage** of the motor will be 12 volts. When controlling the RPM of the motor the DC speed controller will modulate the effective voltage seen by the motor. The lower the voltage seen by the motor the slower it will spin. DC motors have a maximum rated voltage if this voltage is exceeded the motor will fail prematurely.

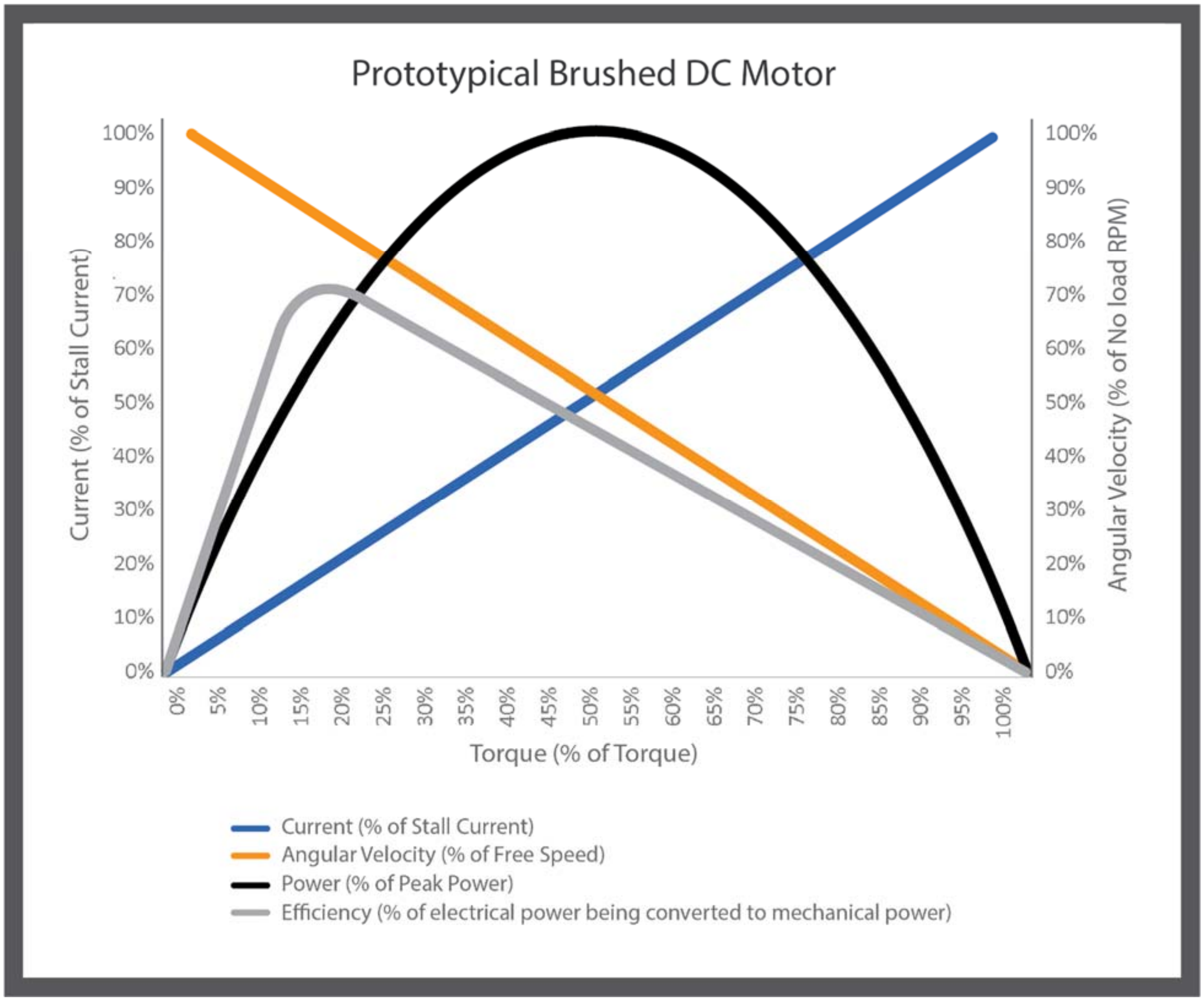


Figure 2: Prototypical Brushed DC Motor Performance

The prototypical performance graph of a Brushed DC motor can be used to estimate the performance of a motor. In most cases amperage is the easiest value to find as it can be reported by the REV Control/Expansion hub.

1.3 Core concepts

When designing a robot selecting the correct motor for the application is a critical design challenge. Some tools can be used to estimate the performance of a motor in a particular application.

Understanding these basic concepts is required to make optimized design decisions which consider the trade-off inherent to any design. This section will briefly cover the definition of these concepts and then explain them in relationship to basic power train concepts.

Speed is the measure of how fast an object is moving. The **speed** of an object is how far it will travel in a given amount of time. For rotating parts like gears and wheels, **speed** is expressed in how many revolutions are made in a given amount of time. Under ideal conditions, the rotation of a wheel is converted into linear **speed** and can be calculated by multiplying the diameter of the wheel by the rotations for a given time. The SI unit for **speed** is meters per second, but **speed** is also commonly expressed in feet per second.

Angular Velocity is how the speed of a rotating object is described. The SI unit for the ***Angular Velocity*** is radians per second (rad/s), revolutions per minute is also commonly used.

Torque is roughly the measure of the turning force on an object like a gear or a wheel. Mathematically, **torque** is defined as the rate of change of the angular momentum of an object. This can also be stated as a force that acts normal (at 90 degrees) to a radial lever arm which causes the object to rotate. A common example of torque is the use of a wrench in order to tighten or loosen a bolt. In that example, using a longer wrench can produce more **torque** on the bolt than using a shorter wrench. **Torque** is commonly expressed in N·m or in·lbs.

When **torque** is turning an object like a spur gear, the gear will create a straight line (linear) force at the point where the teeth contact the other gear. The magnitude of the **torque** created is the product of the rotational force applied and the length of the lever arm (**Error! Reference source not found.**), which in the case of a gear, is half of the pitch diameter (the radius).

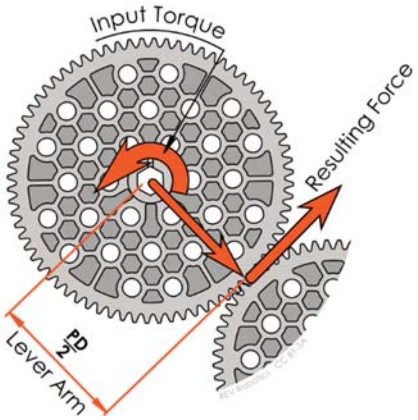


Figure 3: Gear Torque Diagram

Work is concept used to describe changes in energy. Path independent ***Work*** is defined as force times displacement for example if a 1 kilogram(kg) weight is lifted vertically 1 meter(m) against gravity at a constant velocity the work done is 1(kg)*9.8(m/s^2)*1(m) = 9.8 (kg*m^2/s^2) or 9.8 joules(J).

Power (P) is the rate of work over time. The concept of **power** includes both a physical change and a time period in which the change occurs. This is different from the concept of work which only measures a physical change. The difference in these two concepts is that it takes the same amount of work to carry a brick up a mountain whether you walk or run, but running takes more **power** because the work is done in a shorter amount of time. The SI unit for **power** is the Watt (W) which is equivalent to one joule per second (J/s). Rotational **power** is calculated by multiplying **torque** and **angular velocity**.

In competitive robotics, the total amount of available power is determined by the motors and batteries allowed to be used. The maximum speed at which an arm can lift a certain load is dictated by the maximum system **power**.

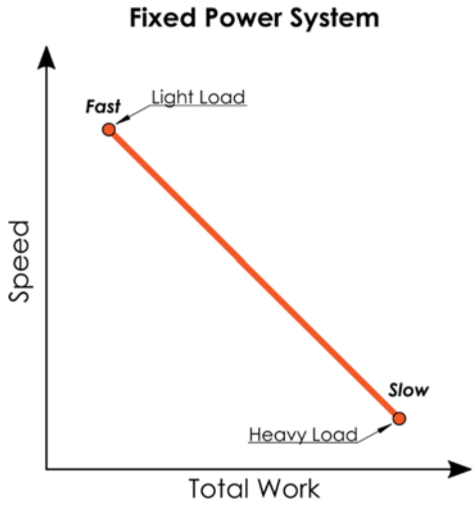
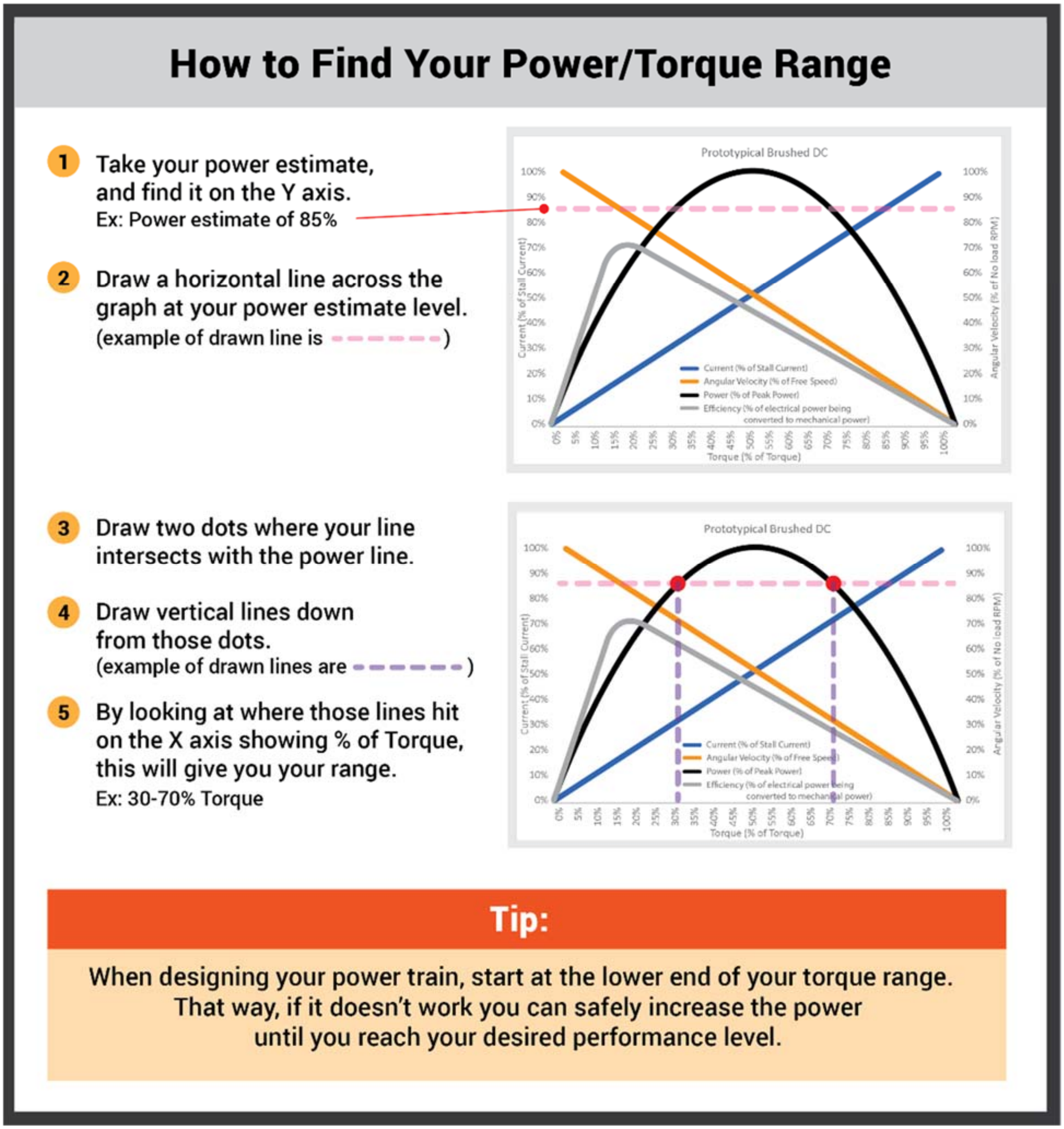


Figure 4: Execution Speed in a Fixed Power System by Load

By changing the size of the gears, we change the length of the lever arm shown in **Error! Reference source not found.**. Meshing two or more gears together is known as a gear train. By selecting the gears in the gear train as larger or smaller relative to the input gear we can either increase the output speed, or increase the output torque as shown in **Error! Reference source not found.**4, but the total power is not affected.

1.4 Estimating Motor Performance

A motor performance graph can be used both for selecting a motor and for understanding the motors behavior once installed in the robot. When selecting a motor, the expected power requirement for the motor is used.



How to Find Your Power/Torque Range

1. Take your power estimate, and find it on the Y axis.
   Ex: Power estimate of 85%
2. Draw a horizontal line across the graph at your power estimate level.
   (example of drawn line is - - - - - -)
3. Draw two dots where your line intersects with the power line.
4. Draw vertical lines down from those dots.
   (example of drawn lines are - - - - - -)
5. By looking at where those lines hit on the X axis showing % of Torque, this will give you your range.
   Ex: 30-70% Torque

Tip:

When designing your power train, start at the lower end of your torque range. That way, if it doesn't work you can safely increase the power until you reach your desired performance level.

Figure 5: Using Expected Power to determine motor performance

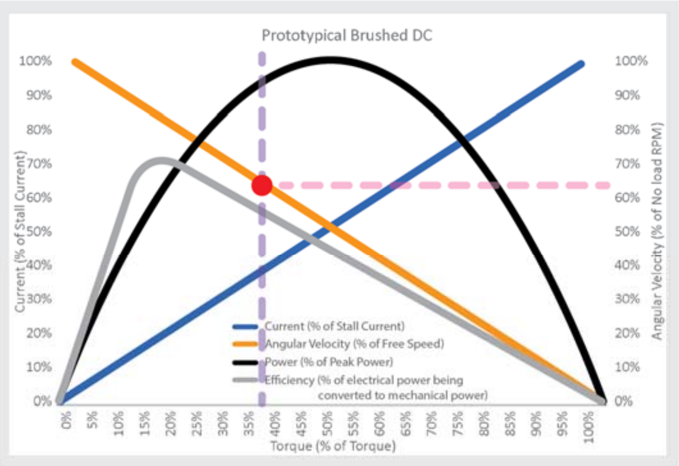
Once the motor is installed in the robot, amperage is the easiest value to find as it can be reported by the REV Control/Expansion Hub. When amperage is known draw a line horizontally at the known value using the current scale, then at the point your horizontal line intersects the current curve, draw a vertical line. The points at which the vertical line intersects the key metric curves will give you the estimated performance for each metric. When designing with minimal constraints it is best maximize power and efficiency. The point of maximum efficiency usually occurs around the 25% of maximum torque point.

Now that you have your Power/Torque Range...

...you can easily find your other metrics!

For Example:

To find your expected Angular Velocity:



1. Draw a vertical line at the '% of Torque' you're using.
   (example of drawn line is – – – – – –)

2. Draw a dot where that line intersects with the Angular Velocity line.

3. By looking at where that dot hits on the axis that corrisponds with Angular Velocity, you can see your expected Angular Velocity percent.

   In this example, the corrisponding axis is on the right side of the graph.
   The line showing where it hits is shown as – – – – – –
   Thus, your expected Angular Velocity is 63%.

Repeat this process to find any of your other metrics.

Figure 6: Estimating Performance using Amperage

1.5 Selecting a Motor

First pass analysis is best done by comparing the maximum **power** the motor is able to output relative to the **power** required to complete the application. If an elevator to lift a game piece is being designed we need make a few basic assumptions about the design in order to estimate the **power** required. For this analysis, we are assuming zero frictional losses and instantaneous acceleration. We can estimate a game piece weighs 0.5 kg, the lifter weighs 1.5 kg and we want the lifter to reach its maximum height of 1.5 meters in 5 seconds.

$$0.5kg + 1.5kg = 2kg$$

$$2kg * 1.5m * 9.8\ \frac{m}{s^2} = 29.4\ Joules$$

$$\frac{29.4\ J}{5s} = 5.88\ Watts$$

$$5.88\ W\ \ \cdot 2\ safty\ factor \approx 12\ watts\ required$$

Based on this calculation the HD Hex Motor would be well suited for this application. If the game object could be lifted more slowly, 10 seconds, the Core Hex Motor would then likely be suitable for the application.

$$\frac{29.4\ J}{10s} = 2.94\ Watts$$

$$2.94\ W\ \ \cdot 2\ safty\ factor \approx 6\ Watts\ required$$

Once a motor has been selected a power train can be designed. The goal of the power train is get the final **torque** and **angular velocity** to the necessary values within the possible range that can be produced by the motor. When designing the power train, the fewer elements present in the power train the more efficient the power train will be. For example, using 30:72 gear box and a 20:20 chain drive will be less efficient than directly using 20:54 chain drive. As a general rule gears are more efficient than chain drive.

Motor performance curves are useful at this stage of design as well because given an estimated power requirement you can estimate an angular velocity and torque range that the motor will be outputting. When designing the power train, the values used should be at the lower end of the viable rpm and torque range as the motor can be given more power to bring it into performance should the estimates be off.

1.6 Preventing Premature Motor Failure

In order to ensure that an electric motor lasts as long as possible a few rules of thumb should be kept in mind:

- Smooth loading, large torque spikes or sudden changes in direction can cause the wear and premature failure of gear box components. This is only an issue when the torque spike exceeds the rated stall torque of the motor. When shock loading is necessary it is best to utilize mechanical braking or a hard stop that absorbs the impact instead of the motor.

- Overheating, when a motor is loaded at near its maximum operating torque it will produce more waste heat than when operating at a lower operating torque. If this heat this allowed to build up the motor can wear out prematurely or fail spontaneously.
    - The Core Hex motor is able to run for approximately 4 hours continuously before overheating at near maximum torque loading.

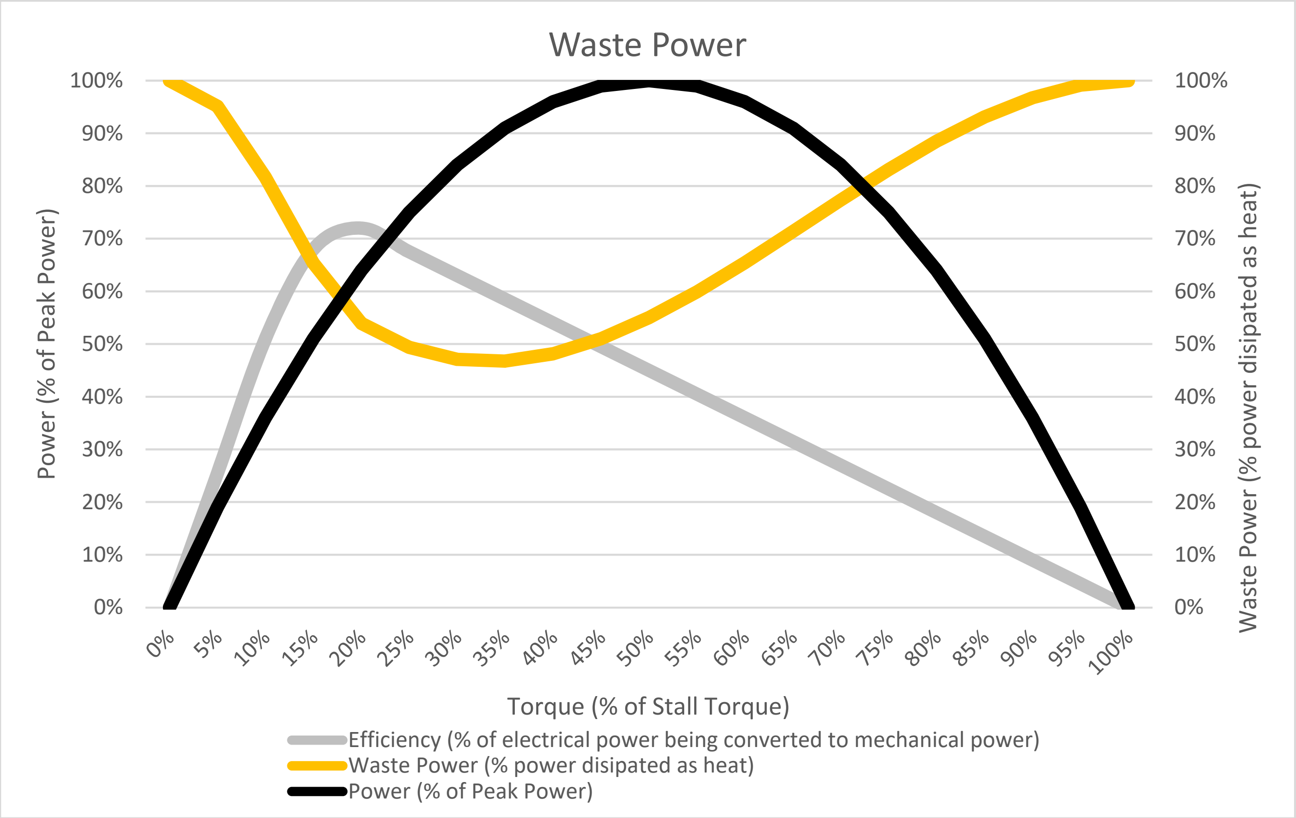


Figure 7: Heat generated by motor

- Poorly supported output shaft, most motor output shafts are not designed to take large thrust forces or forces normal to the shaft. Bearings need to be used to support the axle when loads in these directions are expected.

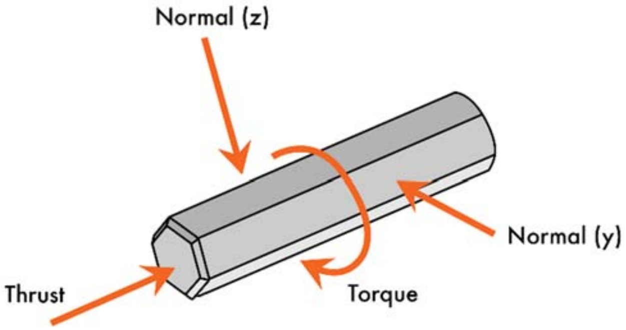


Figure 8: Shaft Loading Directions

2 REV MOTOR SPESIFICATIONS

2.1 REV Robotics motors

All REV Motors have a hex shaft or female hex coupler as the output. The Hex shaft is extremely reliable at transmitting torque without being reliant on set screws that can come loose or not be tightened sufficiently. REV motors also include keyed locking connectors and for both the motor power and the built-in encoder. For more information on the encoder see the Encoder Guide.

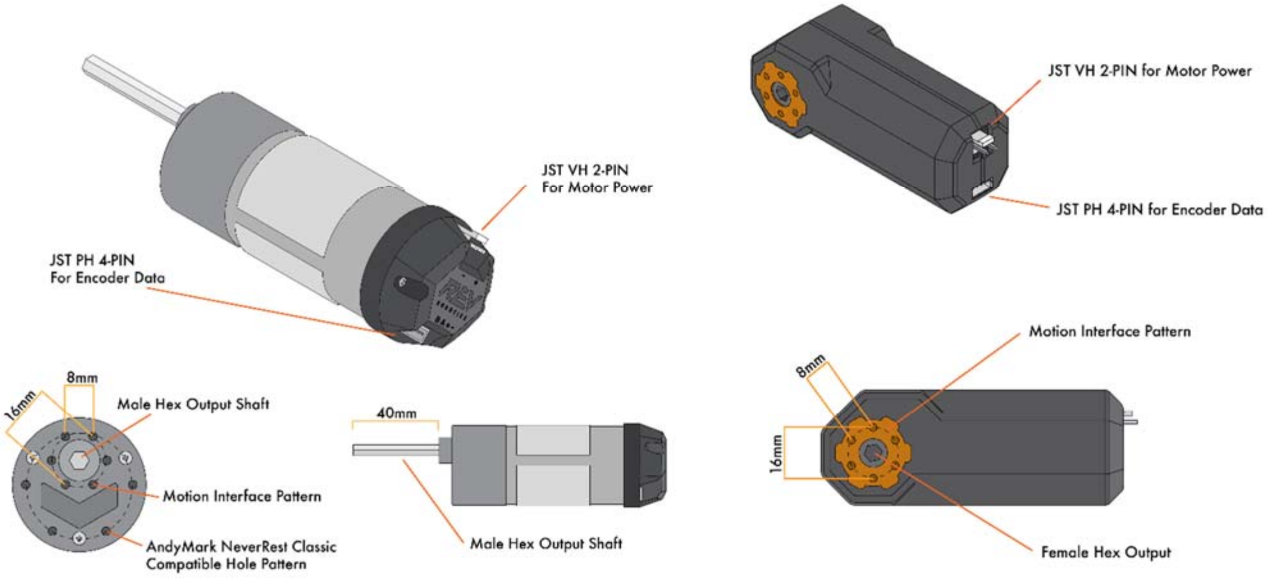


Figure 9: REV motor features

2.2 Motor Mounting Pattern

Most REV Motors have a M3 bolt hole mounting pattern that is on an 8mm pitch as shown in **Error! Reference source not found.**0. This makes it easy to directly mount REV Robotics brackets and extrusion to motors. The 8mm pitch is also compatible with many other building systems. REV motor mounting brackets are available on an 8.5mm or 21.5mm height offset from the top of the extrusion.

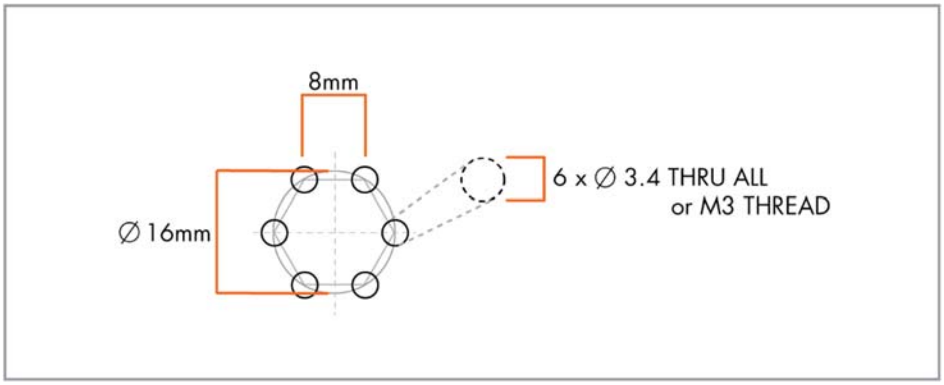
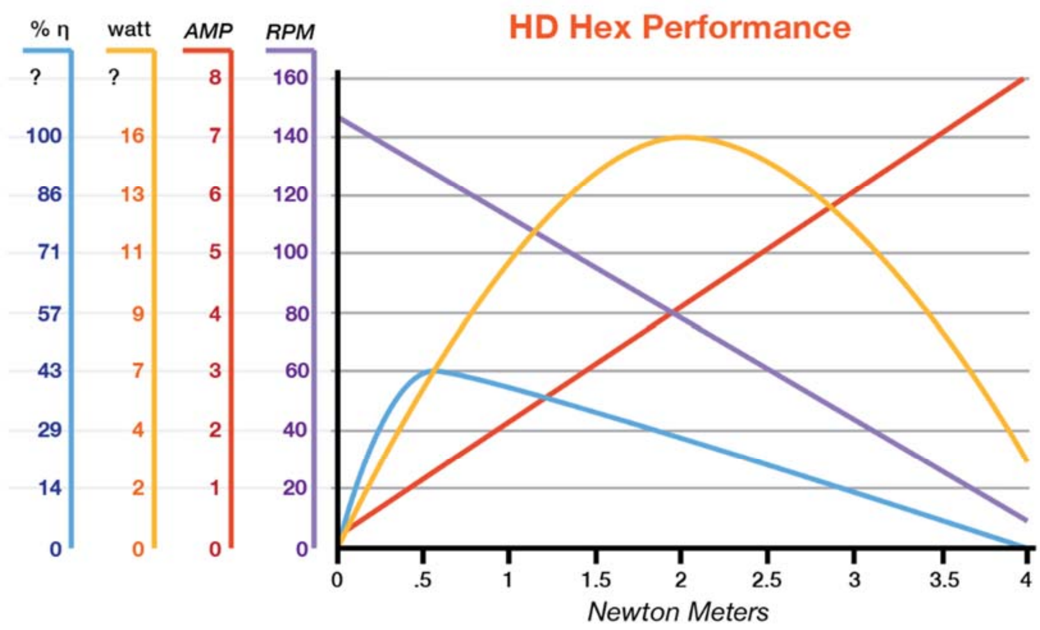


Figure 10: Motion Interface Pattern

2.3 REV Motor Detailed Spesifcations

Table 1: REV Motor Details

	Stall Torque	Free Speed	Operating Voltage	Stall Current	Maximum Output Power
HD Hex, 40:1 REV-41-1301	4.2 N·m 594.7 oz·in	15.7 rad/s 150 RPM	12 V	8.5 Amps	15 Watts
HD Hex, 20:1 REV-41-1301	2.1 N·m 297.4 oz·in	31.4 rad/s 300 RPM	12 V	8.5 Amps	15 Watts
Core Hex, 72:1 REV-41-1300	3.2 N·m 453 oz·in	13 rad/s 125 RPM	12 V	4.4 Amps	8 Watts
Core Hex, 38.4:1 REV-41-1300	1.7 N·m 241 oz·in	24.5 rad/s 234 RPM	12 V	4.4 Amps	8 Watts



"% η" means "percent efficency"

Figure: HD Hex 40:1 Performance Graph