

Platinume

Innovation—Beyond Efficiency



It's the motor you weren't quite expecting. It's more.

Platinum e.™ It delivers what other motors only promise.

Give it a casual glance and you might miss that you're looking at a technical wonder. Because in Platinum e[™] LEESON delivers the best of everything that our customers have been seeking. Platinum e[™] is a name that truly fits transitional motor design—one with value that continues to pay back year after year.

Platinum e[™] series exceeds the efficiency of traditional AC induction motors.

- Energy efficiency over a wide speed range
- Desired output power in smaller frame sizes
- Variable speed operation in constant-torque and variable-torque applications
- Lower routine and long-term maintenance

A product line in fractional and integral frame sizes.

Platinum e[™] permanent magnet technology provides energy savings across a broad range of fractional and integral horsepower motors. By reducing rotor losses, the patent-pending radial magnet design greatly improves motor efficiency and specific output power. What's more, the compact design of Platinum e[™] motors enables easy integration with existing machine designs and processes to optimize system efficiency.

The people of LEESON design and build Performance Matched Solutions[™] in the USA



Platinum®





Platinum e[™] motors and variable frequency drives. The perfect combination.

Today, industry is responsible for more than 70% of electricity consumption. And that means motorized applications have tremendous potential for efficiency gains and corresponding savings. While a Platinum e[™] motor must be matched with a variable frequency drive, the combination will help optimize mechanical systems to achieve maximum output and lowest total cost of operation.

Platinum e™ makes sense

- Pumps
- Fans/blowers
- HVAC
- Compressors
- Conveyors
- Extruders
- Presses
- Process applications
- Generators, and more

Guaranteed efficiency and torque over wide speed ranges

- High Speed with Low Power Density
- High Speed with High Power Density
- Low Speed/High Torque with Low Power Density
- Low Speed/High Torque with High Power Density

Save energy—at and below speed

Platinum e[™] delivers more than torque. It also delivers a lower utility bill. Because throughout the speed range, Platinum e[™] motors use less energy—far less than "high-efficiency" AC induction motors. And below rated speed? That's where efficiency becomes even more significant, making Platinum e[™] ideally suited for variable speed applications. That means return on investment typically occurs in 12 to 24 months.

Compact, modular, and smart

Significantly more compact and lighter than comparable AC induction motors, Platinum e[™] solutions contribute to lower overall machine weight and smaller dimensions. This helps simplify installation, minimize lifting equipment needs, reduce transport costs, and more. A range of accessories ensures the modular Platinum e[™] series is easy to retrofit where conventional motors are installed.

Cool operation reduces maintenance

Heat is a motor's worst enemy. But with the permanent magnet design of Platinum e[™] motors, rotor loss is minimized, which significantly reduces operating temperature. You'll also see longer maintenance intervals as well, and increased service life of the entire drive system since power transmission devices such as pulleys, belts, and gear reducers have been simplified or removed.

Guaranteed efficiency and torque over wide speed ranges

Conduit box includes a terminal block



Platinum e[™] Motor Eff. ■■■■ Platinum e[™] Motor PF

NEMA Prem. Eff.
 NEMA Prem. PF

ASSUMPTIONS: 10 HP @ 1800 RPM 150 Hz, 215 T Frame IP-55 Protection against the elements

Bearings for 180 frames and larger may be greased

Typical Fractional Horsepower Inverter Motor Performance



Horsepower

ASSUMPTIONS:

3-phase .82 Passive Power Factor Correction <87% System Efficiency 200% Starting Torque 230 Volts 9.6 Amps 460 Volts 4.8 Amps Permanent magnet motor

> Stator and Rotor Severe Duty Treatment as standard for 180 frame and larger—48/56 frame available upon request

> > IRIS[™] insulation

Fractional models feature rolled-steel construction

Integral models feature cast-iron construction

Various NEMA and IEC mounting configurations

In-line maintenance

A complete range of options and accessories

Sustainability—a LEESON commitment LEESON Electric is doing its part to reduce carbon emissions through innovative designs.







Performance Matched Solutions™

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Understanding AC induction, permanent magnet and servo motor technologies:

OPERATION, CAPABILITIES AND CAVEATS

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Engineers today are tasked with understanding, evaluating and applying myriad motor technologies because the majority of rotary motion is ultimately powered by electric motors.

In this eBook, we outline the capabilities of driven AC induction motors, permanent-magnet motors and servomotors — the three major technologies with partially overlapping functionalities for larger, higher-end applications requiring precisely metered torque, speed or positioning. We then expound on some engineering caveats and compare all three options for specific situations.

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(PMAC) motors and servomotors. Then we will compare each technology and explore how each motor type is most suitable for a given set of applications.

Illustrated here are magnet-induced flux and current-induced flux, upon which all electric motor operation is based.



CHAPTER ONE: AC INDUCTION MOTORS

In all its iterations, the induction motor induces magnetism that is leveraged to output rotary motion. The stationary outer stator is connected to an external electrical power source; this is fed to the rotor's poles in a rotating progression that causes revolutions of the magnetic field within the motor. Conducting bars in the rotor interact with the stator's magnetic fields; current is induced in those bars, which in turn generate magnetic fields that are attracted to those of the stator. As the rotor's



This exploded view of a LEESON Electric AC induction motor shows the stator windings, rotor (in red), support bearings, cooling fan (in white) and other elements.

induced current and magnetism cause it to follow the field generated by the stator, rotary motion is output.

Because an AC induction motor increases the flux enclosed by its stationary coils, it is a transformer with a rotating secondary (rotor). The rotor current's effect on the air gap flux causes torque.

AC induction motors are built by manufacturers according to established National Electrical Manufacturers Association (NEMA) standards in myriad fractional and integral horsepower ratings and associated frame sizes. These AC induction motors are quite common — the workhorse of industry.

AC induction motor technology overview

An induction motor's stator consists of a stack of thin, highly permeable steel laminations with slots; the laminations are either secured in a steel or cast-iron frame that provides a mechanical support. The windings that accept the external power supply are run through the slots. The AC inductor rotor assembly resembles a cage consisting of aluminum or copper conducting bars connected by short-circuiting end rings — hence the nickname *squirrel cage* for induction motors. The rotor also has laminations; radial slots around the laminations contain the bars. As mentioned, the rotor turns



when the moving magnetic field induces current in the shorted conductors, and the rate at which it rotates is the motor's synchronous speed — determined by power-supply frequency and the number of stator poles.

$$N = \frac{120 f}{P}$$

Where N = Synchronous speed

$$f =$$
 Frequency

$$P =$$
 Number of poles

Synchronous speed is the fastest theoretical speed a motor can spin — when the rotor spins at the same speed as the motor's internal rotating magnetic field. In practice, an AC induction motor is an asynchronous motor (in which the rotor lags field speed), so its rotor must spin more slowly than the field, or *slip*. This allows the induction of rotor current to flow, and production of torque to drive attached load while overcoming internal losses.



Current is induced in the rotor's conducting bars and associated magnetic fields interact with those of the stator. This causes the rotor to follow the field generated by the stator, to rotate the output shaft.

AC induction motor capabilities for force, torque, speed and other factors

AC induction motors are either single-phase or poly-phase. Single-phase AC motors power myriad low-horsepower commercial and industrial applications where three-phase power is impractical; they're not efficient, but can last a lifetime. They're also classified by how they are started, as these motors alone develop no starting torque, but require external means for initial actuation.

The simple split-phase (induction-start-induction-run) motor has a small-gage-start winding with fewer turns than the main winding to create more resistance and put the start winding's field at a different electrical angle than that of the main — causing the motor to rotate until it reaches 75% of rated speed. Then the main winding of heavier wire keeps the motor running. This inexpensive design develops high starting current (700% to 1,000% of rated), so prolonged starts cause overheating. Suitable applications include small grinders, blowers and low-starting-torque applications requiring up to 1/3 hp.



This single-phase, capacitor-start, induction-run motor from LEESON Electric is an instant reversing motor designed for parking gates and door operators requiring up to 1 hp. This type of general-purpose motor has a beefed-up start winding plus a capacitor for boost. Starting torque is typically 200% to 400% of rated load; starting current to 575% of rated current allows higher cycle rates and thermal resiliency.

Split-capacitor motors are common but slowly being replaced with more efficient motors and variable-frequency drives (VFDs), which we'll explore later. Split-capacitor motors have a run-type capacitor permanently connected in series with the start winding, making the latter an auxiliary winding once the motor reaches running speed. Starting torques are 30% to 150% of rated load, unsuitable for hard-tostart applications. However, starting current is less than 200% of rated load current, making them suitable for cycling or frequent reversals — in fans, blowers, intermittent adjusting mechanisms and quick-reversing garage door openers.





LEESON Electric FHP Series (fractional hp) AC inverters are suitable for driving permanent-split capacitor, shaded pole

and AC synchronous motors. Many three-phase inverter manufacturers claim that they can run single-phase motors effectively by wiring only two phases; however, this method may cause instability due to the lack of feedback from one of the motor connections. Furthermore, motor torque is reduced considerably because the phases are 120° apart. In contrast, LEESON's FHP inverter uses a twophase connection but its fundamental design enables more efficient operation. These solid-state inverters run in volts/ hertz mode (which we'll outline later in this chapter) and are simple to set up and calibrate as SCR-type DC control.

Most powerful of all single-phase types, capacitor-startcapacitor-run motors have a start capacitor in series with auxiliary winding, plus a run-type capacitor in series with the auxiliary winding for high overload torque. Some have lower full-load current and higher efficiency — so operate more coolly than other single-phase motors of comparable horsepower. Cost is higher but these motors are indispensable in woodworking machinery, air compressors, vacuum pumps and other 1 to 10-hp high-torque applications.

Lastly, inexpensive, shaded-pole, single-phase motors have only one main winding. Starting is through a copper loop partially covering a portion of each motor pole — causing the magnetic field in the ringed area to lag behind that in the unringed portion. The reaction of the two fields causes shaft rotation; varying voltage controls speed. These are disposable motors, and are common in household fans; efficiency is 20% or lower.

THREE-PHASE ASYNCHRONOUS MOTORS

Far and away the most common industrial motor is the three-phase AC induction motor. Approximately 90% of all three-phase AC induction motors are used in industrial applications. Why? The standard utility has three-phase power at 60 Hz. Single-phase motors are versatile but three-phase (and other poly-phase) motors offer higher power and efficiency, and require no switch, capacitor or relays. More specifically, three-phase induction motors have high starting torque because six poles (only 60° per phase apart) work in pairs to boost the power factor — also useful in large

industrial applications. (For example, 3 lb-ft of torque from a four-pole motor yields 1 hp.)

NEMA classifies general-purpose, three-phase motors as A, B, C or D according to their electrical design. For example, NEMA Design C motors have higher starting torque with normal start current and less than 5% slip.

Some of these motors are connected directly to line power with a basic switch; others are fitted with wyedelta windings or soft starters. However, roughly one-third of all industrial designs are variable-load applications; in these designs, motors are increasingly being driven by VFDs — which have (thanks to increasingly sophisticated, yet affordable, semiconductors and circuitry) proliferated over the last two decades.

In these devices, pulsewidth modulation (PWM) is used to vary motor voltage. In turn, solid-state switches such as insulated gate bipolar tranOVERSIZING AND UNDERSIZING

Carefully define application requirements before choosing a replacement motor, or one for a new design: An undersized motor exhibits electrical stresses and premature failure. An overly powerful motor (with high locked-rotor and breakdown torques, for example) can damage the equipment it drives, and runs at less than full-rated load, which is inefficient.

sistors (IGBTs) or gate turn off SCRs (GTOs) execute PWM. Here, AC line voltage is converted to DC and then reshaped so that motor speed varies with the frequency of the pulses in the output voltage. PWM AC drives allow wide speed ranges, programmable acceleration and deceleration ramps, and good energy efficiency; speed and torque precision can, in some cases, match that of DC systems.

• In its simplest iteration, **Volts-per-Hertz** VFD operation holds the ratio of voltage and frequency constant by tracking voltage magnitude. This prevents magnetic saturation (at



which a motor's rotor cannot be magnetized further, causing high currents); voltage to be applied is calculated from the applied frequency required to maintain air-gap flux — a method that provides passable speed control, though no direct control of motor torque.

• Sensorless vector control also modulates frequency but measures (and compensates for) slip by determining the amount of current in phase with the voltage for approximated torque current — for both magnitude and angle between current and voltage. This helps to keep the motor running at target speed even under varied load.



With its power range up to 25 hp, LEESON Electric SM2 Flux Vector Series inverters excel in applications where inverter technology once was considered too costly. They carry four modes of operation — V/Hz, enhanced V/Hz, vector speed and Torque. Applications include packaging, material handling and HVAC.

• Slightly more sophisticated, **flux vector** drives leverage the fact that in induction motors, some current magnetizes or fluxes the rotor to magnetically couple it to the stator. Flux vector drives hold this flux current at the minimum required to induce a magnetic field, while independently modulating torque-producing current pulsing through the stator.

Finally, the VFD iteration, called **field oriented control**, pairs a drive's current regulators with an adaptive controller to independently meter and control motor torque and motor flux. This kind of drive can be paired with an encoder for closed-loop servocontrol but its consistent performance doesn't typically require feedback. Torque output is consistent from zero to full load over myriad speeds.

AC induction motor limitations, performance challenges and potential concerns

Even under sophisticated VFD control, AC induction motors exhibit inherent efficiency limitations and can require an encoder for feedback if low-speed accuracy is required. In addition, retrofitting an existing design with a new VFD can be troublesome, particularly when equipped with older motors. Why? Its inverter's synthesized AC waveform accelerates heating (although advances continue to improve the waveform to more closely approximate an AC sine wave). Extended operation of a VFD-powered motor at less than 50% of base speed also is unacceptable; modern inverterduty motors have higher insulation ratings but extreme cases require a separately powered cooling fan.



LEESON Electric Inverter-Duty motors are designed for inverter or vector applications in which up to 2,000:1 constant-torque speed range is required. Class H inverter insulation withstands the heat generated by inverter-driven operation.143T to 256T frame units output constant horsepower to 2 x base rpm; other sizes output 1.5 x base rpm.

In fact, the wasted heat generated by any AC motor is capable of degrading the insulation so essential to motor operation. Stator insulation prevents short circuits, winding burnout and failure: Magnet wire coating insulates wires within a coil from each other; slot cell and phase insulation

Most general-purpose VFDs have no position control but vector-controlled, pulse width modulated (PWM) drives do - using regulators with microprocessors and DSPs that improve position regulation. Vector drives with built-in position control of this type, when paired with AC induction motors, are suitable for palletizing and other fairly sophisticated tasks. Similarly equipped PM drives paired with PMAC motors are also suitable, and execute such functions more efficiently.



(composite sheets installed in stator slots) shield phaseto-ground; stator varnish dip boosts moisture resistance and overall insulation.

NEMA sets specific temperature standards for motors of various enclosures and service factors (of 1.5 or more in most cases). These standards are based on thermal insulation classes often B, F and H. Maximum winding temperature ratings are total temperatures,

based on 104°F maximum ambient plus the temperature rise generated by motor operation. 5 hp and greater, premium efficiency and inverter-duty motors typically have Class F insulation. Beyond that, many manufacturers design their motors to operate more coolly than their thermal class definitions. Class H insulation is reserved for heavy-duty, hot or high-altitude conditions.

Another consideration is cycling: Motors built for frequent reversals can withstand it but start-stop cycles in others can cause overheating. This is because a typical motor under these conditions draws five to six times the rated running current, which accelerates heating. NEMA limits three-phase, continuous-duty induction motors to two starts in succession before allowing the motor to stabilize to its maximum continuous operating temperature.

Finally, the VFDs commonly used to drive three-phase AC induction motors are sensitive to inertia, horsepower, motor lead length and power quality, so they must be programmed with full-load and no-load amps, base speed and frequency, and motor voltage when initially connected to a new motor. Typically, VFDs also require tuning, during which motor response and electrical characteristics are logged.

CHAPTER TWO: PERMANENT-MAGNET AC MOTORS

Permanent magnet AC (PMAC) motors do not rely entirely on current for magnetization. Instead, magnets mounted on or embedded in the rotor couple with the motor's currentinduced, internal magnetic fields generated by electrical input to the stator. More specifically, the rotor itself contains permanent magnets, which are either surface-mounted to the rotor lamination stack or embedded within the rotor laminations. As in common AC induction motors, electrical power is supplied through the stator windings.

Permanent-magnet fields are, by definition, constant and not subject to failure, except (as we'll explore) in extreme cases of magnet abuse and demagnetization by overheating.

PMAC, PM synchronous, and brushless AC are synonymous terms. Until recently, PMAC motors were available but not widely distributed; now these motors are proliferating. All PMAC motors require a matched PM-drive and must be operated with such; PMAC motors are not to be started for across the line starting.

THE MAGNETS IN PERMANENT-MAGNET MOTORS

Rare-earth elements are those 30 metals found in the periodic table's oft-omitted long center two rows; they're used in many modern applications. Magnets made of rare-earth metals are particularly powerful alloys with crystalline structures that have high magnetic anistropy — which means they readily align in one direction, and resist it in others. Discovered in the 1940s and identified in 1966, rare-earth magnets are one-third to two times more powerful than traditional ferrite magnets — generating fields up to 1.4 Teslas, in some cases. Their magnets are used in MRI machines, portable electronic devices, hysteresis clutches, accelerometers and — last but not least —permanent-magnet rotary and linear motors.

Permanent-magnet motor technology overview

A PMAC motor has a sinusoidally distributed stator winding to produce sinusoidal back-electromotive force (EMF) waveforms. Back EMF is voltage that opposes the current that causes it. In fact, back EMF arises in any electric motor when there is relative motion between the current-carrying armature (whether rotor or stator) and the external magnetic field. As the rotor spins (with or without power applied to the windings), the mechanical rotation generates a voltage — so, in effect, becomes a generator. Typical units are (V/krpm) — volts/(1,000 rpm).



Back EMF is the voltage generated by a rotating permanent magnet machine. As the rotor spins (either with or without power applied to the stator windings) the mechanical rotation generates a voltage — in other words, becomes a generator. The resultant voltage waveform from back EMF is either shaped like a sine wave (AC) or a trapezoid (DC), depending on the power supply from the drive. In fact, as we'll explore, the major difference between PMAC and permanent magnet DC motors is that the faster a PMAC's rotor spins, the higher back-EMF voltage is generated.

PMAC-compatible drives (known as PM drives) substitute the more traditional trapezoidal waveform's flat tops with a sinusoidal waveform that matches PMAC back EMF more closely, so torque output is smoother. Each commutation of phases must overlap, selectively firing more than one pair of power-switching devices at a time. These motor-drive setups can be operated as open-loop systems used in midrange performance applications requiring speed and torque control. In this case, PMAC motors are placed under vector-type control.

In fact, though PMACs require a drive specifically designed to drive PM motors, the PM drive setup is most similar to flux vector drives for AC induction motors, in that the drive uses current-switching techniques to control motor torque — and simultaneously controls both torque and flux current via mathematically intensive transformations between one coordinate system and another. These PM drives use motor data and current measurements to calculate rotor position; the digital signal processor (DSP) calculations are quite accurate. During every sampling interval, the three-phase AC system — dependent on time and speed — is transformed into a rotating two-coordinate system in which every current is expressed and controlled as the sum of two vectors.

AC permanent-magnet motor cutaway



Many engineers associate permanent-magnet construction with DC servomotors; however, newer PMAC motors are now an option, and they exceed the power density efficiency of traditional AC induction motors. For example, LEESON's Platinum e[™] permanent-magnet technology reduces rotor losses to save energy for myriad fractional and integral horsepower motors; a patent-pending radial magnet design greatly improves motor efficiency and specific output power. Variable speed operation in constant and variable-torque applications is also possible.

Permanent-magnet motor capabilities for force, torque, speed and other factors

In PMAC motors, speed is a function of frequency — the same as it is with induction motors. However, PMAC motors rotate at the same speed as the magnetic field produced by the stator windings; it is a synchronous machine. Therefore, if the field is rotating at 1,800 rpm, the rotor also turns at 1,800 rpm — and the higher the input frequency from the drive, the faster the motor rotates.

SYNCHRONOUS MOTORS, AND SWITCHED RELUCTANCE OPERATION

A permanent magnet AC (PMAC) motor is a synchronous motor, meaning that its rotor spins at the same speed as the motor's internal rotating magnetic field. Other AC synchronous technologies include hysteresis motors, larger DC-excited motors and common reluctance motors. The latter includes both a stator and rotor with multiple projections; the stator's poles are wrapped with windings that are energized, while the rotor's magnetically permeable steel projections act as salient poles that store magnetic energy by reluctance — leveraging the tendency of magnetic flux to follow the path of least magnetic reluctance in order to repeatedly align the rotor and stator poles.

Though extended coverage of reluctance-motor variants is not within the scope of this eBook, it's helpful to know a bit about its switched-reluctance iteration: This motor can be built to deliver up to 200 hp, overlapping with induction and PMAC motor capabilities. In switched-reluctance motors, the stator coils are synchronously energized with rotor rotation, with overlapping phases. While reluctance motors are typically used as open-loop steppers, their switchedreluctance derivative (also sometimes called variable reluctance) is typically operated under closed-loop control. In fact, stepmotors are somewhat similar to switched reluctance, and step to each defined rotor position, resulting in high repeatability and accuracy.

Switched-reluctance motors produce high efficiency and control, and produce 100% torque at stall indefinitely — useful for applications that require holding. Finally, although torque ripple must be overcome, switched-reluctance motors can be operated at higher speeds than PMACs, as they lack back-EMF constraints.

Most manufacturers of synchronous motors hold pole count constant so input frequency dictates the motor's speed. For example, for a 48-frame motor with six poles, the motor's input frequency from the drive must be 90 Hz to obtain 1,800 rpm. To extract the same speed from a 10-pole 180-frame motor, input frequency must be 150 Hz. To calculate required input frequency (Hz) when the number of poles and speed are known:

$$Hz = \frac{rpm \times \text{Number of Poles}}{120}$$

PMAC motors are suitable for variable or constant-torque applications: The drive and application parameters dictate to the motor how much torque to produce at any given speed. This flexibility makes PMACs suitable for variable-speed operation requiring ultra-high motor efficiency.

Now a word on a common misconception: Cogging — the unwanted jerking during motor spinning from repeatedly overcoming the attraction of permanent magnets and stator's steel structure — is often associated with PM motors. Particularly at startup, cogging arises from the interaction of the rotor magnets and stator winding when it is energized, due to harmonics. Cogging, in turn, causes noise, vibration

SALIENCY

In reference to PMAC motors, saliency refers to the difference in motor inductance at the motor terminals as the motor rotor is rotated. This difference corresponds to alignment and misalignment of the stator's rotor — a characteristic that a motor's drive tracks to monitor rotor position during operation.

and non-uniform rotation. Many methods for reducing cogging can be leveraged to eliminate torque and speed ripple. Some PMAC motors are designed with more poles than equivalent AC induction motors, which helps reduce these issues. Case in point: LEESON Platinum e[™] PMAC fractional-horsepower motors (48-56/140 frames) have a six-pole design; Platinum e™ integral-horsepower PMAC motors (180 frame and larger) utilize a 10-pole rotor design.

CLOSED LOOP FUNCTIONALITY

In specialty cases, PMAC motors are used in closed-loop configurations using speed feedback. Feedback allows the drive to track the exact rotor position — to provide true infinite speed range, including full torque at zero speed. The speed reference required from an external source can be an analog signal and encoder feedback, or a serial command from a feedback device on an axis one wishes to follow — or a PLS, POT or any external device that can create and communicate a value to the drive. This normally is a velocity signal, sometimes further processed in the drive before it is used as a command.

Permanent-magnet motor limitations, performance challenges and potential concerns

PMAC motor speed is limited by back EMF because the latter increases directly with motor speed. The motor is connected to the electronic drive and its electronic components are designed for a maximum voltage above the rated drive voltage. Normally, the motor and controls are designed to operate well below the maximum voltage of the components. However, if motor speed exceeds the design speed range (either being powered from the control or being driven by the load), it is possible to exceed the maximum voltage of the drive components — and cause failures. Note that VFD drives are capable of limiting motor back EMF when operating properly. However, if the drive faults and loses control during overspeed, it cannot protect itself.

In addition, PMAC motor control requires some technical knowledge for implementation: All commercially available PMAC motors require a PM-compatible drive to operate, although there is ongoing research in the development of a line-start PMAC motor.

PMAC motors also require careful servicing: Rare earth permanent magnets, such as Neodymium or Samarium Cobalt found in PMAC motors, have very strong magnetic properties. This makes them indispensable for producing high flux levels — but also means they must be handled with care. Catching one's finger between two of these magnets (during servicing, for example) poses a serious pinching hazard, so the motor supplier or an authorized shop should generally execute any magnet-related maintenance tasks on

PM motors. Those with pacemakers or other medically implanted devices (including hearing aids) should exercise extra caution when working around the strong magnetic fields of these devices; cell phones and credit cards also may be at risk. That said, when a PM motor's rotor is secured within the enclosure, radiated magnetic energy is no higher than that of an induction motor.

Not all AC drives are suitable for operation of PMAC motors; only drives specifically designed

WARNING

Terminal voltage rises with shaft speed during windmilling. Therefore, even with power off, never touch a PMAC's terminals

if its shaft is rotating, as they present a shock hazard. At high shaft speed, voltage can rise to levels that can cause serious injury or death.



for permanent magnet motor compatibility are suitable. Often, a parameter in the drive programming allows an operator to set the drive for a PM motor. Some drives not specifically designed for it can run and control PM motors, though performance is degraded — and one can damage the motor or drive if they are mismatched.

Finally, high current or operating temperatures can cause the magnets in PMAC motors to lose their magnetic properties. Permanent magnets, once demagnetized, cannot recover, even if the current or temperatures return to normal levels. PM drives reduce the risk of high-current demagnetization, as these are equipped with over-current protection. Some motor designs further minimize the possibility of excessive-temperatures magnet failure with high-temperature magnets, integrated thermostats and restricted motor operating temperature.

AXIAL AND RADIAL FLUX MOTORS

As with other motor designs that include permanent magnets, PMAC axial flux motors exist. In these motors, magnetic force (through the air gap) is along the same plane as the motor shaft — along the motor length. Axial flux can be thought of as having the same orientation as disc brakes on a regular vehicle, as the disc rotates like the rotor in an axial flux design. Radial flux motors are the more traditional design, in which the magnetic force is perpendicular to the length of the motor shaft.

A design's form factor determines which orientation is most suitable: Does the machinery require a longer, skinnier radial motor or is a "pancake" axial design more appropriate? The final determining factor may be cost as the axial design, once tooled for production, provides equivalent torque but uses less active material for better power density.

Though not yet suitable for elevator applications, engineers are developing PMAC radial motors to incorporate axial air-gap PMAC designs into elevators sans machine rooms.

CHAPTER THREE: SERVOMOTORS

Servomotors are motors that use feedback for closed-loop control of systems in which work is the variable.

Servomotor technology overview

AC induction motors designed for servo operation are wound with two phases at right angles. A fixed reference winding is excited by a fixed voltage source, while a variable control voltage from a servo-amplifier excites the winding. The windings often are designed with the same voltage-to-turns ratio, so that power inputs at maximum fixed phase excitation, and at maximum control phase signal, are in balance. Any motor designed for servo use is typically 25% to 50% smaller than other motors with similar output and the reduced rotor inertia makes for quicker response. For example, AC servomotors are used in applications requiring rapid and accurate response characteristics — so these induction motors have a small diameter for low inertia and fast starts, stops and reversals. High resistance provides nearly linear speed-torque characteristics for accurate control. Wound-field DC motors (in various iterations, with copper segments in the rotor connected by magnetic-wire windings and stator windings) are another option. More often,

Commutation refers to how current is precisely
routed to a brushed DC rotor's array of coils, to
generate the torque needed via brushes and a
commutator. A commutator is mounted on the rotor
shaft and includes pads, on which the brushes
rest. Current is conducted from the brushes to the
commutator and then to the connected coils as
the rotor spins. Sometimes the term commutation
is used to refer to brushless DC motor operation,
even though electronics and a sensor on the rotor
shaft replace any brushes or commutator. In this
case, current is still switched, but by electronics.
The term loses meaning in the world of AC motors,
though sometimes refers incorrectly to how AC
voltage is generated in the drive.

however, compact brush DC motors (which employ permanent magnets affixed to the inside of the motor frame, plus a rotating wound armature and commutating brushes) are used as servomotors because speed control is easy: The only variable is voltage applied to the rotating armature. There are no field windings to excite, so these motors use less energy than wound DC designs, and have better power density than wound-field motors. Servo-built brushed DC motors also include more wire wound onto the laminations, to boost torque.

Three-phase PMDC motors (brushless motors) also are commonly used for servo applications. Most brushless DC windings are interconnected in an array and most units are

DC SERVOCONTROL: SOPHISTICATED

Reliable speed controls for DC motors abound. Many use solid-state devices; silicon controlled rectifiers (SCRs or thyristors) are common, converting AC line voltage to controlled DC voltage that is applied to the DC motor's armature. Increasing voltage increases speed — so this is sometimes called armature-voltage control. It's highly effective for motors up to approximately 3 hp, allowing 60:1 speed regulation and constant torque even at reduced speeds. Servocontrol, on the other hand, takes control to the next level with feedback — and is suitable for larger designs.

High-voltage DC motors are typically used with an SCR or PWM controller in applications requiring adjustable speed and constant torque throughout the speed range. The LEESON Electric SCR Rated/General Purpose motor (shown here) is widely used in applications requiring dynamic braking or adjustable speed and reversing. The brush holder design provides easy access, while the brushes themselves are large for extended life.



fitted with a trio of Hall sensors at one stator end. These Hall sensors output low and high signals when the rotor's south and north magnet poles pass — to allow the following of energizing sequence and rotor position.

In its most basic form, the drive for a servomotor receives a voltage command that represents a desired motor current. The servomotor is modeled in terms of inertia (including servomotor and load inertia) damping, and a torque constant. The load is considered rigidly coupled so that the natural

PERMANENT-MAGNET DC MOTORS IN SERVO APPLICATIONS

Today, many PM motors are DC and used in servo applications requiring adjustable speed. For quick stops, these can minimize mechanical brake size (or eliminate the brake) by leveraging dynamic braking (motorgenerated energy fed to a resistor grid) or regenerative braking (motor-generated energy returned to the ac supply). In addition, PMDC motor speed can be controlled smoothly down to zero, followed immediately by acceleration in the opposite direction without power circuit switching.

In typical three-phase brushless DC motors, energization is controlled electronically. In some designs, permanent magnets are installed on the stator. More common designs include stators with stacked steel laminations and windings through axial slots; permanent magnets are installed on the rotor. Here, the stator winding is trapezoidally wound to generate a trapezoidal back EMF waveform with six-step commutation.

Brushless DC switches energize changing pairs of motor phases in a predefined commutation sequence. Most units are fitted with a trio of Hall sensors at one stator end, to allow the following of energizing sequence and rotor position. Output torque has considerable torque ripple, which occurs at each step of the trapezoidal commutation. However, due to a high torque-to-inertia ratio, brushless DC motors respond quickly to control-signal changes — making them useful in servo applications.

mechanical resonance is safely beyond the servocontroller's bandwidth. Motor position is usually measured by an encoder or resolver coupled to the motor shaft.

A basic servocontrol generally contains both a trajectory generator and a PID controller: The former provides position setpoint commands; the latter uses position error to output a corrective torque command that sometimes is scaled to the motor's torque generation for a specific current (torque constant.)

Servomotor capabilities for force, torque, speed and other factors

Servocontrol exhibits less steady state error, transient responses and sensitivity to load parameters than open-loop systems. Improving transient response increases system bandwidth, for shorter settling times and higher throughput. Minimizing steady-state errors boosts accuracy. Finally, reducing load sensitivity allows a motion system to tolerate fluctuations in voltage, torque and load inertia.

Typically, a profile is programmed for instructions that define the operation in terms of time, position and velocity:

A digital servocontroller sends velocity command signals to an amplifier, which drives the servomotor. With the help of resolvers, encoders or tachometers for feedback (mounted in the motor or on the load), the controller then compares actual position and speed to the target motion profile, and differences are corrected.

Servomotor limitations, performance challenges and potential concerns

Most importantly, the increased performance of servomotor designs comes at dramatically increased cost.

In addition, there are two situations in which servomotor efficiency declines — low voltage and high torque. In short, servomotors are most often employed because of their ability to produce high peak torque, thus providing rapid acceleration — but high torque often requires that servomotors run two to three times their normal torque range, which degrades efficiency.

Finally, servos are designed to operate over a wide range of voltages (as this is how their speed is varied) but efficiency drops with voltage.

CHAPTER FOUR: COMPARISONS AND CONCLUSIONS

Designers and motor personnel benefit from finding a supplier that is an experienced resource of information to help in pragmatic motor selection. Involve application specialists as early as possible, as they can help develop prototypes, custom electrical and mechanical designs, mountings and gearboxes. This also reduces costs associated with shorter lead times and rush delivery.

In the end, all industrial motor subtypes have strengths and weaknesses, plus application niches for which they're most suitable. For example, many industrial applications are essentially constant torque, such as conveyors. Others, such as centrifugal blowers, require torque to vary as the square of the speed. In contrast, machine tools and center winders are constant horsepower, with torque decreasing as speed increases. Which motors are most suitable in these situations? As we will explore, the speed-torque relationship and efficiency requirements often determine the most appropriate motor.

PMAC versus servomotors

Servomotors are utilized in motion control applications where low inertia and dynamic response are important. In

fact, many motors used for servo applications are similar to PMAC motors but use special controllers (amplifiers) and feedback to control position rather than just speed. However, the price for servosystems is quite high — often 10 to 20 times than that of an equivalently rated induction motor. Applications requiring near-servo performance are excellent candidates for PMAC motors, benefitting from their cost-toperformance ratio. Case in point: PMACs are quite suitable for typical pump operations, which typically run at variable speed between 75% to 85% of maximum speed.

Where are PMAC motor systems not suitable? The speed of some servomotor applications sometimes reaches 10,000 rpm, which is out of the PMAC motor range. In addition, without feedback for the PMAC, designers can find it difficult to locate and position to the pinpoint accuracy that servomotors must often deliver.

Let's compare PMAC motors to those most commonly used for servo applications — brushless DC motors. A brushless-DC drive waveform is trapezoidal; two of the motor's three leads are used for the phases, and the third is used for hunting — so it's regularly changing fields. In contract, the three leads of the PMAC are all actively used; input waveforms are sinusoidal, which is useful because these waveforms boost efficiency while minimizing noise and vibration. As mentioned, brushless DC motor and PMAC motor stator winding patterns are specialized for controllers that produce trap-

OPERATION, CAPABILITIES AND CAVEATS

OVERVIEW OF THE PROS AND CONS OF EACH MOTOR TYPE

	Induction motor	РМАС	Servomotor
SPEED	Less speed range than PMAC motors • Speed range is a func- tion of the drive being used — to 2,000:1 with an encoder, 120:1 under field-oriented control	VFD-driven PMAC motors can be used in nearly all induction-motor and some servo applications • Typical servomotor applica- tion speed — to 10,000 rpm — is presently out of PMAC motor range	Reaches 10,000 rpm • Brushless DC servomotors also operate at all speeds while maintaining rated load
EFFICIENCY	Even NEMA-premium efficiency units exhibit degraded efficien- cies at low load	More efficient than induction motors, so run more coolly under the same load con- ditions and throughout the given speed range	Designed to operate over wide range of voltages (as this is how their speed is varied) but efficiency drops with voltage
RELIABILITY	Waste heat is capable of degrading insulation essential to motor operation • Years of service common with proper operation	Lower operating temperatures reduce wear and tear, maintenance • Extend bearing and insulation life • Robust construction for years of trouble-free oper- ation in harsh environments	Physical motor issues are minimal; demanding servo applications require careful sizing, or can threaten failure
POWER DENSITY	Induction produced by squir- rel cage rotor inherently limits power density	Rare-earth permanent magnets produce more flux (and resultant torque) for their physical size than induction types. They are suitable for power-dense applications	Capable of high peak torque for rapid acceleration
ACCURACY	Flux vector and field-oriented control allows for accuracy that approaches that of servos	Without feedback, can be difficult to locate and position to the pinpoint accuracy of servomotors Note that PMACs can operate at "near servo" levels, but are not meant to have servo-type regulation. Therefore, if an application requires speed regulation, it's recommended that the designer specify a servo.	Closed-loop servomotor operation utilizes feedback for speed accu- racy to ±0.001% of base speed
COST	Relatively modest initial cost; higher operating costs	Exhibit higher efficiency, so their energy use is smaller and full return on their initial purchase cost is realized more quickly	Price can be tenfold that of other systems

ezoidal and sinusoidal current waveforms, respectively. One cannot differentiate the two by visual inspection.

A controller that produces trapezoidal waveforms is less costly than those that produce sinusoidal waveforms. However, sinusoidal controllers and motors produce more consistent shaft rotation than trapezoidal — and rotor inertia, motor rating and specific controller characteristics magnify the difference in performance.

One caveat: In low-voltage applications (anything below 110 V), traditional brushless DC or AC induction motors are still better choices than PMAC motors — although there's work being done to address the issues that arise in these situations. In short, brushless DC motors are commonly built for voltages down to 12 or 24 V. However, to wind a PMAC for this voltage is (in effect) taking a 200 or 300 hp and winding it for 200 V. Here, lead sizes can grow to the size of an average coffee cup (an inane result) and winding such a motor's

magnet wire (with a machine or by hand) is problematic, as manufacturers in this case must redesign the stator and rotor fairly extensively to ensure that the setup is physically possible.

AC induction motors versus PMAC motors

For an apples-to-apples comparison of AC induction motors to PMAC motors, we must consider both with a drive — as the latter requires a drive for operation, and cannot connect directly to supply power as typical AC motors can.

System efficiency is higher for a PMAC motor/drive setup from 40% to beyond 120% load. In addition, a PMAC motor exhibits higher power density than an equivalent induction motor: Rare-earth permanent magnets produce more flux for their physical size than the magnetic energy (and resultant torque) produced by an induction motor's squirrel cage rotor. In the latter, the effect of back EMF also is

more pronounced: Back EMF reduces current and works to slow the motor — and gets larger as speed increases. When a load isn't present, it approaches the input voltage magnitude, reducing efficiency. Consider that, in general, LEESON Platinum e[™] PMAC motors are rated for variable or constant torque to 20:1 without feedback (open loop) or 2,000:1 for closed loop (with an encoder).

Speed (input frequency) has less effect on PMAC motor efficiency than it does on AC induction motors, which translates into more energy savings at reduced speeds. PMAC motor losses (the inverse of efficiency) are 15% to 20% lower than NEMA Premium induction motors. Each efficiency index represents 10% fewer (or greater) losses than its neighbor, so efficiency rating is one to three indices higher. Depending on motor size, electric utility rate and duty cycle, designers can realize full return on a Platinum e[™] PMAC motor purchase in one year. PMAC efficiency ratings are one to three indexes above NEMA Premium, which translates to 10% to 30% fewer losses than a conventional motor. Electricity is estimated to comprise approximately 95% to 97% of the total life-cycle cost of electric motors, so energy savings significantly reduce the total investment.

In short, permanent magnet AC motors are inherently more efficient due to elimination of rotor conductor losses, lower resistance winding and flatter efficiency curve. Due to their synchronous operation, PMAC motors also offer better dynamic performance and speed-control precision — a major benefit in high-inertia positioning applications. Although in some cases the system power factor with a drive may not be as high as a motor-only induction machine, PMAC motors generally provide higher power density due to higher magnetic flux. This means more torque can be produced in a given physical size, or equal torque produced in a smaller package. Finally, PMAC motors generally operate more coolly than AC induction motors, resulting in longer bearing and insulation life.

Because a permanent-magnet rotor lacks conductors (rotor bars), there are no I²R losses — so everything else being equal, a PMAC motor is inherently more efficient.



Typical integral horsepower inverter motor performance

On the integral-horsepower curves, consider how the AC inductionmotor curve past 60 Hz falls off asymptotically to the X axis: Although it outputs constant torque to 60 Hz (and typically outputs constant horsepower 60 Hz to roughly 90 Hz) at about 35% to 40% load, the torque falls off. In contrast, a PMAC is stable from the 40% load line to roughly 120% to 150% and maintains system efficiency and torque.



Typical fractional horsepower inverter motor performance

Let's say we have a 5-hp induction motor for an 89.5% NEMA Premium efficiency value. In contrast, a comparable PMAC motor (LEESON's Platinum e[™]) built after December 2010 (when the Energy Independence and Security Act or EISA went into effect) exhibits 91.7% efficiency.

On one specific integral-horsepower line (of LEESON's Platinum e[™] PMAC motors), the winding design has shorter end turns and a concentrated bobbin-type winding. Unlike a distributed winding, used in induction machines, there are no shared slots — so the potential for phase-to-phase shorts is eliminated. Shorter end turns reduce waste and make more room in the housing for more active material, enhancing power density (as end turns do nothing to generate torque).

PMAC sound and vibration is often comparable to that of an induction motor, though the sound and vibration of PM motors varies widely from manufacturer to manufacturer and models designed for quiet operation exist. This tends (as with most other motor types) to depend on the type of application for which a specific motor is designed.

Although the term *service factor* (SF) often is misunderstood and not recognized by the International Electrotechnical Commission (IEC), it's still commonly applied to describe the maximum output of NEMA motors. LEESON's Platinum e^{im} PMAC motors have a Service Factor (SF) of 1.0 on inverter power, which is comparable to that of inverter-duty induction motors. Operating any motor beyond its rated power results in additional (possibly detrimental) heating. Intermittent operation above rated power is most normally acceptable, as long as its components can withstand the additional thermal stress.

On a similar note, reserve torque capability is an expression of a motor's ability to safely deliver increased torque, due to higher peak torque capability, and is subject to the drive's ability to deliver increased current. LEESON's Platinum e[™] PMAC motor has a reserve torque capability of 150% for 60 seconds.

MAKING THE CHANGE TO PMAC MOTORS

Most applications compatible with induction motors can utilize PMAC motors. In centrifugally loaded variable speed applications (pumps, fans and blowers), PMACs boost efficiency — and, in many instances, can direct-drive these designs. Fans are unique in that they're typically sized by torque; yet here, direct-driving PMAC motors can eliminate the need for belts, pulleys and sheaves. This in turn simplifies maintenance, which is particularly helpful where fans are installed on roofs.

In applications that incorporate belts, chains or gearboxes, PMACs boost power density — and it's these applications in which reducing or eliminating power transmission devices makes the most improvement in efficiency and reduced maintenance cost.

There are situations for which direct driving isn't possible or desirable. Consider conveyors driven by gearbox-fitted motors: Here, a PMAC motor may not be able to eliminate the need for a gearbox, but can typically help designers reduce the gearbox by a size or two — which then allows downsizing of other equipment as well. For example, a 48-frame PMAC can carry 72 in.-lb of torque, which equates to roughly 4 hp at 3,600 rpm. One caveat: PMACs are not particularly suitable in fixed-speed applications, as PMAC motors require PM drives.

If an average AC induction motor is replaced or retrofitted with a PMAC system, typically the drive also must be replaced. The drive topologies and logarithms are different; divergent, too, are the software and ladder logic, particularly with regards to how the two drive types handle back EMF. In addition, the motor must be able to communicate with the drive and vice versa. Stated another way, PMAC motors are controlled by a PWM AC drive similar to those used with induction motors, but with software to control a PM machine.

In most situations, replacing existing induction motors with PMACs requires no mechanical changes to the equipment. In addition, proprietary tools abound to simplify conversion.

• A Performance Matched Solution[™] for LEESON's PMACs ensures that the latter are tested and qualified with RBC PM drives plus a variety of commercially available PM drives to ensure superior performance. A list of qualified drives is available upon request, while testing is ongoing with others.

• Platinum e[™] PMAC motors incorporate patented IRIS[®] Insulation to provide long, reliable service life under the stresses of today's fast switching IGBT-based PM drives and protection from voltage stresses imposed by PM-type operation.

• Due to the incorporation of a terminal block (IHP only) for electrical connections, Platinum e[™] PMAC motor installation is quicker and safer compared to flying leads.



Platinum e[™] IHP integral-horsepower PMAC motors are equipped with a full Class H insulation; however, the design intentionally limits operating temperature to no more than Class B rise, for extra thermal protection and longer insulation life.



USEFUL FORMULAS

Converting hp to kw: hp \cdot 0.746 (kw/hp) Converting kw to hp: hp \div 0.746 (kw/hp) or kw \cdot 1.3410 Efficiency: kw (output power) / kw (input power) \cdot 100% Rule of thumb formula for hp: (torque \cdot f.l. rpm) / 5,252 Actual equation for hp: Torque \cdot 33,000 / ($2 \cdot \pi \cdot$ f.l. rpm) kva/hp: $\sqrt{3} \cdot v \cdot l.r.a.$ / (1,000 \cdot hp) Lr.a.: kva/hp \cdot 1,000 \cdot hp \div (volts $\cdot \sqrt{3}$) Percent slip = Synchronous rpm - f.l. rpm \div (synchronous rpm) Synchronous rpm = f \cdot 120 \div np where np = Number of poles and f = Frequency = 60 Hz Hand calculate full load amps (fla) = (hp \cdot 746) / (volts \cdot efficiency \cdot power factor) Efficiency and power factor (pf) is at full load, and entry is a decimal

SUGGESTED READING

Electrical Machinery & Transformers — 2nd Ed. Guru and Hiziroglu.

Electric Machines – Steady State Theory and Dynamic Performance. Mulukutla S. Sarma

DC Motors Speed Controls Servo Systems — 4th Ed. Electro-Craft Corp. Handbook

Handbook of Small Electric Motors. William Yeadon & Alan Yeadon.

Switched Reluctance Motor Drives – A Reference Book of Collected Papers. T.J.E. Miller, Ed. – University of Glasgow, Intertec Communications Inc.

Induction Machines – Their Behavior and Uses. P.L. Alger

Design of Electrical Apparatus. J.H. Kuhlman

Theory and Design of Small Induction Motors. C.G. Veinott

Electric Machinery. M. Liwschitz-Garik and C.C. Whipple

FREQUENTLY ASKED QUESTIONS – PERMANENT MAGNET AC MOTORS (8/10/2011)

- Q. In terms of construction, how do Permanent Magnet AC (PMAC) motors differ from AC Induction motors?
- A. In the broadest sense, the major difference is in the rotor itself. In a squirrel cage induction motor, current is induced into the rotor from the field (stator) through the air gap, and conducted through aluminum (or other material) bars, which are most often die cast in the slots of the rotor laminations. In the case of a PMAC motor, the rotor itself contains permanent magnet material, which is either surface-mounted to the rotor lamination stack or embedded within the rotor laminations. In either topology, electrical power is supplied through the stator windings.
- Q. What are the primary benefits of PMAC motor versus AC Induction?
- A. Permanent Magnet AC motors are inherently <u>more efficient</u> due to elimination of rotor conductor losses, lower resistance winding and "flatter" efficiency curve. Due to their synchronous operation, PMAC motors offer <u>more precise speed control</u>. PMAC motors provide <u>higher power density</u> due to the higher magnetic flux as compared with induction machines. Finally, Permanent Magnet motors generally operate cooler, resulting in <u>longer bearing and insulation life</u>.
- Q. What is the difference between "axial" and "radial" flux motors?
- A. In an axial flux motor, the magnetic force (through the air gap) is along the same plane as the motor shaft, i.e. along the length of the motor. A radial flux motor is the more traditional design, in which the magnetic force is 90° (perpendicular) to the length of the motor/shaft. Think about axial flux like the disc brakes in your vehicle, where the disc rotates like the rotor in an axial flux design. Axial flux is not peculiar to permanent magnet motors.
- Q. What applications are more suitable for axial- versus radial-flux designs?
- A. The answer depends upon which engineer you speak with, as some are "axial fans" and others favor radial. Seriously, it most often comes down to "form factor": does the customer require a longer, skinnier (radial) motor or is a "pancake" (axial) design more appropriate for the application? The "tie breaker" may be in the form of cost, as the axial design, once tooled for production, provides equivalent torque but uses less active material...i.e. it's more "power dense".
- Q. What are some of the major differences in performance between AC Induction and PMAC?

A. The most obvious performance difference is that a PMAC motor rotates at the same speed as the magnetic field produced by the stator windings; i.e. it is a synchronous machine. If the field is "rotating" at 1800 rpm, the rotor turns at the same speed. An induction motor, on the other hand, is considered an asynchronous machine, as its rotational speed is slightly slower than the magnetic field's "speed". An asynchronous motor is said to have "slip" (the difference between the motor's physical speed of, say, 1750 rpm, and its stator's magnetic speed of 1800 rpm) and cannot produce torque without this difference in speed, as the rotor is constantly trying to "catch up" with the magnetic field. The synchronization of PMAC results in improved efficiency, better dynamic performance and more precise speed control...a major benefit in positioning applications.

Other performance differences include higher efficiency and power factor in a PMAC motor (although system power factor...with a VFD...may not be as high as a motor-only induction machine). Since a permanent magnet rotor lacks conductors (rotor bars), there are no fR losses, so with everything else equal, a PMAC motor is inherently more efficient. Shorter end turns, due to Platinum e's winding methodology, provides a number of additional benefits (see next question).

Generally speaking, PMAC motors provide higher flux density than a comparable induction motor. This means that more power (torque) can be produced in a given physical size, or equal torque produced in a smaller package.

- Q. Is the winding different in a Platinum e[™] motor?
- Platinum e[™] IHP motors utilize a "concentrated winding"...essentially a bobbin winding. Several notable benefits are derived from this: 1) Unlike a "distributed winding", used in induction machines, there are no "shared slots"; this essentially eliminates the potential for phase-to-phase shorts. 2) Shorter end turns reduce waste and make more room in the housing for more active material, contributing to enhanced power density (end turns do nothing to generate torque).
- Q. What's the difference between PMDC, PMAC, Brushless AC, PMSM (Permanent Magnet Synchronous Motor) and BLDC (Brushless DC)?
- A. PMDC motors typically employ permanent magnets affixed to the inside of the motor frame, rotating wound armature and commutator (brushes). PMAC, PMSM and Brushless AC are synonymous terms. They are PM machines that operate on a PWM AC drive or control similar to an induction motor but with software to control a PM machine. BLDC motors are very similar to PMAC machines in terms of construction, but utilize DC (trapezoidal) drives rather than AC ("sine") drives, which are used to control PMAC motors.
- Q. Are Platinum e[™] motors suitable for Variable or Constant Torque applications?
- A. Yes. The same motor can be used in either mode. The VFD and application parameters will dictate to the motor how much torque to produce at any given speed. The flexible design makes Platinum e[™] the logical choice when variable speed operation and ultra-high motor efficiency are key customer needs.
- Q. What is the useful speed range for PMAC motors, as compared to AC Induction?
- A. PMAC machines typically have a wider speed range than AC Induction machines. However the number of poles may be different for the motors being compared and speed range is also a function of the drive being used so it is best to check with the manufacturer about your specific speed range. In general, Platinum e[™] motors are rated for variable- or constant-torque to 20:1 without feedback (open loop) or 2000:1 closed loop (with encoder).
- Q. Explain "Back EMF".
- A. Back EMF is the voltage generated by a rotating permanent magnet machine. As the rotor spins...either <u>with or without</u> power applied to the stator windings...the mechanical rotation generates a voltage, i.e. becomes a generator. The resultant voltage waveform is either shaped like a sine wave (AC) or a trapezoid (DC), depending upon the power supply from the drive. This characteristic is the major difference between "Permanent Magnet AC" (a.k.a. "Brushless AC") and "BLDC" (Brushless DC). The faster the rotor spins (again, with or without power), the higher (BEMF) voltage is generated.
- Q. Why is the Platinum e[™] motor's maximum speed limited by Back EMF?
- A. (Re-read the previous question/answer first). Motor BEMF increases directly with motor speed. The motor is connected to the electronic drive. The electronic components in the drive are designed for a maximum voltage above the rated voltage of the drive. Normally the motor and control are designed to operate well below the maximum voltage of the components. However if the motor speed exceeds the design speed range (either being powered from the control or being driven by the load) it is possible to exceed the maximum voltage the drive components and failures would result. Note that the drive is capable of controlling or "limiting" motor BEMF when it is

operating properly. However if the drive faults and losses control during this over-speed condition it cannot protect itself.

- Q. Should the user exercise extra caution when the shaft is rotated, even with power off?
- A. Absolutely! Touching the terminals while the shaft is rotating (wind-milling) will produce a shock hazard. If the shaft is turning fast enough...and generating higher voltage to the terminals...touching the connections may result in serious injury or death.
- Q. What other safety considerations are peculiar to PMAC motors?
- A. Rare earth permanent magnets, such as Neodymium or Samarium Cobalt, have very strong magnetic properties (the reason for selecting these materials for our motor, as they produce high flux levels in the motor), and must be handled very carefully. Beyond the potential "pinching hazard", those with pacemakers or other medically-implanted devices (including hearing aids) should exercise extra caution when working around these strong magnetic fields. Cell phones and credit cards may also be at risk. The good news is that, when the rotor is secured within the enclosure, radiated magnetic energy is no higher than that of an induction motor. A new Installation, Operation and Maintenance manual, Form 5968M, has been developed for 180-280 (IEC 112-180) frame Platinum e[™] motors, and is shipped with every new motor.
- Q. What is "cogging torque", and is this an important consideration in selecting a PMAC motor?
- A. The most basic source of cogging torque is the interaction or attraction of the permanent magnets and the steel structure of the stator as the motor rotates. These attractions and overcoming them prevent the rotor from turning smoothly. Another source is the interaction of the rotor magnets and the stator winding when it is energized, due to harmonics. Cogging is often an undesirable feature, causing noise, vibration and non-uniform rotation, so during product development, minimizing this effect was a design "CTQ" (Critical To Quality). As a result, Platinum e[™] motors have extremely low cogging torque, resulting in smoother operation at all speeds, virtually eliminating torque and speed "ripple".
- Q. Are permanent magnets subject to "demagnetization"?
- A. High current or high operating temperatures can cause magnets to lose their magnetic properties. The drive reduces the risk of high current "demag", as these devices are equipped with overcurrent protection. The motor design minimizes the possibility of excessive temperatures causing magnet failure, due to the selection of high temperature magnets, incorporation of thermostats and low operating temperature of the motor. Permanent magnets, once demagnetized, cannot recover, even if the current and/or temperatures return to normal levels.
- Q. Can PMAC motors be operated without a drive?
- A. No. All commercially available true permanent magnet motors require a variable frequency drive to operate. There is on-going research into a "line start PM" motor. There are performance characteristics of this design that have to be taken into consideration to determine if this type of motor is suited for your particular application.
- Q. What is a "switched-reluctance" (S/R) motor, and how is it different from PMAC?
- A. Switched Reluctance motors...which also require a drive...do not utilize permanent magnets in the rotor; rather the topology embodies a rotor core with protruding "poles"...the protrusions are strongly magnetically permeable, while areas *surrounding* these protrusions are weakly magnetically permeable due to the slots cut into them. Coils in the stator act as an electromagnet that attracts the nearest rotor pole. Stator coils are synchronously energized with rotor rotation, with overlapping phases. S/R motors are known for producing high efficiency and good motion-control, producing 100% torque at "stall" indefinitely. Due to their winding design, and resultant

decrease in end turn height, S/R motors can also be used in applications requiring a smaller "form factor" (size). Finally, S/R motors can generally be operated at higher speeds, as they lack the "BEMF" constraint of their PMAC brethren.

- Q. How many magnetic "poles" does the Platinum e[™] motor have?
- A. Platinum e[™] FHP (fractional horsepower, meaning 48-56/140 frame) motors are a 6-Pole design. Platinum e[™] IHP motors (180 frame and larger) utilize a 10-Pole rotor design.
- Q. Why does a PMAC motor have more "poles" than an equivalent AC Induction machine?
- A. It doesn't have to, but we chose this topology to reduce cogging torque.
- Q. Since the Platinum e[™] product line has a fixed number of poles, how do you get various base speeds?
- A. Speed is a function of frequency...the same as it is with induction motors. The higher the input frequency from the drive, the faster the motor rotates. As is the case with most synchronous motor manufacturers, the pole count is most often held constant while the input frequency dictates the motor's speed. In the case of the 48 frame motor, which has 6 poles, the motor's input frequency from the drive must be 90 Hz in order to obtain 1800 RPM. In order to obtain the same speed (1800) in the 10-Pole 180 frame motor, input frequency must be 150 Hz. Here is a simple formula to calculate required input frequency (Hz) when # poles and speed is known:

$$Hz = \frac{RPM \times \#Poles}{120}$$

- Q. How do the performance curves compare between PMAC and IM (induction motor)?
- A. There are a series of performance curves, comparing Platinum e[™] PMAC with an equivalent induction motor. These include <u>Constant Speed Load Curves</u>, <u>Variable Speed Variable Torque</u>, and <u>Variable Speed Constant Torque</u>.
- Q. What impact does speed (input frequency) have on the efficiencies of induction and PMAC?
- A. Generally speaking, a PMAC motor has a "flatter" efficiency curve than its IM counterpart, providing even more energy savings at reduced speed.
- Q. How much additional efficiency should a user expect to obtain from a PMAC motor?
- A. In general, PMAC motor losses (inverse of efficiency) are 15-20% lower than NEMA Premium induction motors. Since each efficiency index represents 10% fewer (or greater) losses than its neighbor, efficiency ratings will be 1-3 indices higher. Depending upon motor size, electric utility rate and duty cycle, customers could see as little as a one-year payback by using Platinum e[™] PMAC motors.
- Q. What are servo and stepper motors, and how are they different from PMAC?
- A. Servo and stepper motors are utilized in many motion control applications, where low inertia, fast response and high dynamic performance are important. Servo motors are very similar to PMAC motors but use special controllers (called "amplifiers") and special feedback to control position rather than just speed. Step motors are somewhat similar to Switched Reluctance, and "step" to each defined rotor position, resulting in high repeatability and accuracy. The price for servo systems is quite high...often 10-20 times that of an equivalent rated induction motor. Applications requiring "near servo" performance may be excellent candidates for PMAC motors, as the cost/performance ratio may be much more beneficial to the user.

- Q. What is "power density", and how does it relate to PMAC motors?
- A. Power density is simply the ratio of output power or horsepower to physical size or volume of the motor. There are many factors such as material characteristics and temperature constraints that limit how much power a machine can deliver of a certain size. Different topologies and machine configurations address these limitations in various ways. For example, rare earth permanent magnets produce more flux for their physical size than the magnetic energy (and resultant torque) produced by an induction motor's "squirrel cage rotor". As such, a PMAC motor can have higher power density than an equivalent rated IM.
- Q. What is "form factor", and how does it relate to PMAC motors?
- A. Form factor is a different way of looking at power density. In this context, form factor refers to the physical (primarily dimensional) properties of the motor, which may be defined as the active materials or the overall envelope size. The simplest view of this is the frame size reduction potential of PMAC versus IM...assuming the same power rating. Another way of looking at this is the ability to "down-frame" the same power rating into a physically smaller package (frame size).
- Q. What is the motor's Service Factor, and how does this differ from "Reserve Torque Capability"?
- A. Platinum e's Service Factor (SF) is rated 1.0 on VFD power, which is in line with all other inverterduty induction motors. SF is an oft-times misunderstood concept, and its use is limited to NEMA motors (the IEC doesn't recognize SF). Operating any motor beyond its rated power will result in additional heating. Heat is the enemy. Intermittent operation above rated power is most normally acceptable, so long as its components can withstand the additional thermal stress. "Reserve Torque Capability" is an expression of the motor's ability to safely deliver increased torque, due to higher peak torque capability, and is subject to the drive's ability to deliver increased current. The Platinum e[™] motor has a Reserve Torque Capability of 150% for 60 seconds.
- Q. What is "saliency", and why is it important?
- A. Saliency typically refers to the difference in motor inductance at the motor terminals as the motor rotor is rotated. This difference corresponds to an "alignment" and "misalignment" of the rotor in the stator. This difference is one way motor drives use to determine the rotor position during operation and is used to control the motor.
- Q. Are all AC drives suitable for operation of PMAC motors?
- A. The drive used should be designed for use with permanent magnet machines. This is included in the specification for the drive and there is often a parameter to set to tell the drive that the motor attached is a PM motor. Some drives, not specifically designed for PM machines, will run and control a PM motor. Performance would typically not be as good in this case and this should be approved by the drive manufacturer before attempting. It is possible to damage the motor or drive if the drive is not set up properly or are mismatched.
- Q. What is the operating temperature of Platinum e[™] PMAC motors, how does this compare with induction, and what is the benefit?
- A. Platinum e[™] motors, because they are more efficient than induction motors and run cooler under the same load condition. This results in longer insulation and bearing life and reduces the amount of heat that goes into the operating environment. A general rule-of-thumb is that for every 10°C increase in operating temperature, insulation life is reduced by half; conversely every 10°C reduction in temperature <u>doubles</u> the insulation life. Platinum e[™] IHP (integral HP) motors are equipped with a full Class H insulation system but the design limits operating temperature to no more than Class B rise, providing very generous "thermal headroom"...and much longer insulation life.

- Q. Can Platinum e[™] motors accept the same modifications and accessories as their induction motor counterparts?
- A. Yes
- Q. How do sound and vibration levels compare, between PMAC and Induction?
- A. The sound and vibration of PM motors varies widely from manufacturer to manufacturer. This tends to depend on the type of application on which the motor is intended to be used. Platinum e[™] motors are designed for most general purpose applications with similar sound and vibration as an induction motor. In some cases the Platinum e[™] motor runs quieter and smoother than an induction machine. A sound and vibration comparison of a typical induction motor versus Platinum e[™] is available upon request.
- Q. How should I sell Platinum e[™] motors?
- A. This innovative new product should be presented to the customer as a means to reduce costs in the following critical areas of operation:
 - Energy cost Efficiency ratings are 1-3 indexes above NEMA Premium, providing electrical energy savings from day 1. This translates to 10-30% fewer losses than a conventional motor, and provides quick return on the investment. Electricity is estimated to comprise approximately 95-97% of the total life cycle cost of electric motors; therefore energy savings significantly reduce the total investment.
 - Maintenance cost and reliability Due to its lower operating temperature, Platinum e[™] motors require less frequent maintenance and offer longer bearing and insulation life. The robust construction of the motor is suitable for virtually any application, providing years of trouble-free operation in harsh environments.
 - Direct drop-in replacement for existing NEMA and IEC motors Under most circumstances, replacing existing induction motors with Platinum e[™] requires no mechanical changes to the equipment.
 - Performance Matched System[™] Motors have been tested and qualified with the Unico (RBC) drive as well as a variety of commercially available PM drives to ensure superior performance. A list of qualified drives is available upon request, while testing is on-going with others.
 - Protection from voltage stresses imposed by VFD Platinum e[™] motors incorporate the patented IRIS[®] Insulation System to provide long, reliable service life under the stresses of today's fast switching IGBT-based drives.
 - Protection from inverter-sourced bearing/shaft current The Platinum e motor is design-ready to accept a variety of devices to protect the motor from the potentially damaging effects caused by common mode voltage.
 - Shorter, more convenient installation Due to the incorporation of a terminal block (IHP only) for electrical connections, installation is quicker and safer compared to "flying leads".

In short, this is a highly featured, highly efficient innovation in motor technology, and should be sold based on the value it brings to the customer...not as a commodity/price sale. Target customers understand total life cycle cost and appreciate the product's many benefits.

- Q. What other supporting documentation is available to sell this new product?
- A. A variety of sales support materials are available on line or by request, which include product brochures, performance comparison curves, payback calculator (soon to be on line) and PowerPoint presentation. Of course, we offer the ability to produce prototypes to provide added assurance that the product will perform as stated. Beyond that, a "Birth Report" is supplied with every production motor, to provide baseline performance.

- Q. What are some typical applications for Platinum e[™] that I should be on the lookout for? Any I should stay away from?
- A. Virtually any application suitable for use of induction motors can utilize Platinum e[™] motors. If the customer is primarily interested in increased motor efficiency, look for centrifugally-loaded variable speed applications like fans and pumps. On the other hand, if they're using belts, chains or gearboxes, they will be more intrigued by this motor's higher power density, as it's in those applications where the benefits of reducing or eliminating power transmission devices becomes apparent, resulting in increased system efficiency and reduced maintenance cost. Sale of this type of motor into a "fixed speed" application will require a major effort, since the motor requires a VFD in order to operate.
- Q. Is a PMAC motor immune from voltage spikes from the drive, causing insulation breakdown and shaft voltages?
- A. Platinum e[™] motors are designed, in much the same way as inverter duty induction motors, to withstand voltage spikes from drives and wiring conditions. A major component is the patented IRIS[®] insulation system. The lower operating temperature also contributes toward longer insulation life on a drive.
- Q. What is commutation and how does the motor accomplish it?
- A. The term commutation comes from the world of DC motors. It refers to how current is routed to the right coils, in the DC rotor, at the right time to generate the torque needed by using brushes and a commutator. A commutator is round, mounted on the rotor shaft and has conductive pads on the O.D. on which the brushes rest. Current is conducted from the brushes to the commutator and then to the connected coils as the rotor spins. This term has been carried over to brushless DC motors where the brushes and commutator have been replaced by electronics and a sensor on the rotor shaft. In this case current is still "switched" but by electronics. The term loses meaning in the world of AC motors but still sometimes refers incorrectly to how the AC voltage is generated in the drive.
- Q. What agency approvals does the Platinum e[™] motor carry?
- A. UL approval has been obtained. CSA, cUL and CE approvals are pending at this time.
- Q. Where are Platinum e[™] motors manufactured?
- A. "FHP" (48 frame) is produced in West Plains, MO. "IHP" (180-larger) is produced in Wausau, WI.
- Q. What is the warranty term for Platinum e[™] motors?
- A. 36 months from date of first use, or 42 months from date of manufacture, whichever occurs first.
- Q. Are spare parts available?
- A. Yes. However, certain components of the rotor...particularly the magnets...are not available separately.
- Q. How are we handling repairs?
- A. All motors are to be returned to the plant of manufacture (West Plains for 48 frame, Wausau for 180 frame and larger) until instructed otherwise.

Remaining questions from Jim Murphy's "Platinum e PMAC Q&A Rev 2 JPM 7-19-11":

- Q. Who builds the controls/drives?
- A. 48 & 56 frame control/drive will be produced by RBC development team. The Integral motors will be packaged with a UNICO drive.
- Q. How are we partnered with a supplier?
- A. See above answer.
- Q. How do we supply or recommend a complete package?
- A. Again we can provide a Performance Matched Solution[™] with our control/drive or we can provide suggestions with regards to drives we have conducted motor tests with. Either way it's a Performance Matched Solution [™].
- Q. Can you provide more detail on the control: Is the drive just three phase input?
- A. 48 frame is Single Phase in to the drive and 56 frame is 3-ph input. Integral motors will use UNICO Drives or Customer supplied.
- Q. Can the drive be single phase 230V input 3 phase 230 to the motor?
- A. 48 frame will have 1-Ph input to the drive and 3-ph to the motor; Integral-UNICO is....
- Q. How many inputs and outputs does the drive have?
- A. 4 each for 48 and 56; 4 each for UNICO drive
- Q. What drive features will be standard? I.e.: like current limit, OL protection, and acceleration/deceleration rate
- A. All drives have these as standard features.
- Q. Does the drive have the capability to talk to external devices through mod-bus, Device Net and similar logic?
- A. Drives can be configured for all established communication protocols.
- Q. Will the drive follow a process signal like 4-20 ma and have a built it PID Loop?
- A. Yes.
- Q. Can the motor be line started?
- A. NEVER! A PMAC motor must be started and used with a PM Drive.
- Q. What is the speed reference required from an external source?
- A. It can be an analog signal, and encoder feedback, or a serial command from a feedback device on an axis you want to follow, or a PLS, or a POT, or any external device that can create and communicate a value to the drive. This is normally a velocity signal that you want to follow. It isn't labeled a command because it could be further processed in the drive before it is actually used as a command, e.g. you may want the drive to always go half the speed of the reference so that signal is internally divided by 2 and then sent to the closed-loop control as a command.
- Q. Can we use the PMAC being offered now in elevator applications?
- A. More design and research needs to be conducted with the PMAC Radial design before committing this to any elevator application. This would be a great candidate for Machine-Roomless Elevator (MRL) or an Axial Air-Gap PMAC design. Axial Air-Gap designs will be reviewed in the future for LEESON Electric.