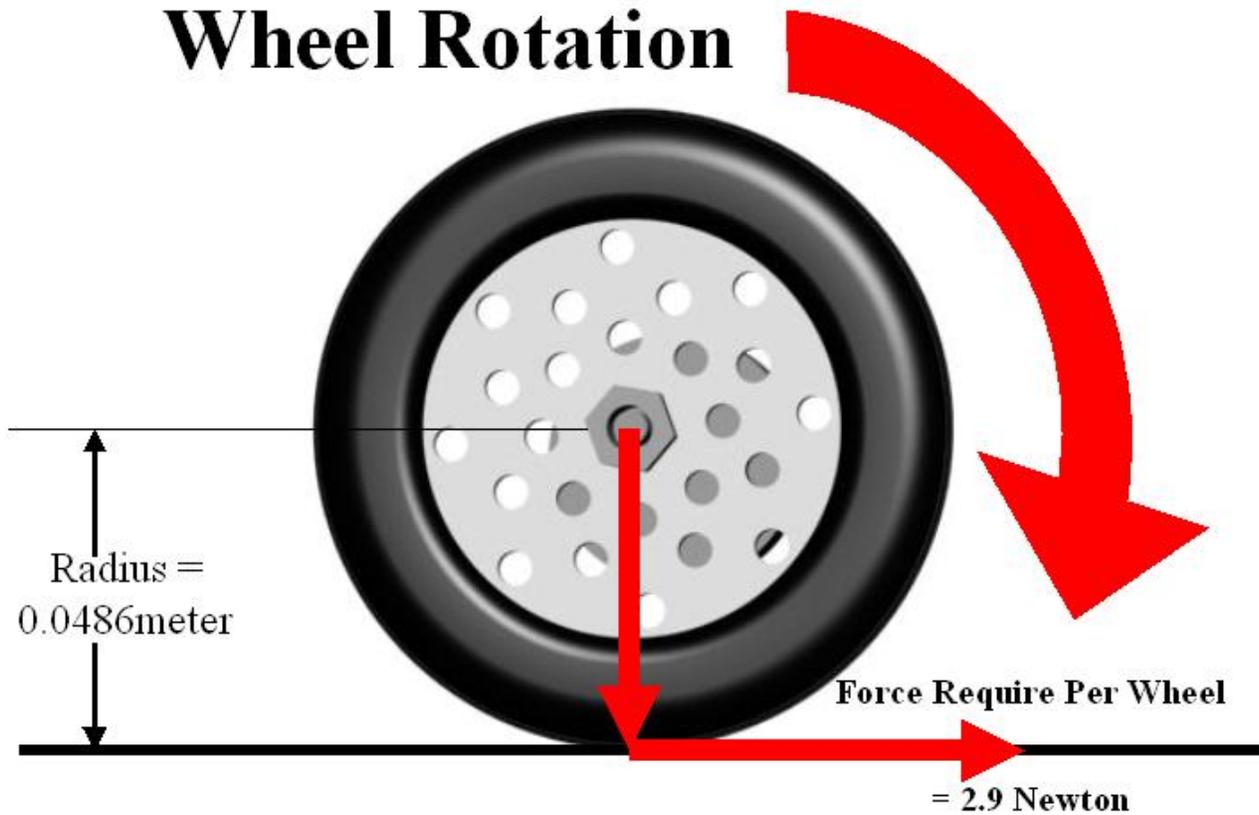


Unit 3 intermediate

Understanding and Using DC Motor Specifications

Wheel Rotation



$$\text{Torque}_{\omega} = \text{Force} \times \text{Distance}$$

Grade Level 8-12 through Post Secondary
Estimated Time 1-4 Hours

Abstract

Engineering design success depends in great part on reducing the time spent creating modules, mechanisms and machines. The use of accurate mathematical models can speed up the design process, and minimize the time wasted on trial and error design methods.

Trial and error design methods are inefficient and costly. Matching a motor to a specific application is not easily accomplished through trial and error. Moreover, the necessity of purchasing and testing many dozens of motors is economically wasteful and time consuming.

Instead, best practices make use of mathematical models early in the design process. The functional requirements and design parameters of a motor system can be determined early in the design process and manufacturer's published motor data can be researched in an attempt to find a suitable match.

Designers and engineers use mathematical models to optimize the time spent designing modules, mechanisms and machines by:

- Reducing the number of possible items in the selection set.
- Reducing testing and prototyping time
- Providing a closer match of motor performance to the functional requirements and design parameters specified early in the design process.

This lesson serves to demonstrate how an understanding of motor performance specifications and mathematical models can be used to more closely match the performance of a DC motor system to a pre-determined specification. This lesson makes extensive use of the experimental data obtained in the previous lesson. In addition, students who participate in this lesson will gain experience in researching manufacturer's published motor data in an effort to best match a DC motor system to an existing specification.

Objectives

Students who participate in this lesson, and the related activities will:

- Use experimental data to create mathematical models of motor performance
- Use experimentally determined motor performance data along with manufacturer's published data to make useful predictions about DC motor performance.
- Use their understanding of Newton's laws of motion, torque and rotational speed to compute the performance requirements of a DC motor system.
- Use engineering methods and mathematical models in an effort to most closely match DC motor performance to a given set of functional requirements and design parameters.

Terms and Concepts

Create word walls, which define and use these terms and concepts accurately.

Acceleration	Mechanical Advantage	Stall Current
Back emf Constant	Multimeter	Stall Torque
Design Parameters	No Load RPM	Torque
Dynamometer	Ohm's Law	Torque Constant
Electromotive Force	Radians per Second	Voltage
Functional Requirements	Resistance	
Gear Ratio		
Mass		

Materials/Equipment/Supplies/Software

GEARS-IDS™ Kit	Calculator	Fully charged 12V Battery or
Internet Access	Multimeter (2)	12v DC power supply

Note: Before beginning this lesson, it will be necessary to review and understand how to use Ohms Law ($E = I \cdot R$) to calculate voltage (E) when both the current (I) and resistance (R) are given.

Use Experimental or Published Data to Create Mathematical Models of Motor Performance

Let's look at the GEARS-IDS™ gearmotor data obtained through previous experiments in Unit 2. Listed below are the experimental results and the manufacturers published specifications:

Stall Current = 12.06 Amps @ 15.1 volts (Manufacturers Specs) = 0.79 Amps/Volt

Stall Current = 9.7 Amperes at 12.5 volts (Experimental) = 0.76 Amps/Volt

K_E (Voltage constant) = 2.43 volts/Thousand RPM (Manufacturers Specs) = 0.0232 volts/rad/sec.

K_E (Voltage constant) = 2.43 volts/Thousand RPM (Experimental) = 0.0232 volts/rad/sec.

K_T (Torque Constant) = 3.21 oz-in./ampere (Manufacturers Specs)

K_T (Torque constant) = 3.02 oz-in./ampere (Experimental)

Model GM9X34 Winding Data (Other windings available upon request)

Line No.	Parameter	Symbol	Units	9X34			
58	Reference Voltage	E	V	12.0	19.1	24.0	30.3
59	Torque Constant	K _T	oz.in/A	(18.2 X 10 ⁻³)	(28.7 X 10 ⁻³)	(36.5 X 10 ⁻³)	(45.9 X 10 ⁻³)
60	Back-EMF Constant	K _E	V/krpm (V/rad/s)	1.91 (18.2 X 10 ⁻³)	3.01 (28.7 X 10 ⁻³)	3.82 (36.5 X 10 ⁻³)	4.81 (45.9 X 10 ⁻³)
61	Resistance	R _T	Ω	0.83	1.89	2.96	4.62
62	Inductance	L	mH	0.63	1.56	2.51	3.97
63	No-Load Current	I _{NL}	A	0.33	0.21	0.16	0.13
64	Peak Current (Stall)	I _p	A	14.5	10.1	8.11	6.55

Note: The Torque Constant K_T shown in the table above is called out as Oz.in/Ampere but is given instead as Newton-meters/ampere. This is a manufacturer's publishing error that was not addressed at the time of this printing. To convert N-m/A to oz.in/A simply multiply N-m/A x 141.611.

Use the data from the previous page to make some useful predictions about the DC gear head motor found in the GEARS-IDS™ Kit.

To do this we must look at a couple of useful algebraic expressions:

$$T = K_T \cdot I$$

$$E = K_E \cdot \omega$$

Where

K_T – Torque Constant is given in N-m/A (Newton-meters/Ampere) or oz.-in/A (Oz.-in/Ampere)

K_E - Voltage constant is given in volts/radians/seconds or volts/krpm (Volts per Thousand rpm)

T - Torque, is given in Nm (Newton-meters)

I - Current is given in Amps (Amperes)

E - EMF, is given in Volts

ω - Angular velocity, is given radians/sec and/or revolutions per second

Remember, when K_T (Torque constant) and K_E (Voltage constant) are given in Amps/Nm and Volts/Radians/sec respectively, they have the same numerical values.

Thus

$$\begin{aligned} K_E \text{ (Voltage constant)} &= K_T \text{ (Torque constant)} \\ 0.0232 \text{ volts/rad/sec.} &= 0.0232 \text{ Nm/Ampere} \end{aligned}$$

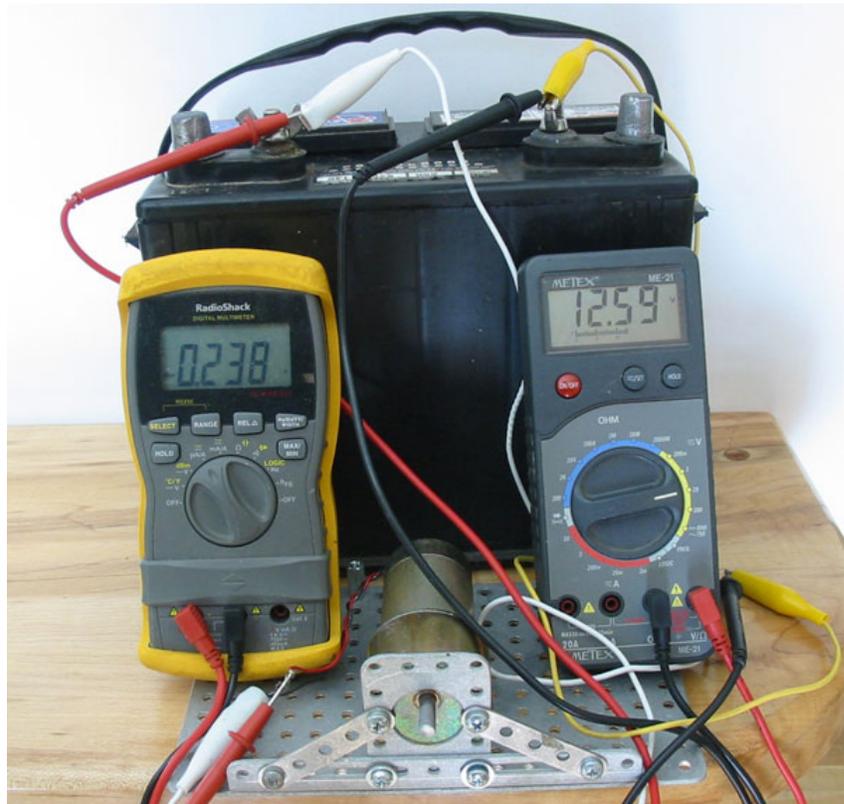
Given this information, and the two equations listed above, it is possible to predict the torque of the motor at any current draw up to stall current. In addition, we can determine the rotational speed (Angular velocity) of the motor armature at any given voltage.

Using the K_E (Voltage constant)

Suppose you wished to determine the shaft RPM of the Pittman gear head motors supplied in the GEARS-IDS™ Kit, at a given applied battery voltage.

Begin by considering the operation of the motor.

When a fixed magnet DC motor (With no load acting on it) is connected to a battery the armature will rotate at a speed and direction dependent on the battery voltage and polarity.



Theoretically the motor armature should continue to accelerate to a higher and higher speed unless there is a force that works in opposition to the battery voltage. Clearly the motor armature does not continue to accelerate but instead reaches a finite top speed.

The motor shaft will not continue to rotate faster because the spinning of the armature coils within the permanent magnetic field of the motor generates a voltage or a back emf that opposes the applied voltage.

Under these circumstances there are several forces at work.

1. The forward emf (Voltage) supplied by the battery which energizes the motor and spins the armature.
2. The back emf (Voltage) generated by the armature spinning within the fixed magnetic field of the motor. This force works in opposition to the forward emf (*voltage*)

Note: The relationship between the back emf (voltage) and the rotational speed of the armature is given as the K_E (Voltage constant).

3. The emf or voltage drop ($I \times R$) across the internal resistance of the armature. The resistance of the armature is relatively slight in comparison to the back emf effect.

In order for the motor armature to continue to spin, a current must continue to pass through the armature windings. The battery voltage must therefore supply enough emf (voltage) to equal both the back emf (voltage) induced within the armature windings as well as the emf (voltage drop) across the armature resistance.

By setting the supplied voltage equal to the back emf (the K_E) at a chosen (fixed) rotational speed and adding the voltage drop across the armature resistance ($I \times R$), we can create an algebraic expression that will allow us to calculate the rotational speed of the armature when any given voltage is applied to it.

Using the voltage constant, K_E , we find that the voltage induced in the motor armature can be calculated for any rotational speed by multiplying the K_E (Voltage Constant) x the rotational speed of the armature. **Note: The voltage constant, K_E can be determined experimentally as described in the previous chapter, or obtained from the manufacturer's published specifications.**

$$E_{induced} = K_E \cdot \omega$$

The voltage drop across the armature resistance can be calculated using Ohm's law. In order to calculate the voltage drop however we will need to determine the "No load" current through the armature as it turns against only the internal resistance of the bearings and gearbox. The current is measured while the motor is free running at the specified voltage (12.6 volts in this example). The current is measured at 0.238 Amperes.

$$E_{drop} = I \cdot R_{armature}$$

$$E_{drop} = 0.238 \text{ Amperes} \cdot 1.26 \Omega = 0.30 \text{ Volts}$$

The battery voltage is a variable that can be determined by the investigator. In this case we elect to calculate the rotational speed of the motor armature at 12.6 volts.

$$E_{battery} = 12.60 \text{ Volts}$$

We can now write an expression that sets the battery voltage $E_{Battery}$ equal to the resistance losses in the armature, plus the counter emf induced in the winding.

$$E_{battery} = K_E \cdot \omega + I \cdot R_{armature}$$

$$12.60V = 0.0232v / rad / sec \cdot \omega + 0.238Amperes \cdot 1.26\Omega$$

Rewriting the equation in terms of the rotational speed or angular velocity of the armature yields the following expression, which can be used to calculate the rotational speed of the motor for any applied voltage.

$$\omega = \frac{(E_{battery} - I \cdot R)}{K_E}$$

$$\omega = \frac{(12.60V - 0.238Amperes \cdot 1.26\Omega)}{0.0232v / rad / sec}$$

$$\omega = 530.2Radians / sec$$

or

$$\omega = 5063.9RPM$$

Note: Convert Radian/sec and RPM using the following formulae;

$$RPM = \frac{Radians / sec}{\frac{2\pi}{60}} \quad \text{Conversely} \quad Radians / sec = \frac{2\pi}{60} \cdot RPM$$

Now we will consider the transmission gearing. The transmission (reduction) ratio is 19.7:1. Calculate the shaft speed by dividing the armature speed by the transmission ratio. This will yield the expected rotational speed of the Pittman gear head motor output shaft.

$$Output \text{ Shaft Speed} = \frac{5063.9RPM}{19.7} = 257RPM$$

Actual measurements of the output shaft (*free running*) speed at 12.6 volts yield a measured 256 RPM! It's nice to know the math works!

Using the K_T (Torque constant)

Suppose you wished to determine the motor torque at $\frac{1}{2}$ the stall current.

Using the torque constant equation above, we find the following relationship between the expected motor torque T , the Torque constant, K_T and the current I .



$$T = K_T \cdot I \quad \text{dividing the stall current by 2 yields} \quad T = K_T \cdot \frac{I}{2}$$

Since K_T and K_E have the same values when the following units are applied:

Torque, T, is given in Nm (Newton meters)

Current, I, is given in Amps (Amperes)

EMF, E, is given in Volts and

Angular velocity ω , or rotational speed, is given radians/sec

We can substitute the (experimental) value of K_E for K_T in the equation above. The resulting answer will give us the expected torque output in Nm (Newton meters)

$$T = 0.0232Nm / \text{Ampere} \cdot \frac{\text{StallCurrent}}{2}$$

$$T = 0.0232Nm / \text{Ampere} \cdot \frac{9.5\text{Amperes}}{2}$$

$$T = 0.1102Nm$$

Choosing the Correct DC Motor for a Specific Application

Design engineers are often faced with having to determine the best DC motor choice for a given functional requirement or design parameter. A typical example might look like this:

Functional Requirement: DC Gear head motor capable of accelerating a 15lb, two-wheel drive robot with wheel diameters of 3.825” at a rate of 3ft/sec/sec. Top speed required will be around 4 feet/sec

Design Parameters: Supplied Voltage = 12Volts, Motor size limited to an overall diameter of approximately 2” and an overall length of not more than 4” (*Less the output shaft length.*)

Design engineers attempt to make the best decision given the universe of possible gear head motor options. Their decisions are often constrained by one of more of these 5 concerns:

1.Time 2.Money 3.Knowledge 4.Power 5.Weight

In order to best solve this design problem, an engineer might choose to accomplish the following tasks in this order:

1. Calculate the required wheel torque and RPM described in the functional requirement
2. Research DC motor manufacturers to determine the availability of gear-head motors that meet the Functional Requirements and the Design Parameters.
3. Compare the published specifications of the various gear-head motors to determine which will provide the best value in terms of the constraints listed above.
4. Choose one or several motors for prototyping and testing.

Step One: Calculate the Required Wheel Torque and RPM

Review the functional requirement: DC Gear head motor capable of accelerating a 15lb, two-wheel drive robot with wheel diameters of 3.825” at a rate of 3ft/sec/sec.

Determine the torque (force) that must be generated at each wheel in order to meet the functional requirement.

Convert all units to SI units (Use <http://www.onlineconversion.com>)

	Imperial	SI
Mass	= 15lbs	6.804 kg
Acceleration	= 3ft/square second	0.9144 meter/square second
Torque	= ft/lbs	Newton/meters

Calculate required force in SI units

$$F = MA$$

$$Force_{Total} = Mass_{kg} \cdot Acceleration_{Meters / sec\ ond^2}$$

$$Force_{Total} = 6.804kg \cdot 0.99144m / s^2$$

$$Force_{Total} = 5.8_{Newtons}$$

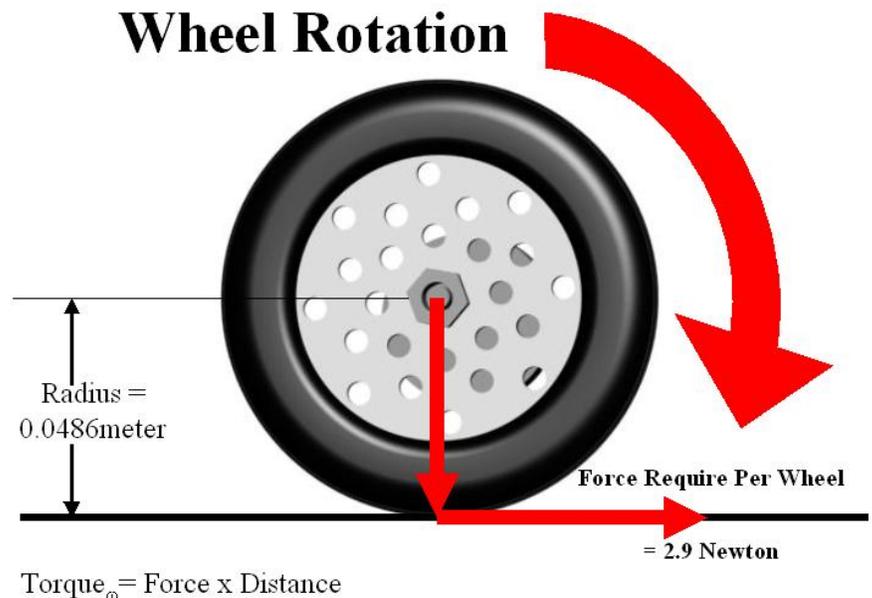
The Total force required to meet the Functional Requirement is 5.8 Newtons. However, the vehicle has 2 motors and wheels. Therefore each motor/wheel combination needs only supply half the required force or 2.9 Newtons.

$$Force_{Wheel} = 2.9_{Newtons}$$

Calculate the torque requirement for each wheel.

Use SI units

Torque is a twisting or turning force that acts on an axis or pivot. The 2 wheels of this vehicle turn on an axis or shaft. The distance from the center of the turning axis to the outside of the wheel is the radius of the wheel. The torque or turning force of the axle acts through the radial distance as illustrated in the graphic below.



$$Torque = Force \cdot Distance$$

Distance	= Wheel Radius	= Wheel Diameter/2	= 3.825"/2 inches	= 0.0486meter
Force	= Force required per wheel		= 2.9 Newtons	

Remember: Keep all the units in the SAME system!

$$Torque_{Wheel} = 2.9_{Newtons} * 0.0486_{meters}$$

$$Torque_{Wheel} = 0.14094 \text{ Newton meters}$$

or it can be expressed in milli Newton meters by multiplying by 1000. Many manufacturer's of fractional horsepower motors express torque in milli Newton meters.

$$Torque_{Wheel} = 140.94 \text{ milli Newton meters or mNm}$$

The required torque at each wheel is 0.14094 Newton meters.

Note: Remember that DC motors develop less torque as the armature rotational speed increases. For this reason we will need to find a motor that can produce 0.14094 Newton meters of continuous torque at or near the design rpm of 250 revolutions per minute.

Calculate the required wheel RPM to maintain a speed of 4 feet per second

$$\begin{aligned} \text{Wheel Diameter} &= 3.825'' &= & 0.0971 \text{ meters} \\ \text{Wheel Circumference} &= \pi \times \text{Diameter} &= & 3.142 \times 0.0971 \text{ meters} = \mathbf{0.305 \text{ meters}} \\ \text{Required Speed} &= 4\text{ft/sec} &= & \mathbf{1.219 \text{ meters/second}} \\ \text{RPS Revolutions Per Second} & &= & \text{rpm}/60 \end{aligned}$$

Remember: Keep all the units in the SAME system!

$$\text{Speed}_{\text{meters / second}} = \text{RPS} \cdot \text{Circumference}_{\text{meters}}$$

$$1.219_{\text{meters / second}} = \text{RPS} \cdot 0.305\text{meters}$$

$$\text{RPS} = \frac{1.219_{\text{meters / second}}}{0.305_{\text{meters}}}$$

$$\text{RPS} = 3.996 \quad \text{RPM} = 239.76$$

Step Two: Research manufacturers in order to determine the availability of gear-head motors that meet the functional requirements and the design parameters.

List the required torque and Wheel velocity from the previous calculations

$$\begin{aligned} \text{Required torque} &= 0.1409 \text{ Newton meters} &= & 1.247 \text{ inch pounds} &= & 19.95 \text{ inch ounces} \\ \text{Wheel velocity} &= 239 \text{ Revolutions per minute} &= & 3.996 \text{ Revolutions per second} &= & 25 \text{ Radians sec} \end{aligned}$$

Note: It is important to calculate the motor specifications using one set of units, but it is also necessary to list the specifications in a variety of units since individual manufacturers use different units.

For the purpose of choosing a motor for this lesson activity, we will consult the Pittman Motor Company specifications.

Review the functional requirements and the design parameters:

Functional Requirement: DC Gear head motor capable of accelerating a 15lb, two-wheel drive robot with wheel diameters of 3.825'' at a rate of 3ft/sec². Top speed required will be around 4 feet/sec

Design Parameters: Supplied Voltage = 12Volts, Motor size limited to an overall diameter of approximately 2'' and an overall length of not more than 4'' (*Less the output shaft length.*)

Note: Motor manufacturers publish their motor specifications online as a convenience to engineers and designers looking to make motor purchases. For the most part these motor manufacturers are expecting to sell caseloads of motors to OEM's (Original Equipment Manufacturers) and are not expecting to sell individual motors.

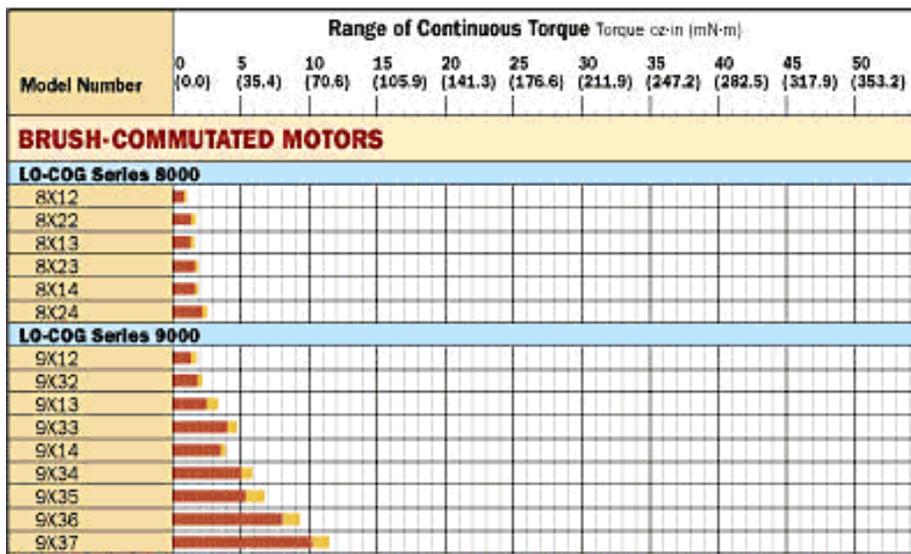
Consult Manufacturer's published specifications choose an appropriate gearmotor

- 1.) [Click here](#) to open the Pittman Motors/Penn Engineering brushed motor data
- 2.) Take the necessary time to review the data and understand how it is organized.
 - a. A quick review of the chart shows torque outputs for different “Series” of brush commutated motors. The motor series of interest are the 6000, 8000 , 9000 and 14000 series motors. We need a motor with a continuous torque output of at least 140.9 mNm or 20 oz. in. of torque.
 - b. Review the manufacturer’s spec sheet (Step 1.) product series to find the motor torques that best fit the calculated requirements. The 14000 series motors on page PE-4 provide torques in this range. The 14000 series motor part number (last column on right) 14203S009 is an almost perfect match with respect to torque. However, this will not be the best decision, as we will see in the next step.
- 3.) find the No-load RPM (column 2) for the 14203S009 motor.
 - a. The torque value listed matches the motor specifications that we described. However, The No-Load Speed listed on line 4 is 3456 rpm! This is way more motor than we require since we are looking for a motor that will yield 20 oz.in of torque at only 250 rpm.

Motor Data

Line No.	Parameter	Symbol	Units	14XX1	14XX2	14XX3	14XX4	14XX5	14XX6	14XX7
1	Continuous Torque (Max.) ¹	T _C	oz-in (N-m)	10.0 (70.6 X 10 ⁻³)	14.0 (98.9 X 10 ⁻³)	21.0 (148.3 X 10 ⁻³)	26.0 (183.6 X 10 ⁻³)	31.0 (218.9 X 10 ⁻³)	36.5 (257.8 X 10 ⁻³)	50.0 (353.1 X 10 ⁻³)
2	Peak Torque (Stall) ²	T _{PK}	oz-in (N-m)	62.8 (.44)	107 (.76)	159 (1.12)	204 (1.44)	225 (1.59)	284 (2.01)	410 (2.90)
3	Motor Constant	K _M	oz-in/√W (N-m/√W)	4.45 (31.4 X 10 ⁻³)	5.93 (41.9 X 10 ⁻³)	7.88 (55.6 X 10 ⁻³)	8.63 (60.9 X 10 ⁻³)	9.97 (70.4 X 10 ⁻³)	10.9 (77.0 X 10 ⁻³)	13.1 (92.5 X 10 ⁻³)
4	No-Load Speed	S _{NL}	rpm (rad/s)	4230 (443)	4087 (428)	3456 (362)	3702 (388)	3056 (320)	3216 (337)	3211 (336)

Since the rpm we require is so low, we can choose a motor series with less torque and use a transmission to lower the rpm while raising the torque. We will now return to the Pittman website and look at **Gear Head Motors.**



4.) Return to the brushed motor data sheet.

This time we will choose a motor that has a least 25% of the specified torque or around 5 oz-in. of torque. The 9000 series motors offer torques in that range. The 9034 series motor is one of several appropriate choices we can make. Let’s start with that selection. This time however we will now

select from the 9000 series Gear Head motors found on page PE-3.

5.) Return to the brushed motor data sheet and Scroll down to the 9000 series Motor Data on page PE-3. Find the continuous torque ratings for the 9234 series Gear Motor. (first 4 numbers of the part number found in the last column to the right)

The continuous torque rating for the 9234 series Gear Motor is listed as 6.1 oz-in. This is not enough torque to meet the required specification we have calculated. However, the no load RPM is listed at more than 6000 rpm. We can select an appropriate gear reduction that will allow us to trade motor speed (rpm) for torque. We will need to select an appropriate gear reduction in order to increase the torque and match the rpm specification. Since it is unlikely that we will exactly match both the torque and the rpm specified, we will choose to more closely match the rpm and accept the resulting torque.

6.) Return to the brushed motor data sheet. Page PE-8 and PE-9. Scroll to where you will find the no load RPM data for the gearmotor GM 9234 motor (@12 volts). Find the No-Load speed for the 9234 Gear motor with a 19.7 to 1 gear reduction. This speed is listed as 313 RPM. This is close to calculated specification since in our application there WILL be a load on the gear motor that will act to slow it down.

7.) Let's calculate the torque available at the transmission output shaft of the 9234 Gear Motor with a 19.7:1 gear reduction transmission.

Gearmotor Data			Reduction Ratios												
Line No.	Parameter	Symbol	Units	5.9:1	11.5:1	19.7:1	38.3:1	65.5:1	127.8:1	218.4:1	425.9:1	728.1:1	1419.8:1	2426.9:1	4732.5:1
NO-LOAD SPEED (All Gears)															
22	GM9X32	S_{NL}	rpm (rad/s)	1189 (125)	610 (63.9)	357 (37.4)	183 (19.2)	107 (11.2)	54.9 (5.75)	32.1 (3.36)	16.5 (1.73)	9.6 (.513)	4.9 (.513)	2.9 (.304)	1.5 (.157)
23	GM9X33	S_{NL}	rpm (rad/s)	1016 (106)	521 (54.6)	305 (31.9)	156 (16.3)	91.5 (9.58)	46.9 (4.91)	27.4 (2.87)	14.1 (1.48)	8.2 (.859)	4.2 (.440)	2.5 (.262)	1.3 (.136)
24	GM9X34	S_{NL}	rpm (rad/s)	1043 (109)	535 (56.0)	313 (32.8)	160 (16.8)	93.9 (9.83)	48.1 (5.04)	28.2 (2.95)	14.4 (1.51)	8.5 (.890)	4.3 (.450)	2.5 (.262)	1.3 (.136)

We will need to look at the input torque from the motor, the mechanical advantage (Torque Multiplier) gained through the transmission gearing and the mechanical advantage lost through the rotational mass and friction of the transmission gears (*Transmission efficiency*).

We will need to record some of the manufacturer's data that we have already reviewed.

9X34 Continuous (Motor) Torque	6.1 oz-in. (Remember, This is the torque the motor puts into the transmission)
9X34 Gear Reduction	19.7:1
9X34 Transmission Efficiency	73% (The sum of all the inertia and friction losses through the transmission gears and shafts)

The expression we will use looks like this:

Out Put Torque (Tran. shaft) = Input Torque (Motor) x Gear Reduction x Transmission Efficiency

$$\text{Output Torque} = 6.1 \text{ oz-in.} \times 19.7 \times .73$$

$$\text{Output Torque} = 87.7 \text{ oz-in. of Continuous Torque}$$

The 9X34 series Gear Head motor is more than adequate for the requirements we specified. The rpm is slightly more than we specified and the torque is more than 4 times what we require. The overall

dimensions of this component almost exactly match our specifications. This motor leaves us with some design “Head Room”. It is not a perfect match, but it is fairly close. The next important consideration would be cost. If however, there is an 8000 series gear head motor that more closely matches our requirements, then it would be our responsibility as design engineers to make that determination.

The challenge offered to you is this:

Using the published Pittman data, to find gear motors motor that most nearly match functional requirements and design parameters determined by yourself, or your teacher. Then call Pittman Express or visit www.clickautomation.com and obtain a price quote for the motor you determine most closely meets the requirements you describe. You can repeat this process for other motor manufacturers in an effort to find the best value.

Good Luck, your on your way to becoming DC motor experts.

Unit3 Work Sheet

Using Experimental and Published Data to Create Mathematical Models of Motor System Performance

Name _____ Date _____ Class _____

Directions: Answer the following questions using the information provided in this lesson.

- 1.) _____ Stall Current is a measure of the _____ amount of current draw through the armature winding.
A.) Maximum B.) Minimum C.) Average D.) Continuous
- 2.) _____ Stall current is measured in _____.
A.) Volts B.) Amperes C.) Ohms D.) Watts
- 3.) _____ Current is proportional to this force in a brush commutated DC motor.
A.) Resistance B.) Acceleration C.) RPM D.) Torque
- 4.) _____ The Torque Constant is measured in the following units.
A.) Volts/rad/sec B.) Amperes/rpm C.) Amperes/oz-in. D.) Oz-in./Ampere
- 5.) _____ The symbol for the Torque Constant is _____.
A.) Ω B.) K_T C.) K_E D.) I
- 6.) _____ A motor generates 15 oz-in. of torque at 3 amperes. The torque constant is _____.
A.) 5 amperes/oz-in. B.) 3 oz-in./ampere C.) 5 oz-in./ampere D.) 3 amperes/oz-in.
- 7.) _____ The DC motor voltage constant is measured in the following units.
A.) Rpm/thousand volts B.) Volts/Thousand rpm C.) Amperes D.) Volts
- 8.) _____ Moving charges or current are measured in which of the following units?
A.) Amperes B.) Volts C.) Watts D.) Both A and C
- 9.) _____ The symbol for the voltage constant is _____.
A.) Ω B.) K_T C.) K_E D.) I
- 10.) _____ Increasing the voltage supplied to a brush commutated DC motor causes a proportional increase in the motor _____.
A.) Resistance B.) Torque C.) Rotational Speed D.) Current
- 11.) _____ A remotely operated vehicle with a mass of 5 kg accelerates at a rate of 0.5 meters sec/sec. What is the (minimum) net force acting to accelerate the vehicle?
A.) 12.5 Newtons B.) 0.25 Newtons C.) 1.25 Newtons D.) 2.5 Newton
- 12.) _____ The voltage constant is also referred to as the _____.
A.) Back-EMF constant B.) Speed constant C.) Power constant D.) Motor constant

- 13.) _____ Ohms law describes the relationship between Voltage, Current and Resistance and is expressed as _____.
 A.) $E = I * R$ B.) $E = I/R$ C.) $I = R/E$ D.) $R = I * E$
- 14.) _____ The E in Ohms Law represents _____.
 A.) Voltage B.) Amperage C.) Current D.) Resistance
- 15.) _____ A DC motor armature draws 0.380 amperes while running at a no load speed of 5000 rpm. The manufacturer lists the armature resistance as being 3.25 ohms. What is the voltage drop across the armature windings?
 A.) 1.235 Amperes B.) 1.235 Volts C.) 12.35 Amperes D.) 12.35 Volts
- 16.) _____ A DC motor having a Torque Constant of 3.5 oz-in./ampere draws 5 amperes of current. Calculate the torque produced at the armature shaft.
 A.) 17.5 Amperes B.) 17.5 oz-in. C.) 7.5 Amperes D.) 7.5 oz-in.
- 17.) _____ Ohm's law is an algebraic expression that describes the relationship between Current, Voltage and _____ in a circuit.
 A. Resistance B.) Impedance C.) Amperage D.) The magnetic field
- 18.) _____ The no load speed of a motor is listed by the manufacturer as being 745 radians/sec what is the speed in rpm?
 A.) 711.4 rpm B.) 71.14 rpm C.) 7114 rpm D.) 71146 rpm
- 19.) _____ The back EMF constant can be used to evaluate a motors ability to generate electrical energy.
 A.) True B.) False
- 20.) _____ The no load speed of a motor is listed by the manufacturer as being 5000 rpm what is the speed in radians/second?
 A.) 500 B.) 623 C.) 478 D.) 523
- 21.) _____ A robot wheel has a radius of 2.75 inches. How far will it travel in one complete revolution (*approximately*) ?
 A.) 17" B.) 15" C.) 17.28" D.) 15.3"
- 22.) _____ A motor has a voltage constant, K_E equal to 2.96 volts/thousand rpm. What voltage will be produced across the motor leads if the motor armature shaft spins at 4320 rpm?
 A.) 12.78 B.) 12787.7 C.) 11.9 D.) 13.76
- 23.) _____ A motor supplied with 10 volts, draws 12.8 amperes of current at stall. What is the approximate armature resistance? Hint: Use Ohm's Law $E = I * R$
 A.) 7.81 ohms B.) 78.1 ohms C.) 7.81 ohms D.) 0.781 ohms
- 24.) _____ The K_E (Voltage constant) of a given motor is 0.0445 volts/radians/sec. The torque constant of this same motor will be _____.
 A.) 0.0232 Amperes/Nm B.) 0.0445 Amperes/Nm C.) 0.0232 oz-in/Ampere D.) A and C
- 25.) _____ The Back emf generated in a spinning motor armature opposes current flow through the armature.
 A.) True B.) False

NOTE: The answers to these questions can be found within this document and through online searches. It is the search for the answer that improves the quality of what is learned.

Activity 1

Read and Interpret Manufacturer's Motor Specifications

Purpose

This activity is an exercise in how to obtain, interpret and use engineering data. One of the more compelling reasons for acquiring technical literacy is to develop the ability to access, interpret and effectively use data and information.

Engineers and technicians possess the knowledge and skills necessary to research, read and understand technical specifications. In addition, they are expected to recognize and convert measurements and units so they can make direct comparisons between products that are described using Imperial, SI or metric values.

This exercise challenges students understanding of DC motor technology, as well as their fact finding and problem solving abilities. This exercise can seem like a daunting task, but by working in groups, organizing their data and communicating their findings, they will succeed.

Description

Using the internet, locate vendors who manufacture or distribute fixed magnet, brushed DC motors. Search their websites to find published specifications for the brush commutated DC motors and gear heads they manufacture. Using the manufacturers published data create a list of motor choices that most nearly match the motor design parameters and functional requirements listed below. Present the two best choices you are able to find and explain why your group believes they have found the best options. **While you may not be able to find a perfect match, you will be expected to make the best choice given the motor or gearmotor combination(s) that you are able to find,**

Design Parameters for 12 Volt Brush Commutated DC Motor

Motor Length (Excluding Shaft)	2-1/4" (approximate) +/-1/4"
Motor Diameter	1-1/4" (approximate) +/-1/4"
Motor Weight	7 ounces or less (approximate) +/- 2 oz"
Unit Cost (Single Purchase)	\$100.00 (approximate) +/- 25.00"

Functional Requirements

Continuous Torque	= 2 oz-in. +/- 1 oz-in.
Torque Constant K_T	= 1.75 oz-in/Ampere or more
Back Emf Constant K_E	= 1.3 volts/Krpm or more
No load current	= 0.6 Ampere or less
Stall Current (Max)	= 8.0 Amperes or less
No Load Speed	= 5000 – 9000 rpm
Continuous Power Output	= 5 Watts or more

Present your findings by preparing a slide presentation describing how closely your motor and gearbox choice matches the design parameters and functional requirements. Prepare a spread sheet that compares your groups motor selection with the design parameters and functional requirements given above.

As a class, decide which motor choice is the best, and provide valid and logical reasons for that choice.

The following is a partial list of vendors who provide detailed motor data.

Pittman Motors	http://www.clickautomation.com/products/index.php?func=list&cid=236 This is a link to a Pittman motor distributor whose website publishes easily accessible specifications for Pittman motors.
Buelher Motor	http://www.buehlermotor.com/ This link will take you to the Buehler product specification page. It will be necessary to select gearmotors in order to view specific data.

Johnson Electric	<p>http://www.johnsonmotor.com/Performance-Charts.266.0.html</p> <p>Johnson Electric is a large company. The website can be a intimidating to navigate, but it is worth the effort. There is a great deal of educational material on this site. The link above will lead to a page that offers an excellent explanation of motor performance parameters. Take the time to learn the basics of motor performance so you can evaluate, compare and match motors to specific applications.</p>
Faulhaber Motors	<p>http://www.micromo.com/</p> <p>This is a more technical website through which the manufacturer offers many motor designs and configurations. A knowledgeable user can choose among many motor and transmission combinations in an effort to custom design a solution to their specific application. This is the case with many motor manufacturers. Making the best motor/transmission selection depends on having an in depth understand of the meaning and implication of motor terms, concepts, performance and specifications.</p>
Globe Motors	<p>http://www.globe-motors.com/15sp_in.pdf</p> <p>Globe manufactures many motor/transmission solutions. However this link will take you to a specification page for a motor transmission combination that is a bolt in copy of the Pittman motors used in the GEARS IDS line of products. This provides a rare and excellent opportunity for students and teachers to make a direct comparison of cost/performance between two competing manufacturers. This is an excellent example of the kind of decision making that engineers engage in. Find comparable products and compare them in an effort to obtain the best value.</p>

Remember this; A successful search depends on having the attitude that what you are searching for is in fact out there on the web. Your ability to find answers on-line depends on how much you learn during the search. Use what you learn during the search to target and find the necessary information.

Good web researchers are relentless...they don't give up the search until they find the information, or determine without a doubt that the information does not exist. In this case, the information exists. So keep looking until you learn to recognize it.

Activity 2

Motor Performance Using a Manufacturer's Calculator

This exercise is both educational and enjoyable. The 4QD company manufactures DC motor controllers. In an effort to provide their customers with the information needed to make informed choices about their motor control products, 4QD offers several online calculators.

Your students can use these tools to determine the motor performance (current, voltage and wattage) requirements for a wide variety of mobile platforms operating on flat or inclined surfaces.

The 4QD calculator performs basic physics calculations to determine the functional requirements of the motor.

[Click here](#) to open the 4QD motor performance calculator. Once the calculator is open, take the time to play around with it. That is a good way to learn how to understand it, and use it effectively. Change the (entered) values so you can understand how these values determine the calculated values for motor current, power (Wattage), energy and speed.

After becoming familiar with how the calculator operates, use it to determine the motor performance for the values given in the following scenario.

Scenario

A robot is required to travel at a top speed of 2 meters per second. The combined vehicle weight (payload and chassis) is 7.5 kilograms. The operating voltage is 24 volts. One 12 volt battery weighs .4 kilograms.

The motor current draw along a level surface is measured at .25Amperes per motor for a total current draw of .5 amperes.

The robot must be designed to climb a 100 meters long, 30% gradient (16.7 degrees). In addition the robot must be capable of accelerating to top speed in 1 second.

Use the 4QDmotor performance calculator to compute the following values:

- _____ 1. The total current draw (both motors) at full speed.
- _____ 2. The required climbing power(Watts)
- _____ 3. Time required to climb the full length (100 meters) of the incline.
- _____ 4. The kinetic energy (joules) of the robot at full speed

Compare your assumptions and your answers with the teacher, as well as the other students in the class.

- 1.) What is the affect on the calculated values if you increase or decrease the robot weight by 10%?
- 2.) What is the effect on the calculated values if you increase or decrease the required acceleration?

Extra credit:

- 1.) Can you find a Pittman gearmotor that will best match the required performance for the scenario given above ? What wheel diameter and total gear ratio will be needed in order to match the speed requirement?
- 2.) Make up your own scenarios and run the calculator to determine the motor performance values.

The following screen shot provides the calculated values for the scenario given on the preceding page.

Total mass of all of the above is:	<input type="text" value="8.3"/>	Kilogrammes
Vertical Speed is speed/gradient(V/v) At top speed, rate of climbing is:	<input type="text" value="0.6"/>	metres per second
Power for climbing. (Motor Current needed to climb)		
Power= Mass x G x (V/v) where G is the acceleration due to gravity, $9.80 \text{ metres/sec}^2$		
So the power for climbing is:	<input type="text" value="48.86"/>	Watts
And as this is at full speed the motor current is:	<input type="text" value="2.04"/>	Amperes
Kinetic energy. (Motor Current needed to accelerate)		
KE = $1/2 \times M \times V^2$		
So in this case, KE at full speed is:	<input type="text" value="16.6"/>	joules
But this speed increase took place in the acceleration time you entered. So to get Joules/second, divide by the acceleration time. Now one Joule per second is a watt. We are accelerating from zero to full speed (zero to full battery volts) so divide by the average motor voltage (i.e. by half the battery voltage) to get the		
motor current needed for this acceleration:	<input type="text" value="1.38"/>	Amperes
Total Motor Current		
Add the three currents:	<input type="text" value="3.92"/>	Amperes
That on level ground + that for climbing + that for accelerating		
Time duration of Current		
You chose an acceleration time of	<input type="text" value="1"/>	Seconds
You will climb the hill you specified in	<input type="text" value="50"/>	Seconds

Extra credit:

- 1.) Can you find a Pittman gearmotor that will best match the required performance for the scenario given above ? What wheel diameter and total gear ratio will be needed in order to match the speed requirement?
- 2.) Make up your own scenarios and run the calculator to determine the motor performance values.

In order to determine the answers to the extra credit questions you will need an additional calculator from the 4QDwebsite. This information is necessary to help you make the best choice from the Pittman gear motor products.

[Click here](#) to open the 4QD road speed calculator

Assessment Rubric for Lesson 3

This rubric is offered as an example only. Each instructor is encouraged to create their own assessment tools with respect to the needs and expectations of their individual students/classes.

Proficiency	Meets/Exceeds Requirement	Meets Some of the Requirement	Meets little or None of the Requirement
Demonstrates the ability to read key DC motor Data from manufacturer's published materials			
Researches locates and presents DC motor specifications provided by 3 or more manufacturers.			
Gathers, evaluates, and compares DC motor data from several manufacturers in order to determine the best choice for a given set of design parameters or functional requirements.			
Presents clear and accurate description of Torque Constant, Back-EMF constant, Stall Torque and No Load RPM			
Creates a slide show and presentation that describes and compares several motors with similar specifications.			
Completes all class work, assignments, activities and notebook requirements associated with this lesson			

Performance assessment.

- Portfolio (An organized chronology of individual achievement. This could be a notebook or a web page or a multimedia presentation)
- Work Sheets, Labs and Design Challenges.
- Examples of Spread Sheets to Solve Chain and Sprocket Related Problems
- Tests and Quizzes

Student Response/Journal Entry/Assignments

- 1.) Photographs of working test apparatus and individual projects.
- 2.) Motor Manufacturer's Research Results and/or presentation.
- 3.) Mathematical Models.
- 4.) Tests or Quizzes.