Motors

Recent advances in motor technology can be found in areas such as automation, power / driver integration, and rare-earth magnets.

Switches put a new spin on motors

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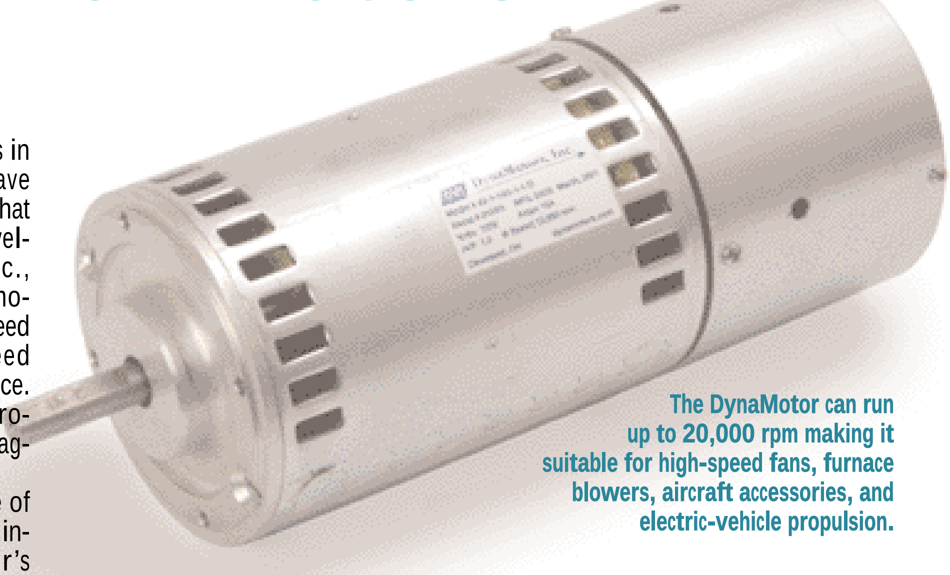


The DynaMotor can run up to 20,000 rpm making it suitable for high-speed fans, furnace blowers, aircraft accessories, and electric-vehicle propulsion.

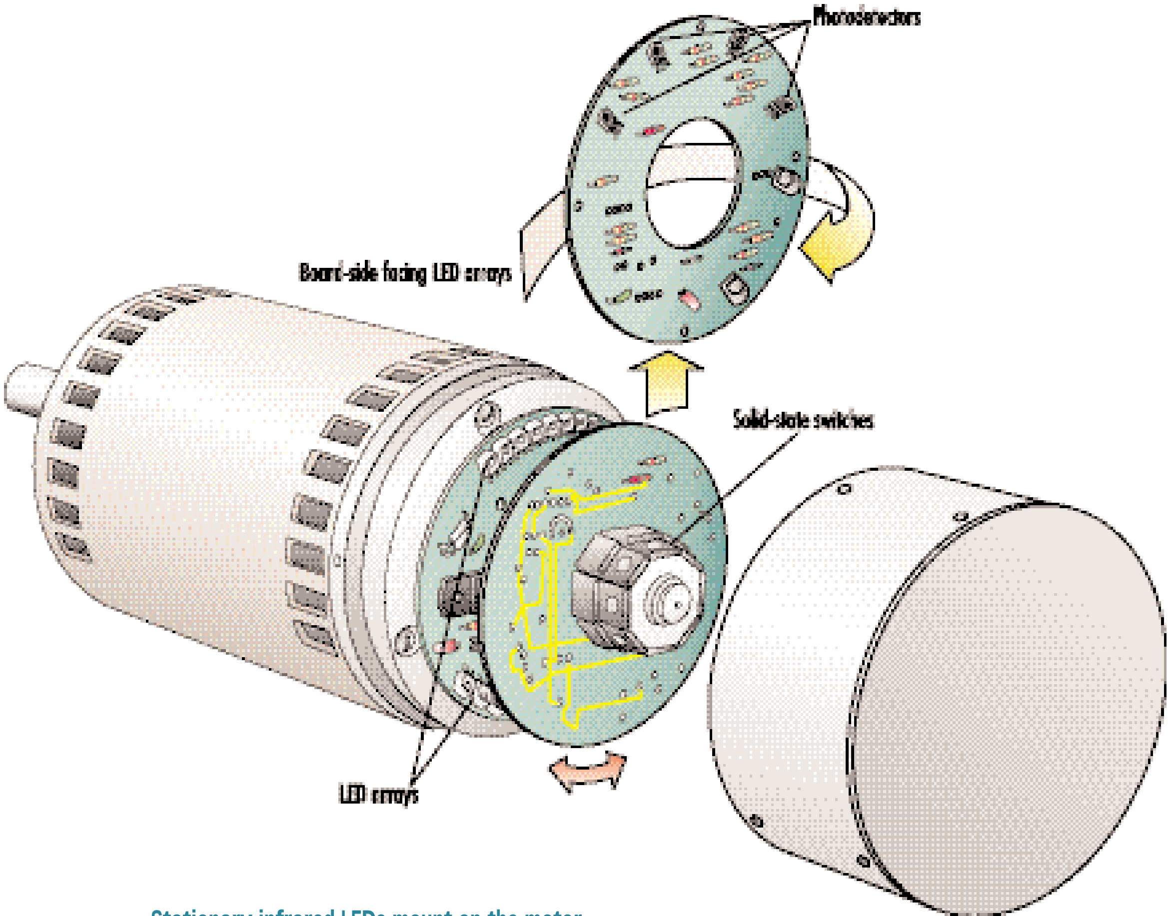
In recent years, improvements in motor and drive designs have generally been incremental. That has changed with recent development by DynaMotors Inc., Cleveland, of a totally integrated motor/drive that provides adjustable speed and high torque over a wide speed range even from a single-phase source. It is brushless, inexpensive, and produces no high-frequency electromagnetic interference.

The primary proprietary feature of the DynaMotor is a solid-state switch inserted into each coil of the motor's wound rotor. When the switch is open, there is no current or torque. Closing the switch lets current flow, which produces flux and torque. The flux from the salient-pole ac-stator field induces a voltage in the armature conductors. Each switch is turned on by an associated photodetector which is illuminated as it rotates past stationary LEDs mounted on the motor end-bell. Selectively turning one or more of the LEDs on or off controls the current, torque, speed, and direction of the motor.

Changing the timing and duration of switch actuation controls the magnitude and polarity of the torque. Because there are multiple coils on the armature, and the coils can be controlled individually and energized simultaneously, it is possible to maintain continuous positive or negative torque. In practice, the switches turn off when the current nears zero to eliminate transient switching losses.

An internal speed sensor provides feedback so the motor becomes a self-contained, closed-loop drive system. A potentiometer or keypad manually controls the motor, or a transducer or serial link can provide automatic control.

The motor combines features of ac and dc motors but also has unique characteristics. Its salient-pole stator is similar to a dc machine and does not create a rotating field, as used in other induction motors. However, as in an ac motor,



Stationary infrared LEDs mount on the motor end-bell. Rotating photodetectors and solid-state switches mount on the shaft outside the main motor housing to isolate them from heat and dirt and for easy maintenance. Armature coil conductors connect to the switches via slots in the shaft.

the stator field induces a rotor current. But because it doesn't follow a rotating field, speed is not related to line frequency. As a result, the motor's speed-torque curve is similar to that of a dc motor: high torque at low speed and maximum speeds higher than 3,600 rpm.

It can be configured to operate up to 20,000 rpm, and has good speed regulation without encoder feedback. A unique feature is that rotation of any horsepower motor can be reversed without contactors or additional power semiconductors merely by changing the sector in which the switches are closed. Also, having only a single stage of power conversion (both ac and dc drives need two) and no power capacitors reduces power components and losses.

The motor uses standard parts with normal tolerances and off-the-shelf electronic components. Having fewer electronic parts typically increases reliability and reduces maintenance. The motor runs directly from a single or three-phase ac line, which eliminates the external drive-control cabinet as well as the interconnecting power and feedback-signal wiring. The switches operate at low frequency and all semiconductor switches are on the armature so the motor stator acts as an effective filter cutting power-line noise and EMI, eliminating the need for external filters and chokes. The motor's line current is sinusoidal, which eliminates the problems associated with discontinuous line current generated by other types of drives.

The DynaMotor can run efficiently from 400-Hz aircraft power, where the motor's high speed gives it a favorable power-to-weight ratio. It can also operate directly from a varying-speed alternator in hybrid vehicles, eliminating the need for variable-ratio transmissions. For battery-only electric vehicles, two or more motors can operate from a single square-wave inverter with each motor running at different speed/torque points.

While development efforts have thus far concentrated on single-phase motors, DMI plans to build larger three-phase units. An additional goal is a regenerative motor/drive without additional power devices. ■

Automation comes to winding lines

The new motor-winding system represents an investment of over $3 million. Over 100 Baldor motors and controls are utilized in the operation of the system, which measures 125 × 65 ft. It's flexible and lets the company produce motors in any volume.

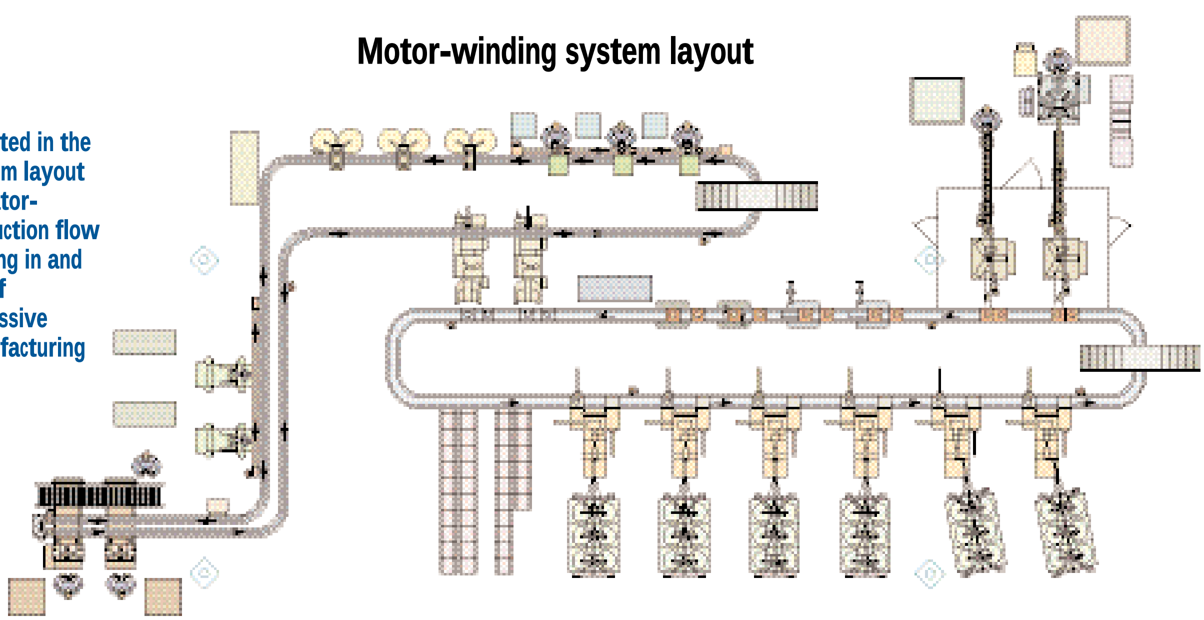
Baldor Electric Co., Fort Smith, Ark., recently installed a new manufacturing system for electric motors, shortening lead times and giving greater manufacturing flexibility.

The new winding system automates virtually the entire manufacturing process, which includes welding and insulating stator laminations, coil winding, testing, and insertion into the motor housing. Stators progress through multiple manufacturing cells along conveyors with minimum human intervention. The line completes a stator approximately once every 25 min at full capacity, versus a turnaround time of nearly 3 hr using the old process. The system produces commercial motors designed for general-purpose applications with low to medium starting torque in horsepower ratings from 1/6 through 2 hp.

Baldor servomotors, drives, and Baldor MINT programming software, are at the heart of the new manufacturing assembly line. John McFarland, Baldor president and CEO commented that the new system will let the company better compete with foreign motors, offering better quality, more variety, and shorter lead times.

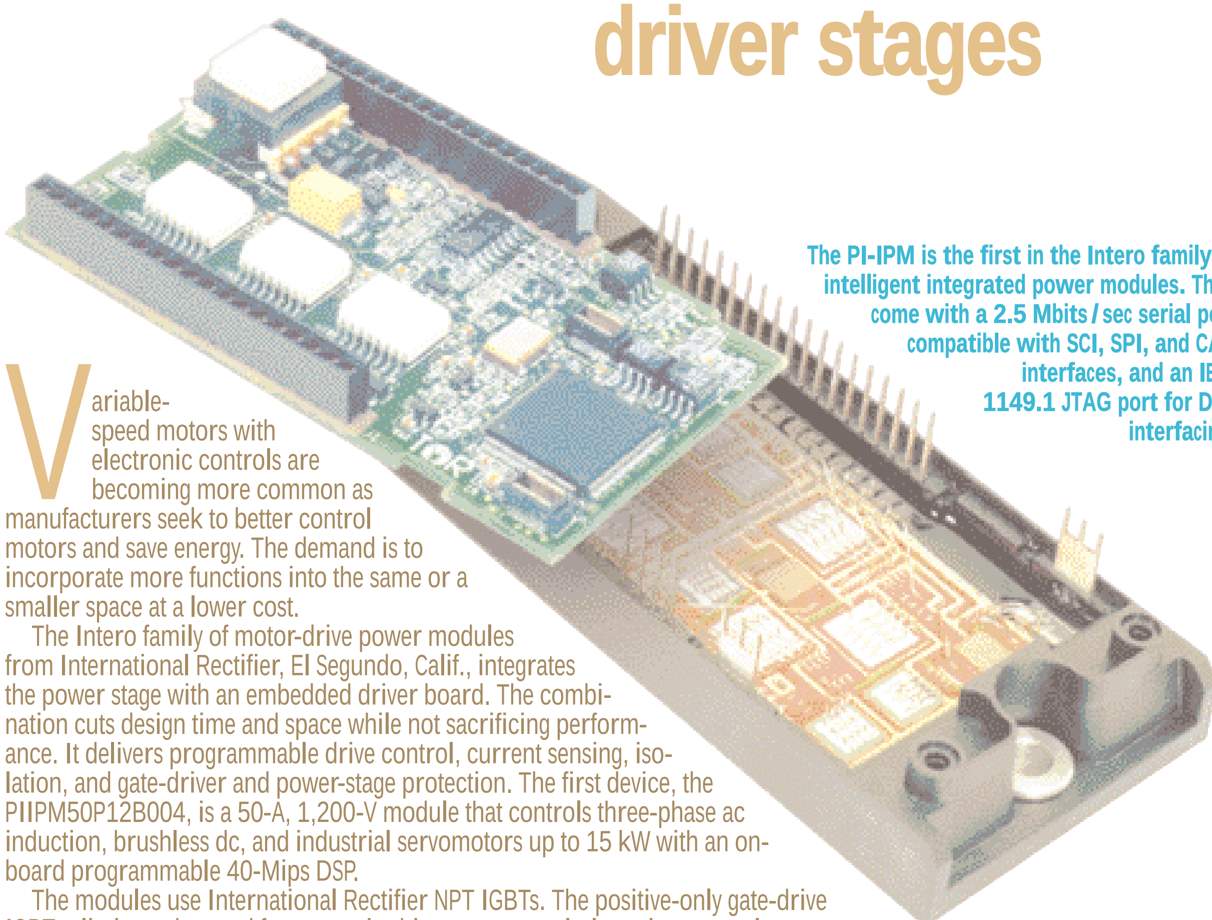
Circle 622

Motor-winding system layout



Depicted in the system layout is stator-production flow moving in and out of successive manufacturing cells.

Motor modules combine power, driver stages



The PI-IPM is the first in the Intero family of intelligent integrated power modules. They come with a 2.5 Mbits/sec serial port compatible with SCI, SPI, and CAN interfaces, and an IEEE 1149.1 JTAG port for DSP interfacing.

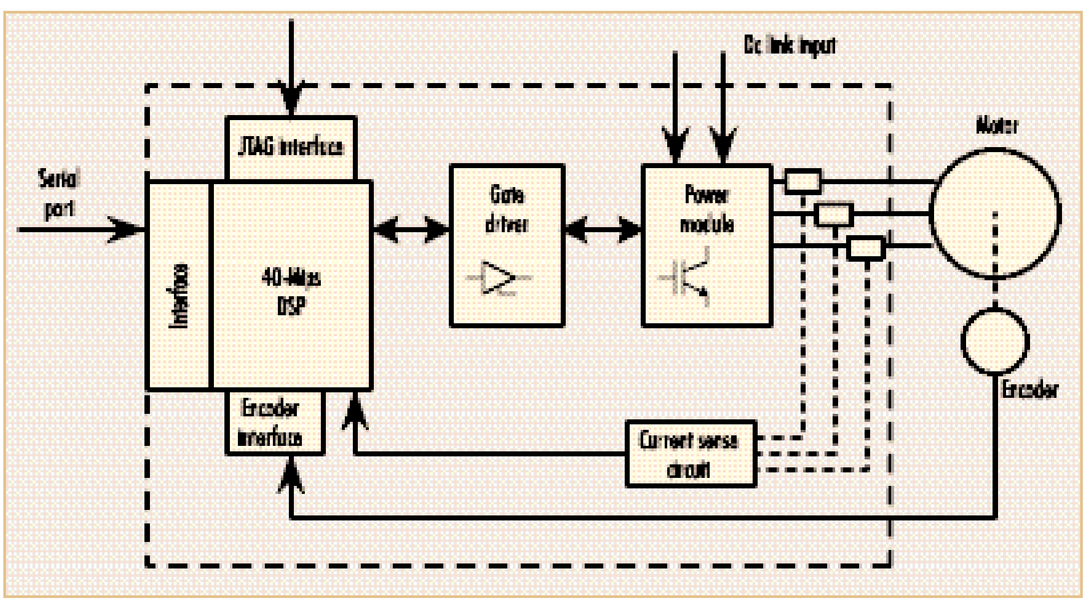
Variable-speed motors with electronic controls are becoming more common as manufacturers seek to better control motors and save energy. The demand is to incorporate more functions into the same or a smaller space at a lower cost.

The Intero family of motor-drive power modules from International Rectifier, El Segundo, Calif., integrates the power stage with an embedded driver board. The combination cuts design time and space while not sacrificing performance. It delivers programmable drive control, current sensing, isolation, and gate-driver and power-stage protection. The first device, the PIIPM50P12B004, is a 50-A, 1,200-V module that controls three-phase ac induction, brushless dc, and industrial servomotors up to 15 kW with an on-board programmable 40-Mips DSP.

The modules use International Rectifier NPT IGBTs. The positive-only gate-drive IGBTs eliminate the need for a negative bias power supply, lowering power losses and reducing trailing currents for lower losses at higher frequencies. This lets the embedded driver board mount directly on top of the power stage.

The smaller size means smaller heat sinks and EMI filters. Also, the power stage can be placed closer to the motor, reducing cable length and noise.

Circle 623



Neo magnets boost fuel economy

Higher efficiency motors, using neodymium-iron-boron magnets, reduce loading on alternators and batteries.

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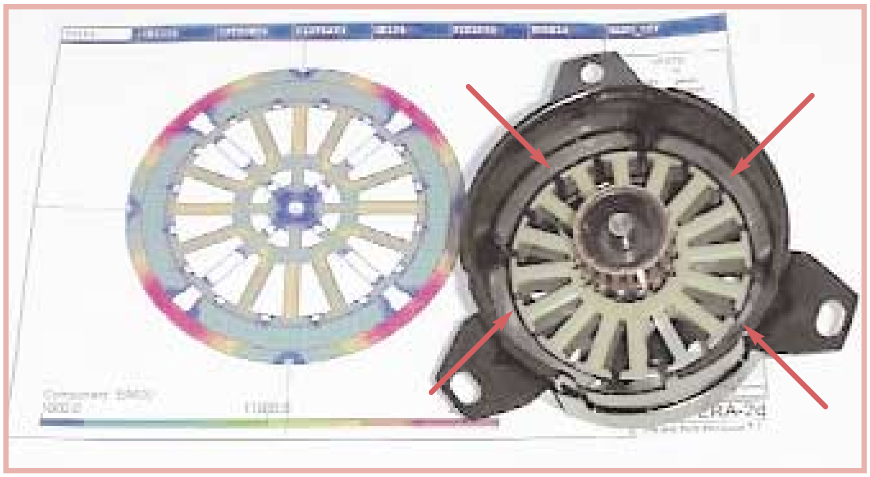
As of last year, the average car employed about two-dozen electric motors, actuators, and sensors containing permanent magnets. This number is expected to increase to well over 30 by 2005. The growing use of electromechanical devices places increasing loads on the power system. So automakers are seeking out ways to increase efficiency and lessen alternator current draw.



A disassembled ECF motor has four new injection-molded Neo arcs installed (arrows), and the armature winding removed in preparation for rewinding.

The engine-cooling fan (ECF) and the heating/ventilation/air-conditioning (HVAC) blower motors have the greatest combined current draw and operating duty cycle. These two brushed-dc motors, using ceramic ferrite magnets, currently draw a combined continuous 35 to 40 A. The ECF motor alone can draw as much as 30 A under peak load conditions.

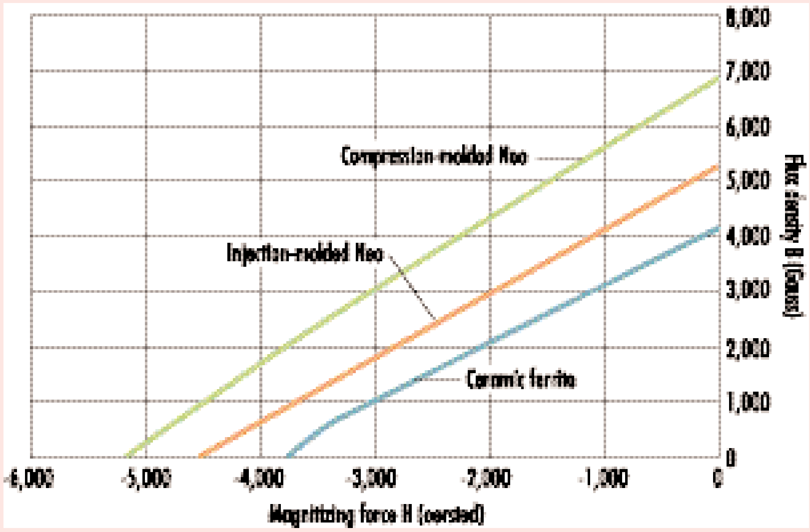
As automakers look for ways to cut power consumption, alternative magnetic materials could be one solution. Higher-energy, permanent-magnet materials allow for higher efficiency motors and actuators to be produced. They have become increasingly practical thanks to improvements in magnetic, mechanical, and thermal properties of neodymium-iron-boron ("Neo") magnetic materials, together with the evolution of low-cost, high-volume injection-molding processes for magnets.

The development of Neo magnets has had a significant technical and economic impact on the traditional electric-motor industry. But they've been slow to gain acceptance in the automotive sector. The reason: the higher cost of Neo compared to ferrite, without regard to the value it can add to most applications. Continual price reductions in both Neo magnets and the powders from which they're made are finally putting them in many low-cost, high-volume applications.

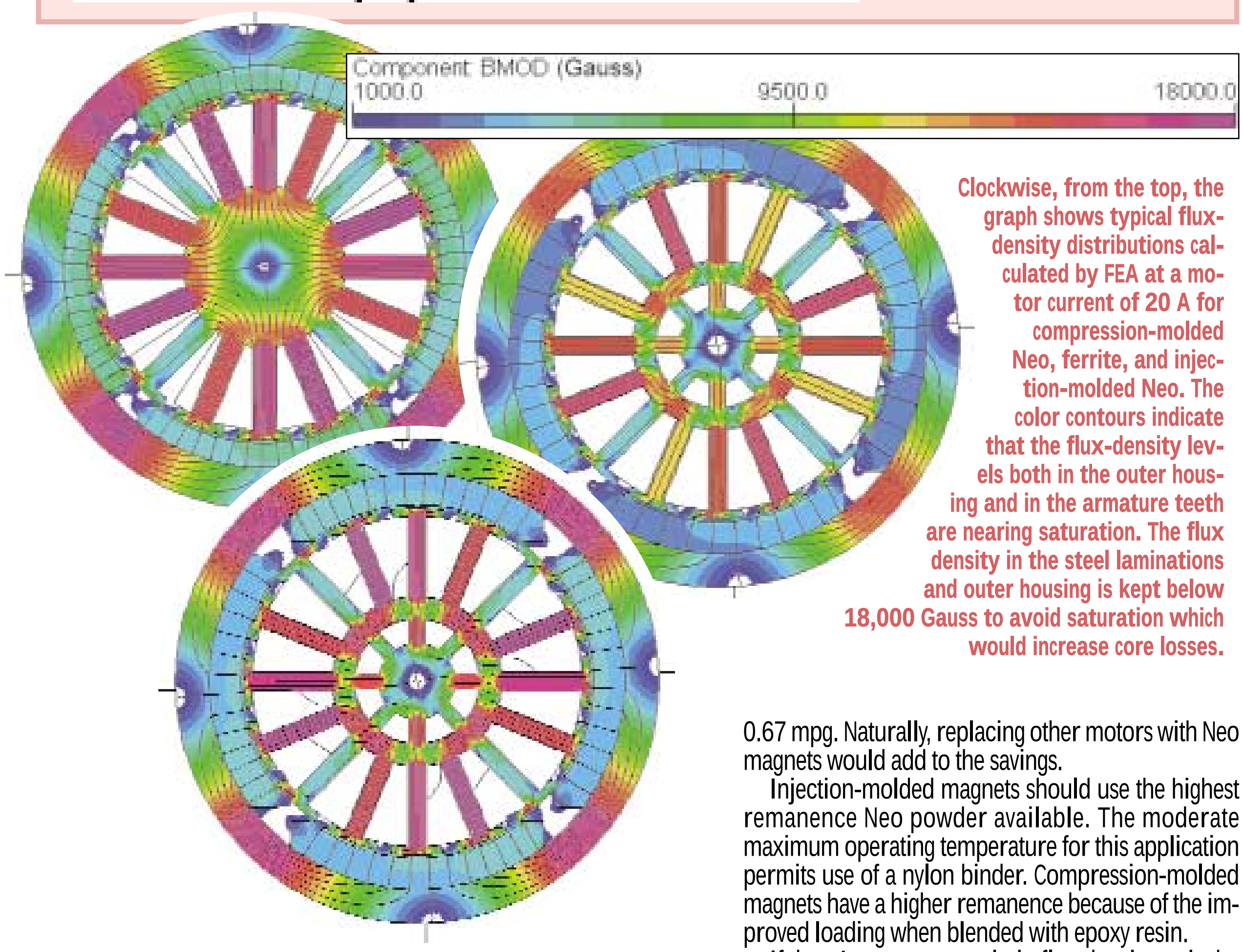
A dual ECF fan (dual motor) assembly on a 2000 Ford Taurus was used to test the replacement of ferrite with Neo magnets. The motor, which has an outer diameter a little over 4 in., is a four-pole, 16-slot brushed-dc machine with sintered ferrite-magnet arc segments. It operates within an ambient temperature range from –40 to 110°C, but the maximum magnet temperature might reach 130°C.

Directly replacing ferrite magnets with injection-molded Neo on the two ECF motors and the single HVAC motor reduces total current by 6.0 A under normal continuous operation, and 9.0 A at peak operation. An optimized design would improve these savings by a further 5 to 10%. Replacing ferrite with compression-molded Neo reduces currents by 13.2 A and 16.8 A for continuous and peak operation, respectively.

The benefits of a lower current drain can be quan-



Permanent-magnet performance is measured by a demagnetization characteristic. The standard ceramic ferrite magnet has the lowest magnetic properties, compared to two different types of bonded Neo magnet. The higher the remanence (B_r) of a magnet, the better it can reduce current draw in a dc motor. The product of a magnet's operating flux density (B) and its magnetizing force (H) is a direct measure of its energy density. The maximum, $(BH)_{max}$, is commonly used as a figure of merit for a permanent-magnet material.

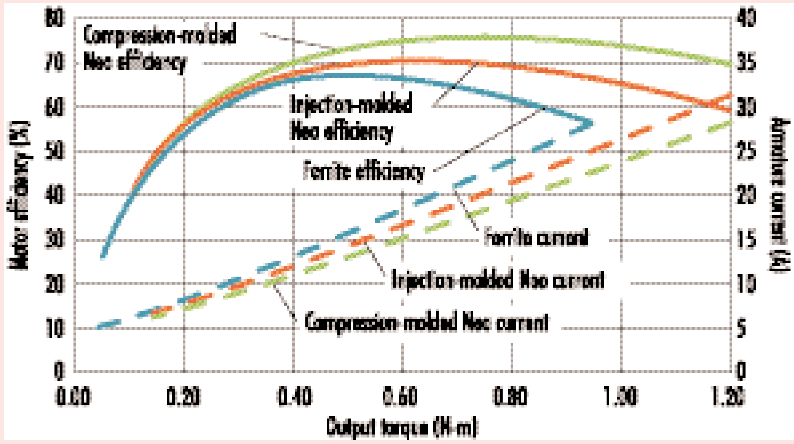


Clockwise, from the top, the graph shows typical flux-density distributions calculated by FEA at a motor current of 20 A for compression-molded Neo, ferrite, and injection-molded Neo. The color contours indicate that the flux-density levels both in the outer housing and in the armature teeth are nearing saturation. The flux density in the steel laminations and outer housing is kept below 18,000 Gauss to avoid saturation which would increase core losses.

tified. Estimates of improvement in fuel efficiency are about 0.04 mpg/A. So fuel economy will improve by 0.24 to 0.36 mpg with just a simple, nonoptimized Neo/ferrite magnet swap in the three blower motors. Using an optimized design with compression-molded Neo magnets improves fuel economy by 0.53 to 0.67 mpg. Naturally, replacing other motors with Neo magnets would add to the savings.

Injection-molded magnets should use the highest remanence Neo powder available. The moderate maximum operating temperature for this application permits use of a nylon binder. Compression-molded magnets have a higher remanence because of the improved loading when blended with epoxy resin.

If there's not a great gain in flux density, as is the case with injection-molded Neo magnets, the existing ferrite arc segments can be directly replaced. This allows use of existing motor housing and armature assemblies. When the original motor was modified, the greater air-gap flux helped lower the motor's current draw and increase efficiency.



Torque versus current and torque versus efficiency graphs show that the total armature current is reduced and the efficiency is increased for any given output torque by using Neo magnets.

When comparing similarly sized motors, the motor constant (K_m) is a reliable figure of merit, and a higher K_m generally translates to higher motor efficiency.

The motor-constant equation is:

$$K_m = K_t/R^{0.5}$$

where K_t = motor's torque constant (N-m/A) and R = armature-winding resistance (ohms). The increased air-gap flux density yields a higher K_m, which can be used either to increase K_t while retaining an identical winding, or to retain K_t while reducing R, or to both increase K_t and reduce R by lesser amounts. Choosing the latter reproduces as closely as possible the original ferrite motor's torque-versus-speed characteristic. This is done by rewinding the armature with fewer turns of slightly thicker wire.

Directly replacing a ferrite magnet with Neo runs the risk that increased flux can drive the housing and armature laminations into saturation, increasing iron losses and limiting the potential gain in efficiency. To work around this problem, the relative radial thicknesses of the magnet and the steel housing should be adjusted for maximum air-gap flux density. The lamination spoke width should increase, and the inner lamination spokes should be converted to a solid rotor hub. Maximum efficiency can easily rise another 5 to 10% by optimizing the magnet, housing, and armature lamination dimensions.

FEA helped evaluate another design iteration that employed magnet arcs made from the compression-molded Neo material. But because this magnet grade is superior to ferrite, it was not practical for a direct replacement in the ECF motor.

There are other benefits to bonded magnets. The original ferrite magnets are ceramic. They are brittle arcs that require careful handling and attachment within the motor. Neo magnets are either injection or compression-molded, which leads to greater flexibility in production and assembly of the motor. Compression-molding produces better magnetic properties than does injection molding, yielding a magnet with higher energy density. ■

FERRITE VERSUS BONDED NEO ECF MOTOR DESIGNS

PARAMETER	UNIT	FERRITE	INJECTION-MOLDED NEO	COMPRESSION-MOLDED NEO
Remanence (B_r)	Gauss	4,200	5,300	6,900
Intrinsic coercivity (H_{ci})	Oersted	4,000	9,500	9,000
Torque constant (K_t)	N-m/A	0.038	0.040	0.044
Winding resistance (R)	Ohms	0.177	0.143	0.113
Motor constant (K_m)	N-m/W$^{1/2}$	0.085	0.105	0.132
Max motor efficiency	%	66.7	71.3	76.2
Current draw @ 0.7 N-m	A	21	19	16.6
Current draw @ 1.0 N-m	A	29.5	26.5	23.9

Comparing ferrite with injection-molded and compression-molded Neo magnets shows better magnetic properties for Neo magnets.