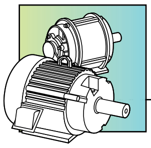

Applying PMDC motors

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When you need high starting/acceleration torque, predictable motor speed properties, compact size, and energy efficiency, Permanent Magnet DC (PMDC) motors may be the solution. Proper application will help you get the most out of them.

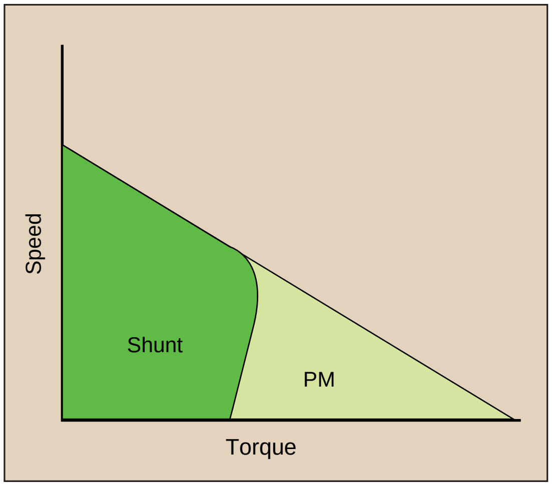

Figure 1 — The high reluctance of PMDC motors prevents the torque drop off common with shunt-wound motors.

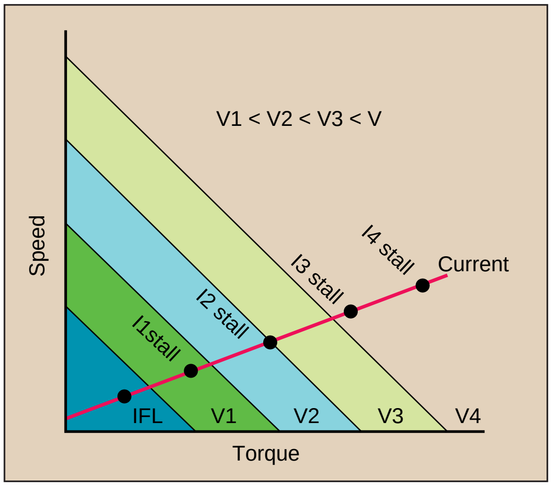

Figure 2 — As applied armature voltage increases in a PMDC motor, the linear speed-torque curves shift upwards.

Permanent Magnet DC motors are useful in a range of applications, from battery powered devices like wheelchairs and power tools, to conveyors and door openers, welding equipment, X-ray and tomographic systems, and pumping equipment, to name a few. They are frequently the best solution to motion control and power transmission applications where compact size, wide operating speed range, ability to adapt to a range of power sources or the safety considerations of low voltage are important. Their ability to produce high torque at low speed make them suitable substitutes for gearmotors in many applications. Because of their linear speed-torque curve, they particularly suit adjustable speed and servo control applications where the motor will operate at less than 5000 rpm

Inside these motors, permanent magnets bonded to a flux-return ring replace the stator field windings found in shunt motors. A wound armature and mechanical brush commutation system complete the motor.

The permanent magnets supply the surrounding field flux, eliminating the need for external field current. This design yields a smaller, lighter, and energy efficient motor.

Armature interaction

Unlike a shunt wound dc motor, a PM motor is free of interaction between the permanent magnet field and the armature demagnetizing cross field. Shunt wound DC motors experience significant interaction between the armature and the stator. The stator's low reluctance (high permeability) iron core ultimately weakens the field as the load increases. The result is a dramatic drop in the speed-torque characteristics at some point.

The PM motor's field has a high reluctance (low permeability) that eliminates significant armature interaction. This high reluctance yields a constant field, permitting linear operation over the motor's entire speed-torque range. In operation with a constant armature voltage, as speed decreases, available torque increases, Figure 1. As the applied armature voltage increases, the linear speed-torque curves shift upwards. Thus, a series of parallel speed-torque curves, for different armature voltages, repre-

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sents the speed-torque properties of a PM motor, Figure 2. Speed is proportional to voltage and torque is proportional to current.

Speed control methods

Speed is controlled by varying the voltage applied to the armature. Feedback devices sense motor speed and send this information to the control to vary its output voltage up or down to keep speed at or near the set value. Feedback techniques include voltage tachometers, optical encoders, electromagnetic pulse generators, and back emf monitoring.

Regulation is the ability of the motor and control system to hold speed constant over the torque range. It extends from 0.1% for highly divided (e.g., 1000 div/rev) optical encoders to 5% for a simple back emf system. Most manufacturers provide the servo constant data for predicting system response.

Form factor

In practice, the voltage used to power a PM motor is not a pure DC. It is derived DC voltage formed by rectifying an AC voltage. Thus, the DC drive voltage has a wave or ripple component that is related to the frequency of the AC input.

Form factor, which is the ratio of I_{rms} to I_{dc}, indicates how close the driving voltage is to pure DC. By definition, form factor for a pure DC source, such as a battery, is 1.0. For a power source, the higher the form factor is above 1.0, the more it deviates from pure dc. Table A shows typical form factors for commonly used voltage sources.

Most manufacturers of PMDC motors recommend that form factor not exceed 1.4 for continuous operation. Half wave rectification is also *not* recommended because it increases the form factor.

Driving a motor with a higher form factor control than intended can cause premature brush failure and excessive internal heating. If you use a control with a high form factor, you may need special brushes and commutators, a high temperature insulation system, or a larger motor. It may cost more, but a control that reduces form factor can reduce heating effects in the motor.

Table A—Comparison of driving voltage to pure DC.

Form factor	Dc voltage source
1.0	Battery (pure dc)
1.05	Pulse width modulation (PWM)
1.4	Full wave rectification
1.9	Half wave rectification

Because PM motors lack armature interaction, they can generate high momentary starting and acceleration torques, typically 10 to 12 times full rated torque. Thus, they suit applications requiring high starting torques or momentary bursts of power. However, they are not intended for continuous operation at the high levels of torque they can produce. This can cause overheating, which can result in non-reversible demagnetization of the field magnets.

A torque (current) limiting function in drive controls limits stall conditions, plug reversing, and current draw, particularly during high torque demand periods, and protects against detrimental overload. (Plug reversing is not recommended because it subjects the armature to higher-than-rated-for voltages). Besides preventing the motor from overheating, a current limiter can help protect driven machinery from excessive motor torques.

Permanant magnets

A number of magnetic materials are available for permanent magnets. These include ceramic oriented ferrites, rare earth permanent magnets, and Alnico, although Alnico's use is waning. Table B compares these commonly used materials.

Ceramic oriented ferrites, typically made with barium or strontium, develop into products with lower energy than Alnico. Therefore, they have become the material of choice in most PM motors, replacing Alnico, because of their greater resistance to demagnetization, ease of forming, and low cost.

Rare earth magnets may let engineers choose a downsized PM motor, or boost its power rating. They include samarium-cobalt and the more recently developed neodymium-iron-boron. Their characteristics, compared to the previously mentioned materials, include high energy and low susceptibility to demagnetization. The cost of these materials, however, remains high.

The choice of material depends on the application requirements. The motor manufacturer can provide selection assistance.

Table B —
A comparison of permanent magnet motor materials.

Type	Cost	Resistance to demag	Energy product
Ceramic oriented ferrites	Low	Medium	Low
Samarium cobalt	High	High	High
Neodymium iron boron	High	High	High

Brushes

PMDC motors use a mechanical commutation scheme to switch current to the armature winding. Commutator bars connect to the armature windings. A pair of spring loaded brushes make mechanical contact with the commutator bars, carrying the current to the armature. Thus, the brushes link the power source to the armature field windings. The armature commutator and the brushes act as a rotary switch for energizing the windings.

Design and selection of brushes tend to be something of a black art. The ideal brush offers low voltage loss, negligible dust formation, no arcing, little commutator wear, and generates little noise. In many cases, these requirements are contradictory, forcing a compromise in brush selection.

At low applied voltage, the voltage drop across the brushes is the prime consideration in brush selection. At higher voltages, the voltage drop in the brush is less important. Other parameters, such as operating speed, abrasiveness, lubricity and cost, become dominant.

Commonly used brush materials include carbon and carbon graphite, graphite, electro-graphitic, and metal-graphite. Table C compares these brush materials.

Metal graphite brushes consist of a mixture of copper or silver with graphite. They have low voltage loss and high wear rate, limiting their usage to low speed, low-voltage motors.

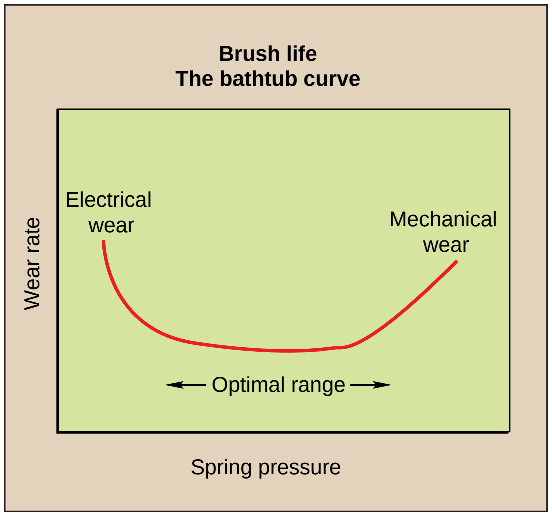

Figure 3 — Too little spring pressure on brushes can result in excessive electrical wear. Too much pressure can result in excessive mechanical wear. Optimal spring pressure is between these regions.

Carbon and carbon-graphite brushes have low current capacity, a relatively high voltage drop across the brush, and tend to be abrasive. These properties limit their use to low speed, high voltage, fractional horsepower motor applications.

Electro-graphitic brushes use a form of graphite developed from carbon subjected to intense heat. They have high current capacity, a relatively moderate voltage drop, and low abrasive properties. They handle high-speed, high-voltage and high-power motor applications.

Natural graphite brushes have a slightly lower current capacity than electro-graphitic brushes. They tend to have greater polishing action than electrographitics, low friction characteristics, and an inherent softness. They fit applications where high-speed operation and quietness are critical. However, their softness, which accounts for their quiet operation, also gives them a limited brush life.

Other factors also affect brush life and performance, including temperature, humidity, altitude, spring pressure, control form factor, size and duty cycle.

Table C — A comparison of motor brush materials.

Type	Voltage drop	Current capacity	Usage limitations
Carbon, carbon-graphite	High	Low	High Voltage Low speed Fractional hp only
Graphite (natural)	Medium	Medium	Medium speed/high voltage
Electro-graphitic	Medium	High	Medium to high speed/Medium to high voltage
Copper graphite	Low	Low	Low voltage/Low speeds
SIlver graphite	Very low	Very low	Very low voltage/lLow speeds

Table D— Electrical insulation systems

Class A	105 C
Class B	130 C
Class F	155 C
Class H	180 C

If spring pressure is too low, excessive electrical wear may occur. If it is too high, excessive mechanical wear may occur. As shown in Figure 3, brush life can be represented as a bathtub shaped curve. The optimal spring-pressure range for minimal wear is between the high electrical and mechanical wear regions.

Low humidity, high temperature or high altitude environments may not have enough moisture present to form the necessary lubricating film between brush and commutator bar. Special lubricant-impregnated brushes can correct the problem.

Under light load conditions, the low current draw can cause poor lubrication of the commutator. Smutting of the commutator and uneven commutation often result. To correct, either use lubricant-impregnated brushes or downsize the brush cross-sectioned area for proper commutation.

Overall, choice of the appropriate brush material is application dependent and is best made with the advice of the motor manufacturer, who typically has thousands of hours of brush test data.

Other considerations for PMDC motor selection include proper choice of enclosure and electrical insulation system. If safety factors dictate a totally enclosed motor, it may be non-ventilated (TENV) or fan-cooled (TEFC). (For an in depth discussion on safety, see PTD, “Explosion Proof Motors for Adjustable-speed Drives,” 9/1991, p. 35.) Electrical insulation systems, Table D, are tested for 20,000 hours at a rated temperature without degradation (as recognized by UL, CSA, BSI, and VDE). Subtract ambient temperatures (usually 25 C or 40 C) to determine allowable rise. You can compute ambient temperatures if you know the operating load, motor efficiency and thermal rise coefficient. Look for a control with a ramping function to help avoid operation in extremely low temperature. ■