Motion for Dummies

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Contents

Introduction

Magnets and Magnetism covers the molecular level of magnetic flux to provide the reader with a better understanding of how and why electrical motors operate the way they do., It gives the true "mechanical" reasons for properties of inductance and Back EMF. Feedback Devices covers the most common means of feedback used for detecting mechanical motion. With brief descriptions and diagrams, the reader will benefit with a more complete understanding of what is out there and how it works.

Mechanical Systems is an overview of basic actuator types and mechanical drive systems including comparison charts to aid in proper selection for any given application.

Understanding Actuator Loading will give insight into the strengths and weaknesses of moment arm loading practices and add to the knowledge required when properly sizing bearing loads for a given linear guide.

Understanding Thrust Curves shows the basis for limits placed on advertised thrust curves for actuators. With this in mind, a better selection can be made when sizing up actuators for longer life and safer operation

Understanding Torque Curves like above, will show limits and the reasons for them. In addition, it shows examples of real world operating conditions and the likely result if run under those conditions. This will greatly aid in troubleshooting systems where proper sizing may have come into question.,

Moment Of Inertia Overview may surprise the user with alternate methods to achieve heavy load control. In a brief detailed description, it uncovers the benefits of gear reduction and speed optimizing.

Advanced Drive Capabilities covers specific capabilities found in Animatics Smartmotors that may open up new applications and means for improved performance in those hard to attain motion profiles.

Example Applications shows an overview of typical systems in the filed where closed loop servo motors have been used to maintain good efficient production with repeatable quality results.

Motion Glossary and Motion Formulas is a collection of common terms and formulas used in the automation industry especially as it applies to motion control.

Domain: A Small area of control, in the case of magnets, a small molecular level sized magnet

Permeability: This refers to how well magnetic fields can reach into or though a material.

Reluctance. : Opposite of Permeability. The magnetic field is reluctant to pass through a material.

Flux: A term given to the lines of field strength in a magnetic field. Like paths of water flow out of a shower head.

Coercivity: Basically describes how much molecules inside a material can move around or stick together.

8 Axioms of magnetism (As it pertains to Flux)

1. Flux lines, like electrical currents, will always follow the path of least resistance. In magnetic terms, this means that flux lines will follow the path of greatest permeance (lowest reluctance).

2. Flux lines repel each other if their direction of flow is the same.

3. As a corollary to condition two (2), flux lines can never cross.

4. As a corollary to condition one (1), flux lines will always follow the shortest path through any medium. They therefore can only travel in straight lines or curved paths, and they can never take true right-angle turns. Meeting the terms of condition two (2), flux lines will normally move in curved paths; although over short distances, they may be considered straight for practical purposes.

5. Flux lines will always leave and enter the surfaces of ferromagnetic material at right angles.

6. All ferromagnetic materials have a “limited ability” to carry flux. When they reach this limit, they are saturated and behave as though they do not exist (like air, aluminum and so on). Below the level of saturation, a ferromagnetic material will substantially contain the flux lines passing through it. As saturation is approached, because of conditions one (1) and two (2), the flux lines may travel as readily through the air as through the material.

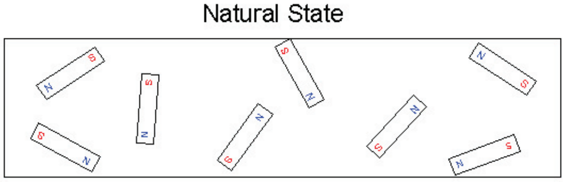
7. Flux lines will always travel from the nearest north pole to the nearest south pole in a path that forms a closed loop. They need not travel to their own opposite pole; although they ultimately do if poles of another magnet are closer and/or there is a path of lower reluctance (greater permeance) between them.

8. Magnetic poles are not unit poles. In a magnetic circuit, any two points equidistant from the neutral axis function as poles, so that flux will flow between them (assuring that they meet the other conditions stated above).

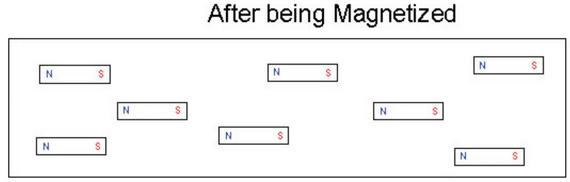
Domain Theory

In 1907 French physicist Pierre Weiss postulated that ferromagnetic materials were fully magnetized at all times. He attributed this to spontaneous “molecular fields” that caused total alignment of atomic magnetic moments. However, he had to explain the absence of an apparent magnetic field when the material was not magnetized. He theorized that macroscopic regions within the material were composed of sub regions, called domains, wherein all atomic magnetic moments are parallel, and that domains arranged themselves randomly when no external (or internal) magneto-motive force was present. This is analogous to world wide power struggles, and maybe even Pierre saw it this way.

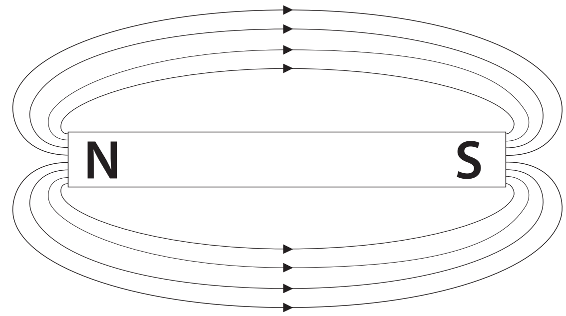
Natural State



After being Magnetized



Magnetic Domains



Magnetic domains function in the same way. All magnetic materials initially have many small randomly aligned domains. Rare earth materials have strong local forces but, unless influenced by some outside force, they live happily with neighbors in a state of equilibrium. Externally, the material appears to have no preferred alignment and it does not influence other objects. When a strong outside force appears, in the guise of a magnetizing pulse, then the magnetic domains all line up with the force and add to it, and the strong domains grow in size.

When the strong external force goes away the domains would relax and go random again unless a strong internal force (coercivity of the material) takes control while the strong external force is present. Internal mechanisms that develop coercivity are "anisotropy". The four types of anisotropy are: (a) crystal, (b) stress, (3) shape, and (d) exchange. To learn more about them please refer to a technical text.

If the material has a high flux density and a strong internal force it can influence other domains. However, domains on the periphery of the magnet volume have fewer neighboring domains for support so they can be turned around and oppose the aligned domains if encouraged to do so by an external force, or random energy additions. The magnet's "king" is a magnetizing, or demagnetizing, force; flux density is the magnet's army; and "coercivity" is the ruler that keep domains aligned when the king goes away. A magnet's useful strength depends on how many domains remain aligned after the external force goes away and they have to face opposing kings and armies on their own. A short magnetic length is like an army with a wide advancing front; it is susceptible to the opposing force everywhere, but mostly at the edges. When the edges are neutralized by opposing external forces the rest of the magnet may be made ineffective. An army column with a good length to width ratio, depending on its internal and external resources, is the most effective and the same is true with magnets. External resources for a magnet would be other magnetic circuit components.

Other factors are also involved. When an external magnetizing force is applied it "moves domain walls" to make the stronger domains larger. It takes just as much energy to move these domain walls back to where they were, so a magnet that is hard to magnetize usually is hard to demagnetize. However, magnets do not like heat; thermal energy reduces pole strength (flux density) and the ability of domains to remain aligned, depending on the temperature reached and intrinsic strength.

Heat first weakens the "magnetic army"; this is a flux density loss that is recovered when things cool off. Next, the outer and weaker domains reverse and these losses are recoverable only by "the king." The process slows as heat travels into the magnet and encounters stronger internal domains. If a magnet gets too hot its chemistry actually changes, and it can be permanently damaged. Heating in air initially results in oxidation; higher temperatures may result in phase changes. The temperature at which chemistry changes may begin to occur in magnet materials is identified as the maximum operating temperature; this is usually much lower than the "Curie temperature". (Curie temperature is the temperature at which an element or alloy becomes totally non magnetic.) Ceramic magnets (strontium or barium ferrite) are the exception; they are made from oxides that do not change composition even after their magnetic temperature limit is reached.

Magnets can be "thermally demagnetized" at moderate temperatures (less than Curie) to allow further processing after testing but, while little or no external field is exhibited, they are far from their virgin state. So long as they have not seen a chemistry change, these magnets will recover fully when re-magnetized. Heat treating in the magnet manufacturing process uses precise heat and cool rates to precipitate the desired phase, a protective gas atmosphere to avoid oxidation, and usually an orienting magnetic field. Magnet material producers use combinations of atomic elements in their magnets to make domain walls harder to move and more resistant to heat. However, these elements take up a portion of the magnet's volume so they produce less total flux (fewer soldiers). "Domain wall pinning" is another factor in making domain walls harder to move; this is like driving a pile into the ground to keep the domain wall from moving.

Domain theory is useful in understanding how magnets work. It cannot account for all observed magnetic phenomena, but it helps scientists describe the internal cause for observed external field changes. It is interesting to note that it has become possible to see magnetic domains with a variety of high power microscopes. So domain theory, once just a convenient way to explain how magnets work, has a factual basis.

Feedback Devices:

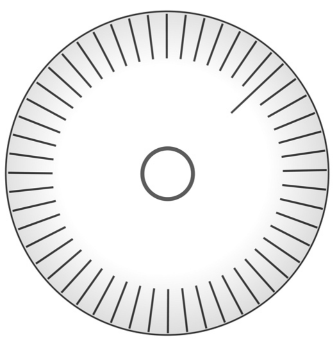
This section covers various means of feedback devices in motion control.

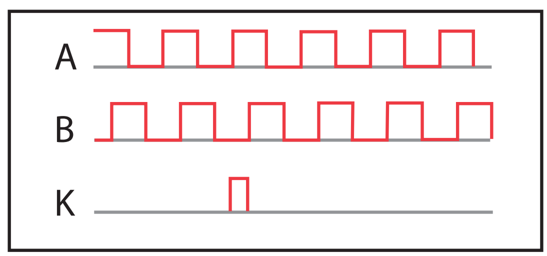
Contents

1: Incremental Encoders

Like any other position feedback device, the incremental encoder is used to determine rotary or linear position. This term ‘incremental’ describes the type of information that the encoder sends out. There are only two options available here, either incremental or absolute.

This encoder provides relative position information. As rotation or linear translation occurs, the incremental encoder sends out one pulse for each set incremental distance of travel. These pulses can be counted to determine the linear or rotary position relative to another position. Motion is quantified by a certain number of pulses. Usually, the incremental encoder will come with three channels, referred to as A,B, and Z. A typical output signal is shown to the below.





A and B are placed 90’ out of phase. With these two channels, the processor determines the distance traveled by the number of steps, and the direction traveled by the leading wave form. The third channel is the reference. Usually the Z channel will have only one pulse per revolution or per length of the encoder, so it can be used to determine an actual location, rather than just an incremental number. These encoders can be either: **magnetic, optical, contacting**, or **capacitive.**

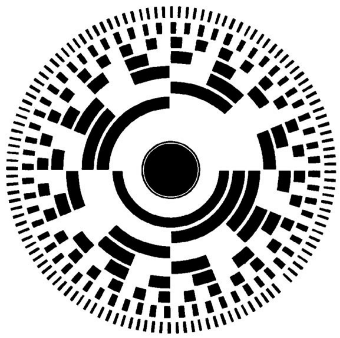
The disadvantage of the incremental encoder is that it is unable to determine its location upon start-up, but this problem can be overcome by taking the time to do a homing or reference pulse sequence, and then moving the desired amount of steps from there. If this is possible, It is recommended.

The added expense and setup time of an absolute encoder should be avoided unless completely necessary.

2: Absolute Encoders

The device is used to determine rotary position. The term absolute defines the type of information that is relayed to the processor. There are only two options available here, either absolute or incremental.

The absolute encoder differs from the incremental encoder in that each angular location is represented by a different digital word. In the case of the incremental encoder, it is only possible to know your location relative to another location. The absolute encoder solves this problem by making each angular position unique. An image of an absolute encoder disk is shown here.



Each separate location can be represented by a binary number, determined by the sequence of light transmission or blockage as you progress inward to the center.

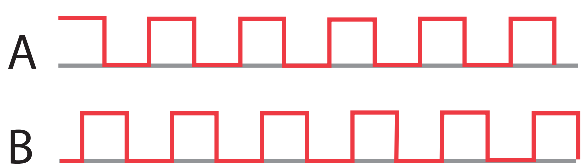
The advantage of the absolute encoder is that the position is not lost in the case of power loss or

noise bursts. The disadvantage is added complexity and price.

3: Linear Encoders

This device is used to convert linear position information into an electrical output signal. The linear encoder consists of a linear tape scale made up of glass or steel, a light source (e.g. LED, laser), and a photoreceptor. The light source, photoreceptor, and additional scale are usually housed together. This housing either surrounds the tape scale in through beam encoders or resides on one side of the tape scale in reflective linear encoders.

Light is projected through or off the tape scale and is detected by the photoreceptor. The fixed scale modulates the light as the receptor and light source progress. The receptor detects these modulations and converts the input into an electrical output usually in the form of a quadrature signal (shown below).



The two channels are always 90' out of phase. The direction of the motion can be determined by the leading channel. The output is the same as that of the incremental rotary encoder.

The linear version is incremental as well, which means that it tells the position of one location relative to that of the other, rather than having a knowledge of its actual location.

A linear encoder is often preferred over a rotary encoder where linear motion is the final output of the system (e.g. conveyors, rodless cylinders). In a linear system you are able to eliminate the inherent backlash and inaccuracies involved with mechanical systems by measuring the linear displacement rather than a rotary displacement.

4: Magnetic Encoders

This device is used to convert position information into an electrical output that can be interpreted by a system controller. The two main components of a magnetic encoder are the read head and the magnetic disc. The read head contains a **magneto resistive** sensor, which is basically an inductor that detects changes in the magnetic flux. The disc is magnetically coded. The magnetic code is interpreted by the sensor as a series of on and off states. One magnetic code is interpreted as a 0 bit value and the next as a 1 bit value. Through this combination the magnetic encoder is able to transmit pulses representing incremental rotary motion.

The magnetic encoder offers good resolution, can operate in a wide variety of conditions, and requires low power for operation; however, they cannot achieve very high speeds.

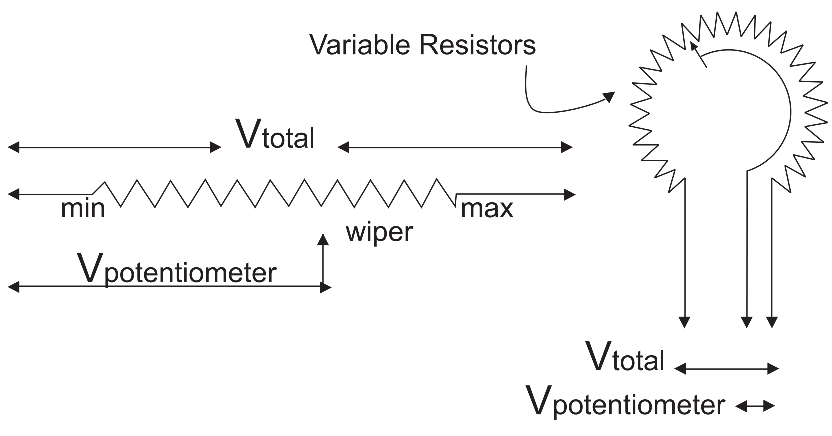
5: Optical Encoders

This feedback device is used to detect rotary or linear position and convert it to an electrical output. A light source, usually either an LED or a laser, is projected through thin slits in a rotary disc for rotary encoders, or a thin tape scale for linear. The LED is adequate for most applications, although the laser has found niches in several high precision, high resolution applications. The disk and tape can either be made of covered glass with thin etchings in the cover, or thin metal with etchings through it. Each has appropriate applications. As light is transmitted, a photo receptor on the opposite side of the disc or tape detects the light and converts it to an electrical output. Different optical encoders can create a wide range of signals, (e.g. TTL, silicon cell, analog, sinusoidal).

Optical encoders offer the higher resolution and accuracy than all other encoders. Some can offer in excess of 1 million counts/revolution. Often times the best way to decide what feedback device you should use for your application is to determine what type of information your controller, PLC, smart drive, or other processor that you are using is capable of processing without too much trouble. Frequently many types of feedback will fit your needs, but only a couple will be simple to integrate. Due of the different signal options and versatility of the optical encoder, this is a very popular position feedback device.

6: Potentiometers

This device provides an output voltage proportional to angular or linear position. The image below shows a schematic of the linear and rotary potentiometer.

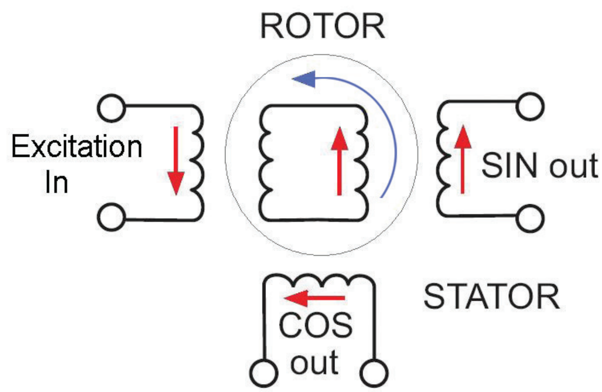


The output voltage in both scenarios varies according to the location of the sliding contact on the resistor. Ideally, distance would be perfectly proportional to the output voltage. Unfortunately, this is not the case due to the non linear characteristics of the resistive element and the additional load of the sliding contact.

A potentiometer is an affordable, adequate position sensor in many applications. However, if you need accurate position monitoring, you should look into a resolver or encoder. Potentiometers are commonly used to transmit a variable analog voltage set by a user. They are commonly found in joysticks, tuning pots, and reference signal controllers

7: Resolvers

This device is an absolute position sensor with an analog output. The resolver is composed of a rotor with one winding and a stator with two windings at right angles to each other. The winding of the rotor is excited with an AC reference voltage. This voltage induces a current in the two windings of the stator



Let's look at the induced voltage of one of the stator windings.

As the rotor spins the voltage that will be induced in the stator will vary. When the windings are parallel to each other, the voltage will be at a maximum. When they are perpendicular to each other, it will be at a minimum. Thus the induced voltage of one stator winding is dependent on the rotor position and governed by this equation V=Vinput SinØ.

Because the second rotor winding is at a right angle to the first, its voltage signal can be calculated using the cosine. In the valley and peak of the sine wave there is only a slight slope, so position variations are difficult to pick up. This is the reason the second winding is needed: to provide clearer positions signals at these points.

The analog signal needs to be translated to a digital signal for the system drive and/or controller to process it. A resolver to digital converter can be used to accomplish this.

Resolvers are very durable. They can be used to provide a speed reference signal to close a velocity loop and a position signal to close the position loop. In this respect **they eliminate the need for a tachometer.** Further the resolver is a device with **very high precision and resolution.**

8: Tachometers

Often referred to as a tach or tacho-generator. The tachometer operates under the same principles as a generator; in fact it is a generator. The basic design of tachometer is very similar to that of a small DC motor. The tachometer is either mounted externally to the motor or is combined internally.

When the tachometer is driven by the motor, it generates an output voltage. The output voltage produced is proportional to the velocity of the motor. The proportionality of this relationship is critical to the accuracy of the device. Designers of tachometers need to focus their attention on ensuring that the output voltage is smooth over a wide range of speeds and that it is stable over temperature variations. These characteristics determine the quality of the product.

A tachometer is the most common way of measuring velocity. The velocity signal can be fed to a rate indicator to display the velocity to the operator, or it can be used to close a velocity loop. A large variety of amplifiers give the option of operating in velocity mode with the use of a tachometer. Tachometers are also a critical component in many servo systems. When using a tachometer with a brushless system, it is wise to use a brushless tachometer so as not to limit the life of the entire system.

Ball Screws, ACME Screws, Rack & Pinion, and Belt Drives, Which way do we go?

It is common to have a new task at hand of moving loads but not knowing or better yet, not realizing the proper mechanics to use .

“Which way do we go” would be better served by asking “what way do we need to go?”.

These are the questions to ask:

1. Is the load a Heavy load or a Light load?
2. Does it need to be moved fast or slow?
3. Is this a high-resolution move to a precise position?
4. Is it a very short incremental move or over a long distance?
5. Is this a vertical or horizontal application?
6. All of these questions usually come in to play even if the answers are realized without thinking about it.

No one question can be seen as over riding any of the others.

Vertical loads burden motors with continuous heat generation. It is better to have the motor sized adequately to insure a good safety margin.

The use of Pneumatic or Electro-mechanical brakes should be used to ensure fail-safe operation on loss of power. Remember that electrical safety brakes add additional heat to the system.

When it comes to high resolution and high speed, they are typically mutually exclusive. It is difficult to get both high resolution and high speed. This can be compared to transmissions in automobiles. A car can go very fast in 3rd or 4th gear but it cannot move very slowly in those gears. In the same manner, it is easy to move incrementally forward in 1st gear.

- Additional gear reduction adds higher resolution
- Less gear reduction gives higher speed.

The same rules apply to ball screws as well.

A 1mm/revolution screw will have higher resolution where a 20mm/revolution crew will have high speed.

Rules to follow for ball and ACME screws:

- Fine lead screw:
  - heavy loads,
  - holding vertical loads
  - high resolution.
- Coarse Lead screw:
  - fast speeds
  - low resolution
  - not as safe for holding vertical loads.

Actuator Type	Efficiency	Thrust Load	Back-Drive	Accuracy	Speed
ACME Screws	low	highest	difficult	good	medium
Ball Screws	high	high	easy	best	fast
Belt drives	medium	low	easy	ok	very fast
Rack & Pinion	medium	low	easy	bad	very fast

Note: ACME screws have the highest static thrust load capability
Ball screws have the highest driving thrust load capability.

This is due to the nature of the threads of ACME screws. They have more support for static load than do ball screw nuts. Ball screws have re-circulating bearing that allow for lower friction and greater running thrust load capability.

Notes on Drive Types:

Belt Drives are typically available with speed ratings to 8 meters/second.

This is not achievable with Ball or ACME screws.

Lead screws of any type have a critical limit speed. This is the speed in RPM that, if exceeded, will result in excessive vibration or damage.

Within a given length, most speed limitations are due to re-circulating ball paths.

Inside of both ball nuts and re-circulating bearing blocks, the small ball bearings have to be re-directed from the exit path back to the other end. The radius of this return path on each end is the limiting factor. Larger re-circulating blocks have a higher speed rating because the radius of the return path is larger and provides less frictional losses. As a result,, compact bearings cannot run as fast.

Gear Reduction: What does it do for you?

Often times, advantages of gear reduction are overlooked or forgotten entirely.

Higher gear reduction provides the following:

1. Increased torque
2. Higher resolution (more encoder counts per revolution at the motor)
3. Lower speed
4. Higher acceleration capability and therefore better moment-of-inertia matching
5. Faster braking or stopping

Overview of Gear Reduction Types

Actuator Type	Efficiency	Backlash	Typical Reductions Available	Speed
Worm	low	medium	3 to 1000	medium
Spur	medium	high	3 to 100	fast
Planetary	high	low	3 to >100	very fast
Cyclical	medium	very low	10 to 200	very fast
Harmonic	medium	extremely low	30 to >500	fast
Toothed Belt	high	medium	>1 to 5	very fast

Notes on Gear Reduction

Most Servomotors use planetary gear heads where as most steppers use Spur gear heads.

Worm gear reduction is typically found on large AC Induction motors or conveyor drives.

Worm gear reduction has the advantage of not being able to be back driven This is good in cases where maintaining load on loss-of power is concerned.

Cycloidal and Harmonic Drive gear reduction is used where extremely high repeatability is needed. They are considered “zero-backlash”. Their limitations are in that they are not available in low gear ratios.

Gear Ratio Selection

When using Brushless servos proper gear ratio selection is very important.

An easy way to size ratios is to start with a few basic rules:

Most Planetary gear heads are limited to approximately 5000 RPM input speed. Giving a margin for error, and lower heat generation, it is bet to limit them to 4000 RPM.

Integrated motor drive servos typically have a torque curve roll-off at approximately 3000 RPM.

After finding out what speed is required for an application, divide that speed into 3000 and the result is the gear ratio needed.

Example:

Suppose A maximum output shaft speed of 240 RPM is required. This is needed at 11 Nm.

3000/240=12.5. Typical gear reductions are 10:1 and 16:1

the 10:1 ratio will provide higher speeds but less torque.

The 16:1 will provide higher torque but less speed.

Since the ratio was calculated off of 3000 RPM and most planetary gears can handle 4000 to 500 RPM, the 16:1 ratio may be a good choice.

240*16=3840RPM

11Nm/16=0.69Nm required at the motor shaft.

These are estimates and do not account for efficiency losses. You should consult the gear box manufacturer for more information.

If the application has fast start and stop moves, it is better to maximize gear ratio to gain the most acceleration and deceleration control. Higher gear ratios always provide better start and stop motion than do lower gear ratios.

Timing Belt or Toothed Belt Reduction:

This method of gear reduction is often under-rated and overlooked. It is the cheapest means to gain more torque. It is also the absolute fasted input speed of any means of gear reduction. Timing belts can be moved at many thousands of RPM.

When ball screws are needed for high thrust loads, where as belt drives may not work, it may be advantageous to use belt reduction into the ball screws. This keeps the ball screw below critical speed while providing optimum torque curve performance of Brushless servos. Most Brushless servos work optimally above 2500 RPMs, bur most ball screws cannot be run that high. By making use of belt reduction, the best of both worlds are achieved. This method also allows the motor to be folded back under the ball screw making the mechanism shorter.

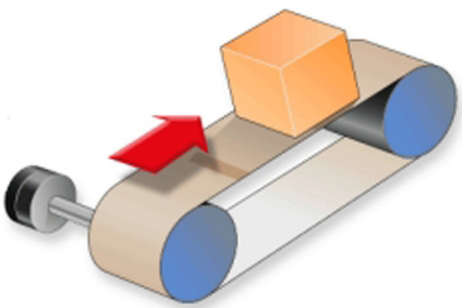
To dynamically brake or not to dynamically brake?

When thinking of braking or brakes, usually mechanical brakes come to mind. There is a different mean to slow down or even stop fast moving loads. Many conventional servo drives come with “regen resistor” options. This is a means to dump generated power in motors back to a resistor bank. In most cases, the reason for doing this is to protect the DC bus from over voltage. integrated motors do not have the luxury of space to fit a regeneration resistor in the controller case. This is where external voltage shunts are needed to dynamically brake motors. When motors slow down rapidly, the load will tend to back drive the motor truing it into a generator. The bus voltage then begins to rise which could lead to electrical damage.

Dynamic shunts provide a means to both protect the DC bus from over voltage as well as a means to dissipation power enabling faster stops. In the extreme case internal motor shunting electronically can stop the generation at it’s source. This is the equivalent of shorting out the motor windings.

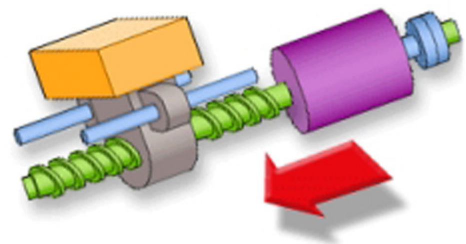
Considerations when employing various drive systems

Belt Drive or Conveyor



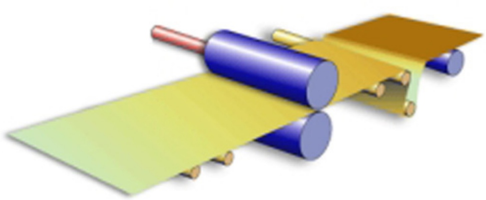
Consider Product Slippage

Lead Screw



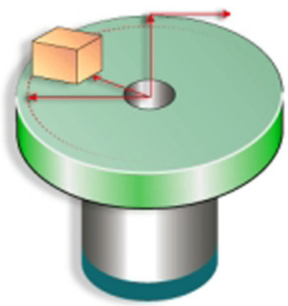
May require Linearity Mapping

NIP Roller



Material may creep or slip over time

Rotary Indexing



Be aware of Odd Gear Ratios

Rack and Pinion

Be aware of easy back-drive

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Consideraitons for Actuator Loading

Forces acting upon actuators consist of a combination of direct forces pushing in from any axis and a twisting force that may be applied due to offset loads.

Direct Forces placed on the Actuator

F.t. : Thrust Force operating in the direction of travel.

Mechanically Limiting Factor: For Lead Screw Actuators, this is typically the thrust bearings and/or lead nut.

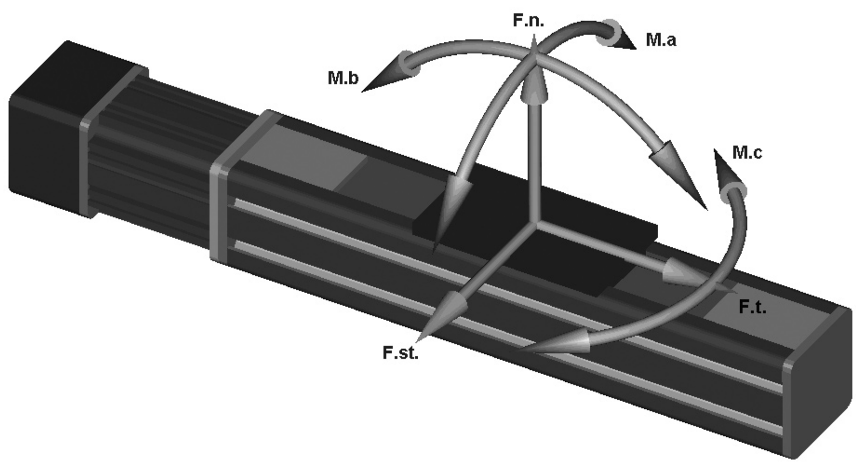
For Harmonic Belt drives, the limiting factor is typically the belt. It may be based on shear strength of the belt teeth or on the actual tensile strength of the belt itself. In a welded belt, it would most likely be based on the weld strength of that belt.

F.st. : Side Thrust Force, acts upon the carriage from one side or the other.

The bearing support is typically the limiting factor. The choice of bearings and their orientation will greatly affect the maximum permissible force.

F.n. : Normal Force downward.

Similar to side force, the limit is based on the bearings and their orientation. It is very common to have a much higher normal downward force capacity than a side force capacity. Since Gravity typically plays a roll in Horizontal applications, most actuators are designed to deal with downward force effectively.



Moment Loading Forces:

This is the twisting force similar to a Moment arm force applying a torque to the supporting bearings.

To insure long life of the actuator it is imperative to not exceed the Moment loading specifications.

In the above diagram, three Moment loads are depicted.

All three Moment loading forces may exist on a given application. It is important to remember that any offset load from the center surface of the actuator carriage will induce one or more of these Moment forces.

While accelerating, that Moment load may increase drastically.

For Example: Suppose in the above diagram, you place a load offset from the center of the carriage in upward direction. Any time the load is accelerated, the M.b. Moment loading will increase.

If the load is placed horizontally offset to one side or the other, dynamic motion will increase the M.c. component of Moment loading of that actuator.

The M.a. component is the only Moment loading that will not typically change with the dynamics of load motion. However, offset side loading is the greatest contributor to the M.a. component.

Understanding Thrust Curves

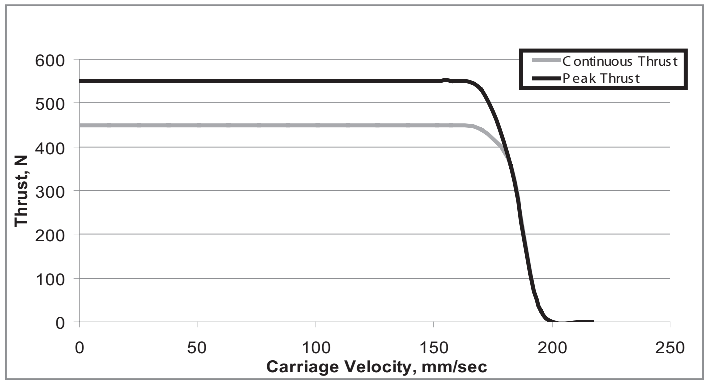
Actuator Thrust Curves are very similar to Servo Torque Curves, but relate to linear motion performance instead of shaft rotation performance. All thrust curves show continuous and peak performance based on the coupled system of Servo and Actuator together. The following examples show the 2 exceptions to the previous statement, where the actuators limitations are taken into account.

Note: The continuous thrust region is where the system should be operated, except for short hard accelerations required in your motion profile. Sustained Operation outside the continuous region will reduce the rated life on the actuator/integrated motor system. Please check the specifications of each actuator for limiting factors such as mechanical critical speed and thrust limits.

Limitation on Thrust Output Example

The curve to the right shows that there is a maximum amount of thrust the actuator can put out continuously and peak. That is why the curve abruptly flattens out (horizontal line) at speeds less than 150 mm/sec. This curve shows that the motor can provide more input torque than the actuator can handle at speeds less than 150 mm/sec.

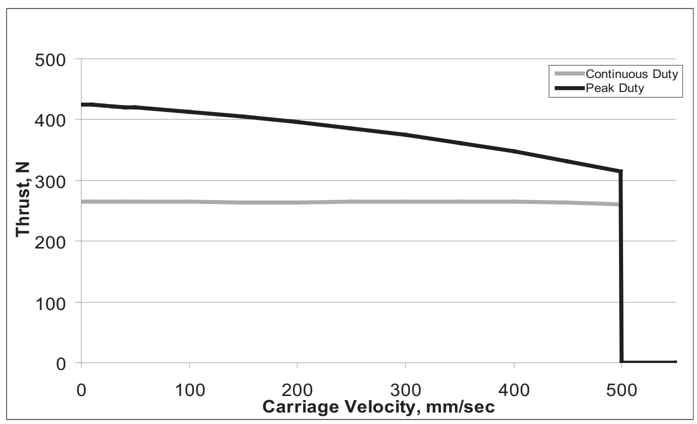
Note: In this example, the maximum allowable thrust is limited to 550 N. Exceeding that could potentially damage the actuator even if the motor limits are not exceeded.



Limitation of Actuator's Speed Example

The curve to the right shows that at 500 mm/sec, the thrust abruptly goes to zero (the vertical line). This means that the actuator has a maximum carriage velocity of 500 mm/sec usually due to ball screw limitations.

Note: This speed limitation is mechanically based. It may be possible to command a servo speed in excess of the Critical speed limits of the actuator. Doing so increases risk of damage and will shorten the life of the actuator.



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Each Set of Torque curves depicts limits of both Continuous and Peak torque for the given SmartMotor™ over their full range speed.

Peak Torque Curve:

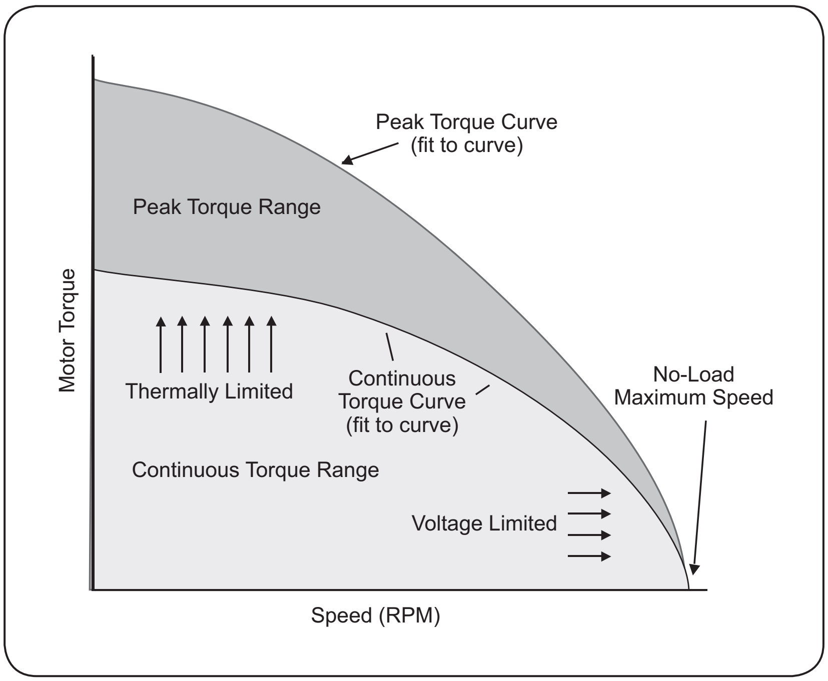
The Peak Torque Curve is derived from dyno testing and is the point at which peak current limit hardware settings of the drive prevent further torque in an effort to protect drive stage components.

Continuous Torque Curve:

The continuous Torque Curve is also derived from dyno testing, but is instead the point at which the temperature rises from an ambient of 25º C to the designed thermal limit.

For example: The motor will be placed on the dyno tester and set to operate at 1000 RPM continuously with the load slowly increased until the controller reaches its maximum sustained thermal limit. This limit is either 70º C or 85º C depending on the model number.

The far lower right side of the curve is limited by supply voltage. This is the point at which Back EMF suppresses any further speed increase. Higher supply voltages will shift the zero torque point of the curves further to the right.



Ambient Temperature Effects on Torque Curves and Motor Response:

If the motor is operated in an environment greater than 27º C, then it will reach its thermal limit faster for the same given load thereby further limiting continuous torque.

Therefore any given motor torque curve MUST BE linearly de-rated for a given ambient temperature from 27º C to 70º C (optional 85º C).

Supply Voltage Effects on Torque Curves and Motor Response:

Higher voltages have two-fold effects on torque curves. As mentioned above, raising voltage will shift the curve to the right. It will also allow higher current into the drive. However, Torque curves depict Torque at a given velocity.

If you double supply voltage, the motor can sustain twice the original velocity. But since acceleration is the differential of velocity, it can achieve 4 times the original acceleration. This is useful for high speed indexing and fast start/stop motion.

Considerations when using torque curves for motor sizing:

For any given product model number, there may be variations of as much as +/-10%.

The following diagram depicts data points collected from dyno testing of a given model motor. A best-fit torque curve is created from these data points and is then de-rated to at least 5% below the worst case data points. The de-rated curve is what is advertized. This means that within any given model number, EVERY motor sold will perform at or better than the advertized torque. Theoretically, ALL motors should be no less than 5% better than advertized and may be better than 20% higher.

The diagram shows motor loading in 4 areas.

Point 1. This is ideal and depicts a load within the normal operating range of the motor. The motor should operate well and have no problems for many years.

Point 2. The load is very close to the operating limit. The motor will run quite warm as compared to Point 1.

Point 3. The load exceeds the advertized operating limit of the motor. However, due to data scatter and de-rating, there may be some motors that will work and others that do not.

Why? Because it is in the area of +/-10% variation expected in motors for a given size. This can become a major problem. Imagine designing a machine that operates in this range. Then you replicate that machine with many of them running on a production floor.

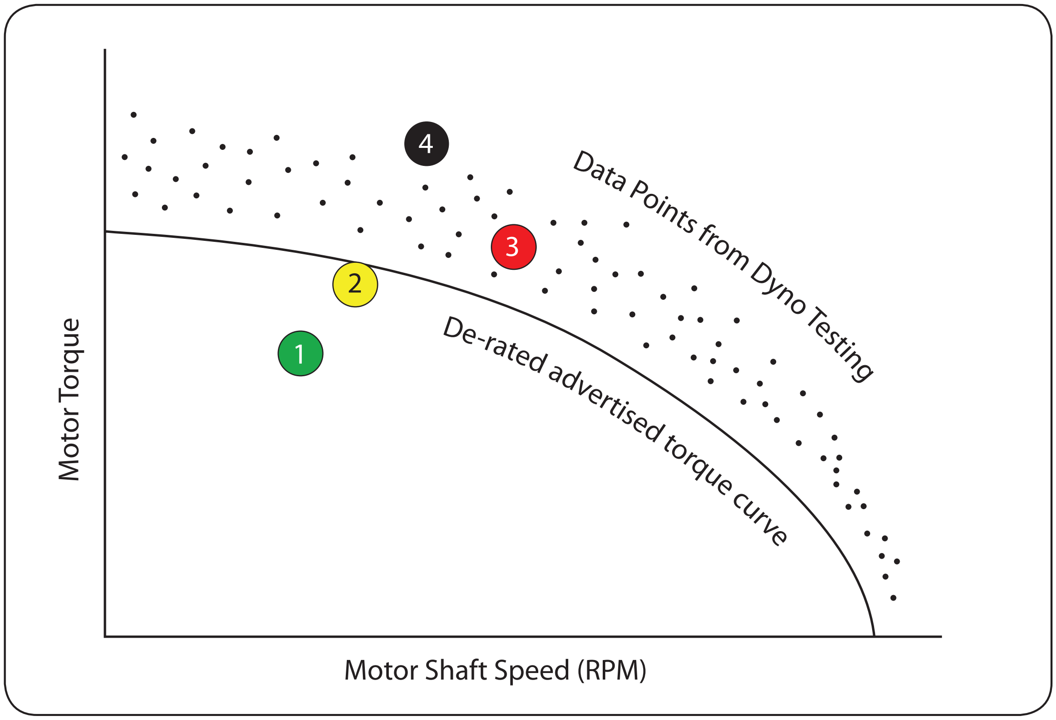
One day, a motor at the lower end of the +/-10% expected variation would be placed on a new machine and that motor would get spurious drive faults.

It would appear as though the motor is malfunctioning because…. "all the other motors work just fine".

This is unfortunate because in reality, all motors were undersized and operating outside of their advertized limits.

This is why it is important to properly calculate load torque to insure the correct motor is designed into the application. Never assume that without proper load calculation and motor sizing, testing of one motor means all of that size may work. This is simply not the case. Try to keep operating conditions below the advertized limits to insure reliable long-life operation.

Point 4. The load exceeds the advertized level and exceeds +10% expected range of possible torque capabilities. In this case, the motor will most likely either overheat quickly and fault out or immediately get a position error because it simply does not have enough power to support the load demand.



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Moment Of Inertia:

A basic understanding of Moment of Inertia serves well in insuring proper motor sizing. It is one thing to look at static points on torque curves, but it is altogether different when considering the dynamic aspects of loads being accelerated at high rates.

The Inertial mass of an object is a measure of its resistance to a change in its velocity.

The Moment of Inertia of an object is at a point of reference of rotation, which is at the pivot point or axis of rotation.

The Moment of Inertia can therefore be thought of as a measure of the resistance to any change in rotational speed.

For linear systems, the rate of change of speed, (acceleration) is proportional to the force applied. Double the mass and the force needs to be doubled for the same acceleration. Similarly for rotational systems, the angular acceleration of the load is proportional to the torque applied. Double the Moment of Inertia and the torque needs to be doubled for the same angular acceleration. Moment of Inertia is therefore a measure of a load's resistance to angular speed change; of how much effort (torque) is required to cause acceleration or deceleration.

Matching Motor To Load:

A common rule of thumb for SmartMotor™ sizing is that the load should have no more than 10 times the Moment of Inertia of the motor rotor that is driving it. This gives a good starting point and typically allows for safe sizing over a wide range of applications.

Since a rotating load wants to maintain the same velocity, then when a motor attempts to accelerated or decelerate the load, it must overcome the Moment of Inertia of that load by applying enough torque to accelerate it or decelerate it.

It takes more torque to change speed than it does to maintain a given speed.

In the same manner, for the motor to slow down a load, the load's Moment of Inertia will keep the motor going the same speed and will in effect, back drive the motor turning it into a generator.

In extreme cases, this can result in over voltage damage to the Drive stage.

How to improve Moment of Inertia Ratio Between Motor and Load :

Adding gear reduction to a motor gives it more leverage to prevent back driving and also gives it a better advantage in accelerating a load up to speed.

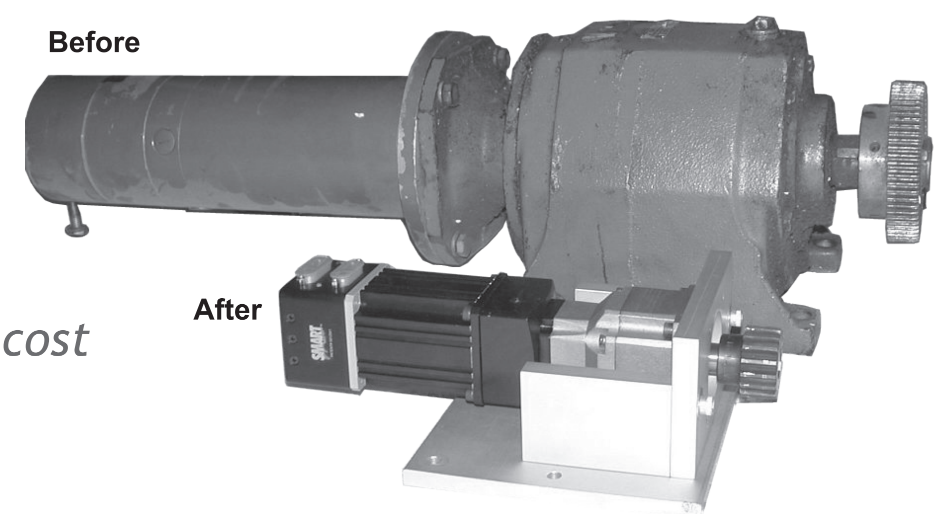
For any given change in gear reduction, you get a proportional change in speed and static torque but you get a squared change in acceleration and dynamic rate of change of torque. The result is that by adding gear ratio you gain a squared decrease in the ratio of Moment of Inertia between motor and load.

Therefore the motor has a greater advantage in both accelerating and deceleration the load. It adds protection against damage to the system as a whole.

Lower System Cost

To give an idea of how much effect you get from additional gear reduction, take a look at the example below. This is an actual photo of the before-and-after drive system of a given application. The larger motor with low gear reduction and larger pulley was replaced by the smaller Animatics SmartMotor™ with much higher gear reduction and smaller pulley. The result was a smoother operating machine with higher resolution and better acceleration.

Optimize gear reduction to improve load dynamics and motor efficiency & reduce system cost



Mode Torque Brake (MTB)

Intended as a means to quickly stop shaft motion in the event of drive fault or drive disable.

- Dynamically shunts windings for quick stops
- 60% peak overload stopping power
  - In other words, the motor has 60% more stopping power than its peak advertised torque at stall when MTB is activated
- Automatically engaged under any shaft protection fault :
  - Position Error (Following Error)
  - Travel Limit Error
  - Over Temperature
  - RMS Over current

By connecting the travel limits to the E-stop circuitry, the motor can be quickly driven to a stop without the need of complete power removal. MTB only requires control power, not drive power.

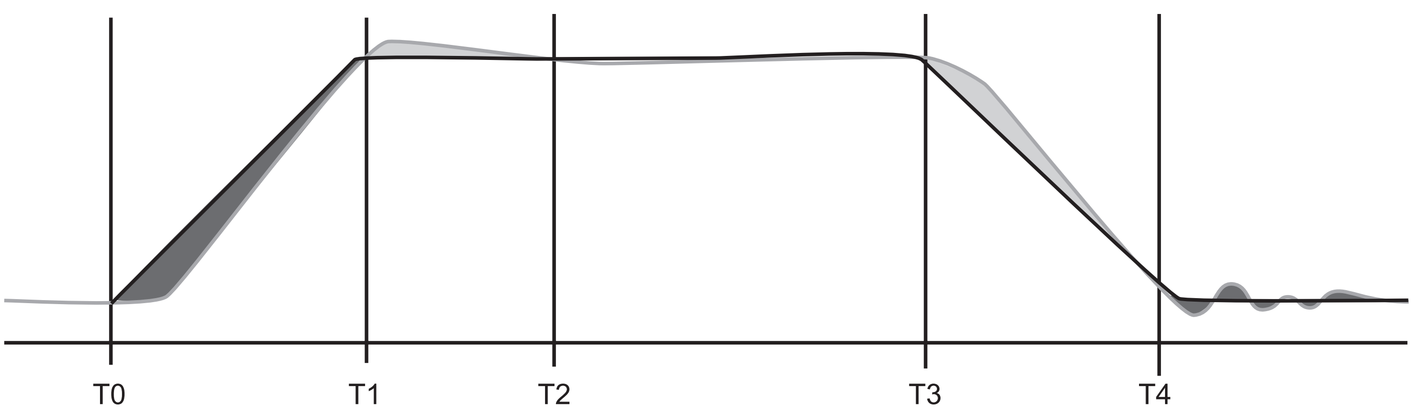
Note: MTB can produce Peak torques as much as 60% beyond advertised stall torque of any given applicable Animatics SmartMotor™.
It is imperative that any gear head or other shaft loads be capable of handling such a peak torque.

Trajectory Overshoot Braking (TOB)

NOTE: Must specify -PS2 firmware

Allows for smooth controlled deceleration and stabilization of high moment-of-inertia mismatch loads.

- PWM controlled Dynamic braking
  - >30% better slowing power to prevent overshoots in speed or deceleration during the entire trajectory path
  - Provides protection against exceeding critical speed limits of lead screws



(Light Grey Areas above Indicate where TOB takes Effect)

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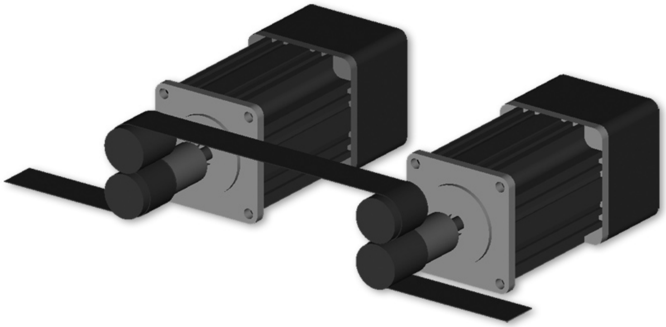
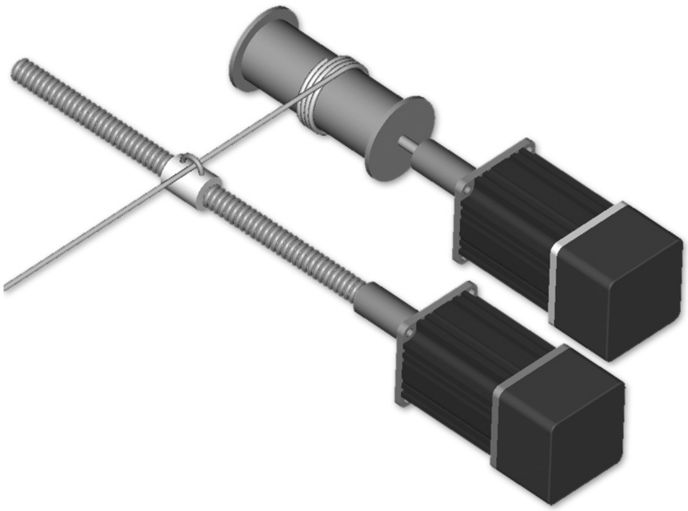


Process Tension Control

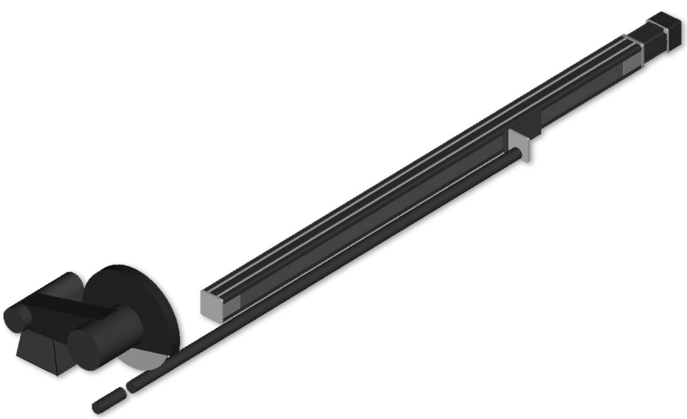
By the use of Phase Offset moves while Electronically gearing Master to Slave, the controllers allow for easy tension control between two sets of nip rollers. Tension can be regulated by pre-test measurement or live analog, serial or digital feedback providing proper control of tension through varying speeds and up or downstream loads.



High Speed Traverse & Take-up Spool Winders

Use of Programmable Software Travel Limits, Electronic Gearing, and Special Firmware drive control, Winders can be set up to wind unlimited variations in spool width, wind angle and end-point dwell as well as step wind, stack wind and tapered wind.

With low inertia motors and high speed acceleration, very precise winding can be achieved in such applications as edge-wound voice coils, guitar strings, catheters and standard textile spool winding.



Programmable Cut To Length Saw Stop or Back Stop Gage

With the ability to program up to 1000 subroutines and 32K of extra data storage, the system can be programmed for hundreds of back stop positions and sequences.

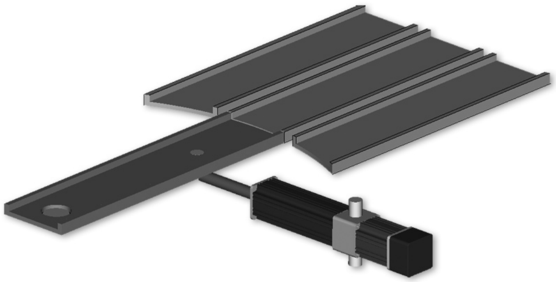
No external PLC or PC would be required. A simple HMI can be utilized for interfacing

Parallel Axis Gantry

In wide gantry applications, the base axis can be moved with two motors, one Master, one Slave. Additionally, the master axis can follow product flow under the gantry for operations such as flying shears, material cutoff, cross-cut saws, etc.

Proper fault handling will prevent racking of the gantry in the event that either the Master or Slave faults out during a move. Homing is done only once at power-up. The Master and Slave sync up maintaining perfect alignment.

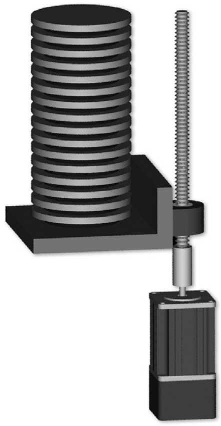
Concepts and Capabilities of the Animatics Product Range:



3-Position Parts Diverter

Simple servo upgrade from existing pneumatic systems, the Animatics SmartMotor™ can be placed into any system to replace 2 or 3 position air cylinders to allow for multi point programmable positioning while maintaining simple I/O trigger control from any PLC.

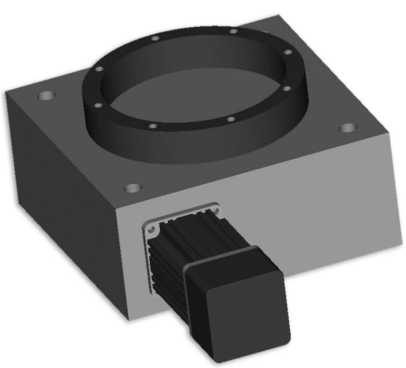
The SmartMotor is placed into Position Mode and programmed to move to a given set point upon I/O input trigger from the PLC.



Input / Output Stacker

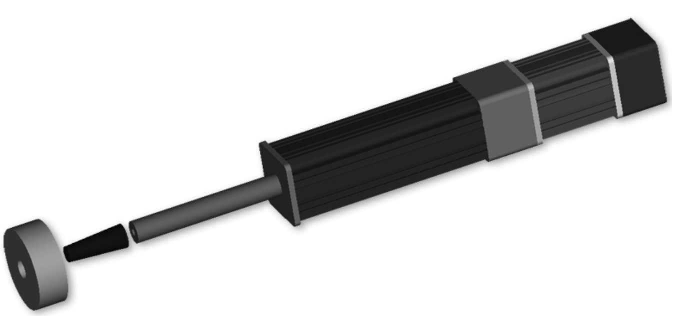
Utilizing Subroutines and variable counter, both Absolute and Relative Position Mode moves allow for start of stack and incremental stack shifts while maintaining parts counts. Having localized I/O within the Integrated Controls, the entire handling of parts can be dealt with by the stacker motor itself.

True Distributed control at a fraction of the cost and footprint.



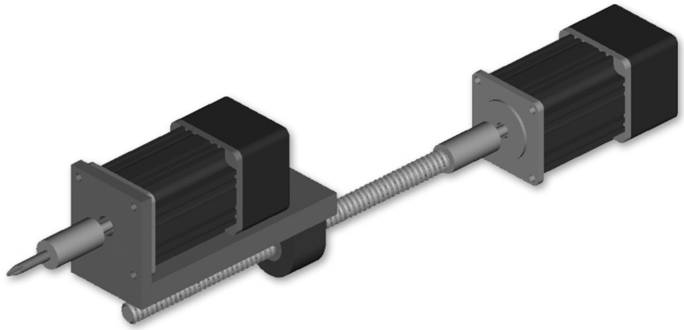
Programmable Rotary Index Table

Typical Mechanical CAM based rotary Index Tables are fixed index and dwell devices. The Index distance cannot be changed and dwell is fixed as a function of assumed constant input RPM. By adding an Animatics Integrated SmartMotor™ to any servo rated Worm Gear box or flange output gear reducer, the system becomes a fully programmable rotary index table and can be programmed to any practical number of indexes and dwell times. Given the I/O and control capabilities, the dwells can be based on end-of-process contrary to fixed mechanical CAM thereby speeding up over all production cycle times.



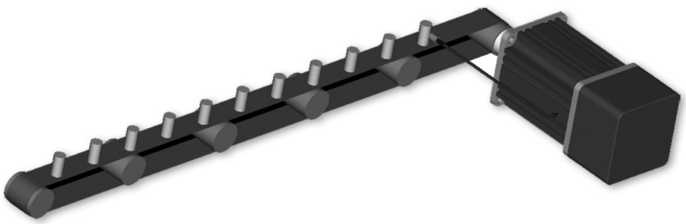
Programmable Force Press-To-Fit

Animatics' integrated approach to drives and controls allows for closely regulated positioning and position error control. This results in the ability for highly repeatable torque limited machine cycles. The result is a very good solution for pressing parts together or any other force limited application where both cycle time and proper force must be tightly regulated.



Drill & Tap/Nut Runner

Set rotating Motor as master and have the linear axis electronically gear off of it to provide high speed drill and taps and screw feed control with limited torque. Adding proper torque detection, the unit can detect when a drill or tap has worn or become dull. As a nut/screw runner, it can pick up on cross thread, broken or stripped thread, missing part or jammed part.

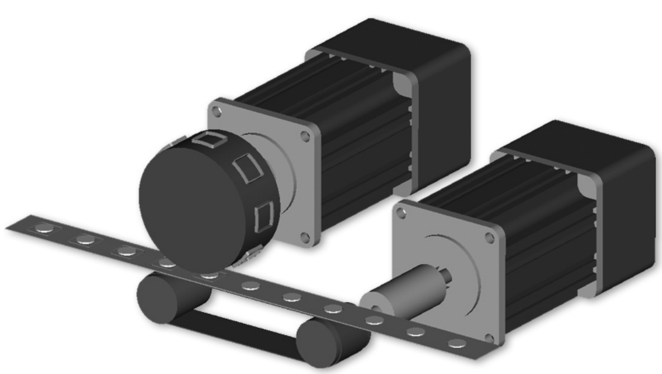


High Speed Parts Counter and Verification

The External Encoder Input can be used to read Quadrature Incremental Encoders, Step and Direction Input or just as a counter where input pulses can be counted at a rate up to 2 Megahertz. As a result, the motor can both feed parts and verify part count even at high rates of speeds and short distance between parts.

Multi-Axis Pick & Place

Up to 100 individually addressed motors can be placed on a communications bus allowing for easy synchronisation of multiple axis applications such as Pick & Place machines, Palletizers, Cross axis cutters, sorters, etc.



Print and Die Cut alignment on-the-fly

When using Electronic Gearing, phase offset adjustment moves can be achieved to properly align die cut processes with printed registration marks. This same technique can be used to insure over mold and multi-layer print alignment and even pocketed blister pack parts placement.

Acceleration
A change in velocity as a function of time. Acceleration usually refers to increasing velocity, and deceleration to decreasing velocity.

Accuracy
A measure of the difference between expected position and actual position of a motor or mechanical system. Motor accuracy is usually specified as an angle representing the maximum deviation from expected position.

Ambient temperature
The temperature of the cooling medium, usually air, immediately surrounding the motor or another device.

Angular accuracy
The measure of shaft positioning accuracy on a servo or stepping motor.

Back EMF
The voltage generated when a permanent magnet motor is rotated. This voltage is proportional to motor speed and is present regardless of whether the motor winding(s) are energized or de-energized.

Bipolar chopper driver
A class of step motor driver which uses a switch mode (chopper) technique to control motor current and polarity. Bipolar indicates the capability of providing motor phase current of either polarity (+ or -).

Breakaway torque
The torque required to start a machine in motion. Almost always greater than the running torque.

Brushless motor
Class of motors that operate using electronic commutation of phase currents, rather than electromechanical (brush-type) commutation. Brushless motors typically have a permanent magnet rotor and a wound stator.

C-face mounting
A standard NEMA mounting design, where the mounting holes in the face are threaded to receive the mating mount.

Class B insulation
A NEMA insulation specification. Class B insulation is rated to an operating (internal) temperature of 130°C.

Class F insulation
A NEMA insulation specification. Class F insulation is rated to an operating (internal) temperature of 155°C

Class H insulation
A NEMA insulation specification. Class H insulation is rated to an operating (internal) temperature of 180°C.

Closed loop
A broadly applied term, relating to any system in which the output is measured and compared to the input. The output is then adjusted to reach the desired condition. In motion control, the term typically describes a system utilizing a velocity and/or position transducer to generate correction signals in relation to desired parameters.

Cogging (Cogging torque)
A term used to describe non-uniform angular velocity. Cogging appears as a jerkiness, especially at low speeds.

Commutation

1. A term which refers to the action of steering currents or voltages to the proper motor phases so as to produce optimum motor torque. In brush type motors, commutation is done electromechanically via the brushes and commutator. In brushless motors, commutation is done by the switching electronics using rotor position information obtained by Hall sensors, a Tachsyn, or a resolver.
2. Commutation of step motors is normally done open loop. Feedback from the motor is not required to hold rotor position precisely.

Continuous rated current (ICR) (Amperes)
The maximum allowable continuous current a motor can handle without exceeding the motor temperature limits

Continuous rated torque (TCR) (lb-in.)
The maximum allowable continuous torque a motor can handle without exceeding the motor temperature limits

Continuous stall current (ICS) (Amperes)
Amount of current applied to a motor (at locked rotor conditions), which results in rated temperature rise. Refer also to definition of "Continuous stall torque"

Continuous stall torque (TCS) (lb-in.)
The amount of torque at zero speed, which a motor can continuously deliver without exceeding its thermal rating. Determined by applying DC current through two windings with rotor locked, while monitoring temperature. Specified with motor windings at maximum rated temperature, with motor in 25 degrees C ambient, mounted to a heat sink. Refer to individual specs for heat sink size.

Controller
A term describing a functional block containing an amplifier, power supplies, and possibly position-control electronics for operating a servomotor or step motor.

Current at peak torque (IPK) (Amperes)
The amount of input current required to develop "peak torque". This is often outside the linear torque/current relationship.

Current, Rated
The maximum allowable continuous current a motor can handle without exceeding motor temperature limits.

D-flange mounting
This type of mount has clearance holes on the flange, and the mounting bolts stick out through the flange from the motor side. This mount is common in cases where the motor is integral to the machine.

Demag current

The current level at which the motor magnets will start to be demagnetized. This is an irreversible effect, which will alter the motor characteristics and degrade performance. Also known as peak current.

Detent torque
The maximum torque that can be applied to an unenergized step motor without causing continuous rotating motion.

DPBV – Drip-proof Blower Ventilated
Type of motor cooled by blowing air through the inside of the motor using an attached blower.

Drive
An electronic device that controls torque, speed and/or position of an AC or brushless motor. Typically a feedback device is mounted on the motor for closed-loop control of current, velocity and position.

Driver
Electronics which convert step and direction inputs to high power currents and voltages to drive a step motor. The step motor driver is analogous to the servomotor amplifier's logic.

Duty cycle

For a repetitive cycle, the ratio of on time to total cycle time.
Duty cycle (%) = [On time / (On time + Off time)] x 100%

Dynamic braking
A passive technique for stopping a permanent magnet brush or brushless motor. The motor windings are shorted together through a resistor which results in motor braking with an exponential decrease in speed.

Efficiency
The ratio of power output to power input.

Electrical time constant (te) (Seconds)
The time required for current to reach 63.2% of its final value for a fixed voltage level. Can be calculated from the relationship te=L/R where L is inductance (henries) and R is resistance (ohms).

Encoder
A feedback device which converts mechanical motion into electronic signals. The most commonly used, rotary encoders, output digital pulses corresponding to incremental angular motion. For example, a 1000-line encoder produces 1000 pulses every mechanical revolution. The encoder consists of a glass or metal wheel with alternating transparent and opaque stripes, detected by optical sensors to produce the digital outputs.

Feedback
A signal which is transferred from the output back to the input for use in a closed loop system.

Ferrite
A type of permanent magnet consisting of ceramic compounds made up of oxides of iron, barium and strontium.

Form Factor
The ratio of RMS current to average current. This number is a measure of the current ripple in a SCR or other switch-mode type of drive. Since motor heating is a function of RMS current while motor torque is a function of average current, a form factor greater than 1.00 means some fraction of motor current is producing heat but not torque.

Four quadrant
Refers to a motion system which can operate in all four quadrants; i.e., velocity in either direction and torque in either direction. This means that the motor can accelerate, run, and decelerate in either direction.

Friction
A resistance to motion caused by contact with a surface. Friction can be constant with varying speed (Coulomb friction) or proportional to speed (viscous friction).

Hall sensor
A feedback device which is used in a brushless servo system to provide information for the amplifier to electronically commutate the motor. The device uses a magnetized wheel and hall effect sensors to generate the commutation signals.

Holding torque
Sometimes called static torque, holding torque specifies the maximum external torque that can be applied to a stopped, energized motor without causing the rotor to rotate. Generally used as a figure of merit when comparing motors.

Horsepower
An index of the amount of work a machine or motor can perform. One horsepower is equal to 746 watts. Since power is equal to torque multiplied by speed, horsepower is a measure of a motor’s torque and speed capability; e.g., a 1 HP motor will produce 36 lb-in. at 1,750 rpm.

Formula:

HP = Torque (lb-in.) x Speed (RPM)/63,025

or

HP = Torque (lb-ft.) x Speed (RPM)/5,252

or

HP = Volts x Amps x Efficiency/746

Note: 1 HP = 746 Watts

Hybrid step motor

A motor designed to move in discrete increments of steps. The motor has a permanent magnet rotor and a wound stator. Such motors are brushless. Phase currents are commutated as a function of time to produce motion.

Idle current reduction
A step motor driver feature that reduce the phase current to the motor when no motor motion is commanded (idle condition) for a specified period of time. Idle current reduction reduces motor heating and allows high machine throughputs from a given motor.

Indexer

Electronics which convert high level motion commands from a host computer, PLC or operator panel into step and direction pulse streams for use by the step motor driver. Indexers can be broadly divided into two classes. A preset indexer typically accepts distance, velocity and ramp time inputs only. The more sophisticated programmable indexer is capable of complex motion control and includes program memory.

Inductance (L) (mH - millihenries line-to-line)

The electrical equivalent to mechanical inertia; that is, the property of a circuit, which has a tendency to resist current flow when no current is flowing, and whencurrent is flowing has a tendency to maintain that current flow. Pacific Scientific measures inductance (line-to-line) with a bridge at 1000 Hz and with the rotor positioned so the back-EMF waveform is at the peak of the sinusoid.

Inductance (mutual)

Mutual inductance is the property that exists between two current carrying conductors or coils when magnetic lines of force from one link with those of the other.

Inertia

The property of an object to resist change in velocity unless acted upon by an outside force. Higher inertia objects require larger torques to accelerate and decelerate. Inertia is dependent upon the mass and shape of the object.

Inertial match

For most efficient operation, the system coupling ratio should be selected so that the reflected inertia of the load is equal to the rotor inertia of the motor.

Insulation Class

The rating assigned to the maximum temperature capability of the insulating components in a motor or other piece of equipment.

Microstepping

An electronic technique for increasing a step motor's position resolution and velocity smoothness by appropriately scaling the phase currents. Microstepping is also a technique used to reduce or eliminate the effects of system resonance at low speeds.
Note: Microstepping beyond 16 microsteps per step only smooths motion, linearity becomes sinusoidal with amplitude of the sine effects increasing with higher microsdtep resolutions.

Mid-range instability

A phenomenon in which a step motor can fall out of synchronism due to a loss of torque at mid-range speeds. The torque loss is due to the interaction of the motor's electrical characteristics and the driver's electronics. Some drivers have circuitry to eliminate or reduce the effects of mid-range instability.

NEMA - National Electrical Manufacturer's Association

Acronym for an organization which sets standards for motors and other industrial electrical equipment.

Neodymium iron boron

A type of rare-earth permanent magnet material.

NTC - Negative Temperature Coefficient

A negative temperature coefficient thermistor is used to detect and protect a motor winding from exceeding its maximum temperature rating. Resistance of the device decreases with an increase in temperature.

Open-loop

A system in which there is no feedback. Motor motion is expected to faithfully follow the input command. Stepping motor systems are an example of open-loop control.

Overload capacity

The ability of a drive to withstand currents above its continuous rating. It is defined by NEMA as 150% of the rated full-load current for “standard industrial DC motors” for one minute.

Peak torque (Tpk) (lb-in.)
The maximum torque a brushless motor can deliver for short periods of time. Operating permanent magnet motors above the maximum torque value can cause demagnetization of the rare-earth magnets. This is an irreversible effect that will alter the motor characteristics and degrade performance. This is also known as peak current. Not to be confused with system peak torque, which is often determined by amplifier peak current limitations, where peak current is typically two times continuous current.

Poles
Refers to the number of magnetic poles arranged on the rotor of the brushless motor. Unlike an AC motor, the number of poles has no direct relationship to the base speed of the motor.

Power

1. The rate at which work is done. In motion control, power is equal to torque multiplied by speed.
2. The rate of doing work or expending energy. It may be written as: Power (watts) = force x distance/time. Expressed in electrical terms it is voltage x current = power (watts)

Power factor
Ratio of true power (kW) to apparent power (kVA).

Pull-out Torque (Poll Slip)
The maximum friction load, at a particular inertial load, that can be applied to the shaft of a synchronous motor (running at constant speed) and not cause it to lose synchronism.

Pulse rate
The frequency of the step pulses applied to a step motor driver. The pulse rate, multiplied by the resolution of the motor/driver combination (in steps per revolution), yields the rotational speed in revolutions per second.

Pulse Width Modulation (PWM)

1. A PWM controller (amplifier) switches DC supply voltage on and off at fixed frequencies. The length of the on/off interval or voltage waveform is variable.
2. Pulse width modulation (PWM), describes a switch-mode (as opposed to linear) control technique used in amplifiers and drivers to control motor voltage and current. PWM offers greatly improved efficiency compared to linear techniques.

Regeneration
The action during motor braking, in which the motor acts as a generator and takes kinetic energy from the load, converts it to electrical energy, and returns it to the amplifier.

Repeatability
The degree to which a parameter such as position or velocity can be duplicated.

Resistance, Hot (RH)(Ohms line-to-line)
The motor's terminal resistance value specified at the hot winding temperature, which is at the motor's maximum rated temperature.

Resolution
The smallest increment into which a parameter can be broken down. For example, a 1000 line encoder has a resolution of 1/1000 of a revolution.

Resolver
An electromagnetic feedback device which converts angular shaft position into analog signals. These signals can be processed in various ways, such as with an RDC (resolver-to-digital converter) to produce digital position information. There are two basic types of resolvers; transmitter and receiver. A transmitter-type is designed for rotor primary excitation and stator secondary outputs. Position is determined by the ratio of the sine output amplitude to cosine output amplitude. A receiver-type is designed for stator primary excitations and rotor secondary output. Position is determined by the phase shift between the rotor output signal and one of the primary excitation signals.

Resonance
Oscillatory behavior caused by mechanical or electromechanical harmonics and limitations.

Restart torque
The maximum friction load, at a particular inertial load, that can be applied to the shaft of a synchronous motor without causing it to lose synchronism when
accelerating to a constant speed from standstill.

Ringing
Oscillation of a system following a sudden change in state.

RMS Current - Root Mean Square Current
In an intermittent duty cycle application, the RMS current is equal to the value of steady state current which would produce the equivalent motor heating over a period of time.

RMS Torque - Root Mean Square Torque.
In an intermittent duty cycle application, the RMS torque is equal to the value of steady state torque which would produce the equivalent motor heating over a period of time.

Rotor
The moving part of the motor, consisting of the shaft and magnets. These magnets are analogous to the field winding of a brush-type DC motor.

Settling time
The time required for a parameter to stop oscillating or ringing and reach its final value.

Shock loading
A load that produces extremely high peak torques for very short durations. This type of load is associated with conveyorized grinding, crushing and separation processes.

Speed
Describes the linear or rotational velocity of a motor or other object in motion.

Stall Torque
The amount of torque developed with voltage applied and shaft locked, or not rotating. Also known as locked-rotor torque.

Stator
The non-moving part of the motor. Specifically, it is the iron core with the wire winding in it that is pressed into the frame shell. The winding pattern determines the voltage constant of the motor.

Step angle
The angular distance the shaft rotates upon receipt of a single step command.

Stiffness
The ability to resist movement induced by an applied torque. Stiffness is often specified as a torque displacement curve, indicating the amount a motor shaft will rotate upon application of a known external force when stopped.

Synchronism
A motor rotating at a speed corresponding correctly to the applied step pulse frequency is said to be in synchronism. Load torques in excess of the motor's capacity (rated torque) will cause a loss of synchronism. This condition is not damaging to a step motor.

TENV - Totally Enclosed Non-Ventilated
Acronym describing a type of motor enclosure, which has no outside air going into it. It is cooled only by convection to the frame, which is usually finned.

Thermal protection
A thermal sensing device mounted to the motor to protect it from overheating. This is accomplished by disconnecting the motor phases from the drive in an over temperature condition.

Thermal resistance (Rth) (°C/watt)
An indication of how effectively a unit rids itself of heat; a measure of temperature rise per watts lost. In Pacific Scientific literature, it is the specified value from the motor windings to the ambient, under locked rotor conditions.

Thermal time constant (tth) (minutes)
The time required for a motor to attain 63.2% of its final temperature for a fixed power input.

Thermostat
A temperature sensitive pilot duty device mounted on the interior of the motor to protect it from overheating.

Torque
A measure of angular force which produces rotational motion. This force is defined by a linear force multiplied by a radius; e.g. lb-in. Torque is an important parameter of any motion control system. Formula: Torque (lb-ft.) = 5,250 x HP/RPM

Torque Constant (KT = lb-ft./A)
An expression of the relationship between input current and output torque. For each ampere of current, a fixed amount of torque is produced.

Torque-to-inertia ratio
Defined as the motor's holding torque divided by the inertia of its rotor. The higher the ratio, the higher a motor's maximum acceleration capability will be.

Torque constants ARE NOT linear over the operating range of a motor.
They apply best at ~75% of no load maximum speed or where the peek and continuous torque curves meet.

Unipolar driver
A step motor driver configuration that uses a unipolar power supply and is capable of driving phase current in only one direction. The motor phase winding must be center tapped (6 or 8 lead) to operate with a unipolar driver. The center tap is used instead of providing the current reversal of a bipolar driver.

Velocity
The change in position as a function of time. Velocity has both a magnitude and sign.

Viscous Damping (KDV) (lb-in./kRPM)
Inherent losses are present in all motors which result in lower torque delivered at the output shaft than developed at the rotor. Losses which are proportional to speed (i.e. speed dependent terms such as windage, friction, eddy current) are related through the motor's "viscous damping" constant, measured as the slope of the damping curve.

Voltage constant (KE) (V/kRPM peak, line-to-line)
May also be termed back-EMF constant. When a motor is operated, it generates a voltage proportional to speed, but opposing the applied voltage. The shape of the voltage waveform depends upon the specific motor design. For example, in a brushless motor, the waveshape may be trapezoidal or sinusoidal in nature. All Pacific Scientific brushless motor designs have a sinusoidal voltage constant. For a sine waveform, the voltage constant can be measured from line-to-neutral or line-to-line and expressed as a peak value or "RMS" value.

Calculating Power : the Real Story

Unit of electrical power where : Watts =(volts)(amps) or W=V*A Watts are a unit consisting of time since amps are a measure of electron flow per unit time

For this reason, Torque cannot be directly equated with Watts or Horse Power without consideration of RPM where Revolutions per min contains time that would cancel out the time in watts to give you torque. This is why Horsepower is a useless unit of measure when sizing motors for motion control applications!

One horsepower equals 746 watts and has nothing to do with torque by itself!!!!!

Formula for Power to Torque:

$$\text{Power (HP)} = \text{Power (Watts) x746}$$

$$\text{Power (Watts)} = \frac{\text{N (RPM) x T(ft-lbs)}}{7.04}$$

$$\text{Power (HP)} = \frac{\text{N (RPM) x T(ft-lbs)}}{5252}$$

Torque required will be:

$$\text{T (ft-lbs} = \frac{\text{Power (Watts) x 7.04}}{\text{N(RPM)}}$$

$$\text{T (ft-lbs)} = \frac{\text{Power (HP) x 5252}}{\text{N(RPM)}}$$

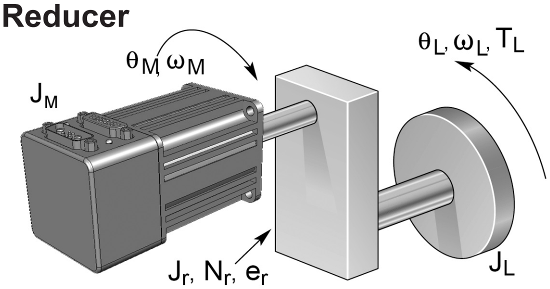
All references on the right side of this page are used in the formulas on the pages that follow

Symbol	Definition	SI	English
C_G	Circumference of Gear	m (or cm)	in (or ft)
$C_{P: 1, 2, 3}$	Circumference of Pulleys, 1, 2, or 3	“	“
D	Diameter of cylinder or . . .	m (or cm)	in (or ft)
D_G	...(pitch dia.) of Gear	“	“
D_{PM}	...(pitch dia.) of Pulleys on Moto	“	“
$D_{P:1, 2, 3}$	...(pitch dia.) of Pulleys 1, 2, or 3	“ “	
e	efficiency of mechanism or reducer	%	%
F	Forces due to	N	lb
F_{Fr}	...friction (Ffr = mWL cos g)	“	“
F_g	...gravity (Fg = WL sin g)	“	“
F_p	...Push or Pull forces	“	“
g	gravity accel constant	9.80 m-s-2	386 in-s^{-2}
J	mass moment of inertia for	kg-m2	lb-in^2
$J_{B\rightarrow M}$	...Belt reflected to Motor	or	or
J_C	...Coupling	g-cm2	oz-in^2
J_G	...Gear	etc.	or
J_L	...Load “ in-lb-s2		
$J_{L\rightarrow M}$	...Load reflected to Motor	“	or
J_M	...Motor	“	in-oz-s^2
J_{PL}	...Pulley on the Load	“	etc.
J_{PM}	...Pulley on the Motor	“	“
$J_{PL\rightarrow M}$	...Pulley on Load reflected to Motor	“	“
$J_{P: 1, 2, 3}$	...Pulley or sprocket 1, 2, or 3	“	“
J_r	...reducer (or gearbox)	“	“
J_{Total}	...Total of all inertias	“	“
J_S	...lead Screw		“ “
N_r	Number ratio of reducer	none	none
N_t	Number of teeth on gear, pulley, etc.		
P_G	Pitch of Gear, sprocket or pulley	teeth/m	teeth/ inch
P_S	Pitch of lead Screw	revs/m	revs/inch
T	Torque...(for “required” Calculations)	Nm	in-lb
T_L	...at Load (not yet reflected to motor)	“	“
T_P .	..due to Preload on screw nut, etc.	“	“
W_M	angular/rotational velocity of Motor	“	“
W_L	Weight of Load	N (or kg)	lb
W_B	Weight of Belt (or chain or cable)	“	“
W_T	Weight of Table (or rack & moving parts	“	“
ϴ	rotation...	radians	revs
$ϴ_{a, c, or d}$ ...	rotation during accel, decel, etc.	“	“
$ϴ_L$	...rotation of Load	“	“
$ϴ_M$	...rotation of Motor	“	“
μ	coefficient of friction	none	none
ɣ	load angle from horizontal	degrees	degrees
$Ш_M$	Maximum Speed (servos & steppers)	“	“

Motion Formulas

Motion Mechanism and Motion Equations | **Inertia, Torque Equations**

Reducer



$$N_r = \frac{\theta_M}{\theta_L} = \frac{\omega_M}{\omega_L}$$

$$\theta_M = N_r \times \theta_L$$

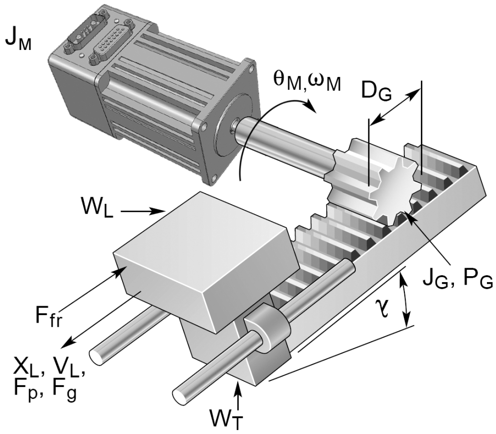
$$\omega_M = N_r \times \omega_L$$

$$J_{Total} = J_M + J_r + J_{L\to M}$$

$$J_{L\to M} = \left(\frac{1}{N_r}\right)^2 \times \frac{J_L}{e} \qquad T_{L\to M} = \frac{T_L}{N_r \times e}$$

J_r = inertia of reducer reflected to input

Rack & Pinion



$$C_G = \pi \times D_G = \frac{N_t}{P_G}$$

$$\theta_M = \frac{X_L}{C_G}$$

$$\omega_M = \frac{V_L}{C_G}$$

$$J_{Total} = J_M + J_G + J_{L\to M}$$

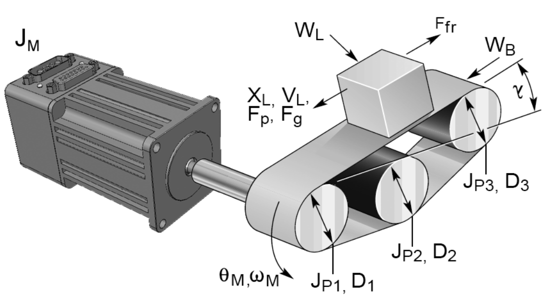
$$J_{L\to M} = \frac{(W_L + W_T)}{g \times e} \times \left(\frac{D_G}{2}\right)^2$$

$$F_g = (W_L + W_T) \times \sin\gamma$$

$$F_{fr} = \mu \times (W_L + W_T) \times \cos\gamma$$

$$T_{L\to M} = \left(\frac{F_P + F_g + F_{fr}}{e}\right) \times \left(\frac{D_G}{2}\right)$$

Conveyer



$$C_{P1} = \pi \times D_{P1} = \frac{N_t}{P_G}$$

$$\theta_M = \frac{X_L}{C_{P1}}$$

$$\omega_M = \frac{V_L}{C_{P1}}$$

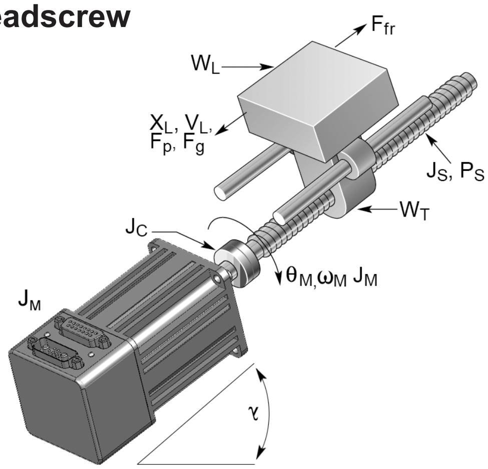
$$J_{Total} = J_M + J_{P1} + \left(\frac{D_{P1}}{D_{P2}}\right)^2 \times \frac{J_{P2}}{e} + \left(\frac{D_{P1}}{D_{P3}}\right)^2 \times \frac{J_{P3}}{e} + J_{L\to M}$$

$$J_{L\to M} = \frac{(W_L + W_B)}{g \times e} \times \left(\frac{D_{P1}}{2}\right)^2$$

$$F_g = (W_L + W_B) \times \sin\gamma \qquad F_{fr} = \mu \times (W_L + W_B) \times \cos\gamma$$

$$T_{L\to M} = \left(\frac{F_P + F_g + F_{fr}}{e}\right) \times \left(\frac{D_{P1}}{2}\right)$$

Leadscrew



$$\theta_M = P_S \times X_L$$

$$\omega_M = P_S \times V_L$$

$$J_{Total} = J_M + J_C + J_S + J_{L\to M}$$

$$J_{L\to M} = \frac{(W_L + W_T)}{g \times e} \times \left(\frac{1}{2\pi \times P_S}\right)^2$$

$$F_g = (W_L + W_T) \times \sin\gamma \qquad F_{fr} = \mu \times (W_L + W_T) \times \cos\gamma$$

$$T_{L\to M} = \left(\frac{F_P + F_g + F_{fr}}{2\pi \times P_S \times e}\right) + T_P$$