Neo magnets boost fuel economy

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

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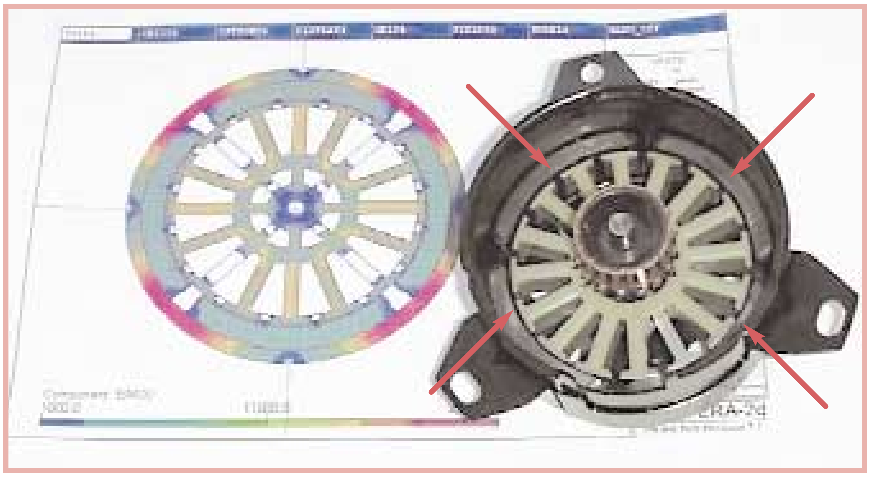


A disassembled ECF motor has four new injection-molded Neo arcs installed (arrows), and the armature winding removed in preparation for rewinding.

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.

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.

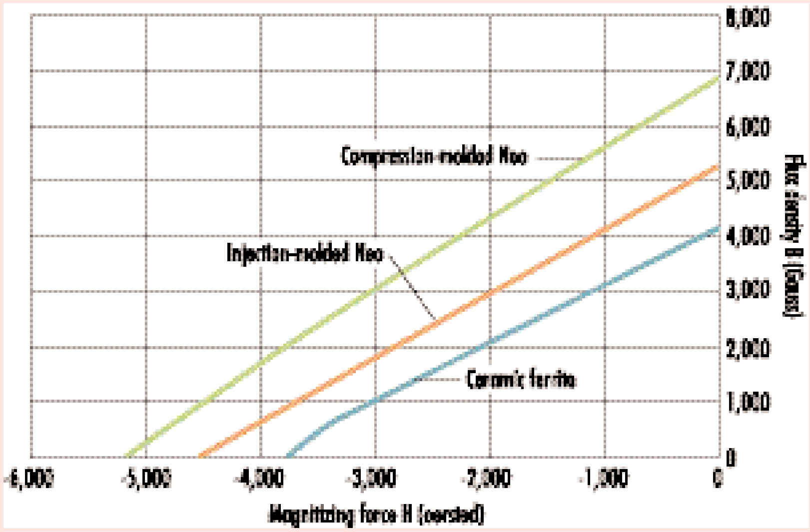
As automakers look for ways to cut power consumption, alternative magnetic materials could be one solution. Higher-energy, permanent-magnet materials allow for higher efficiency motors and actuators to be produced. They have become increasingly practical thanks to improvements in magnetic, mechanical, 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.

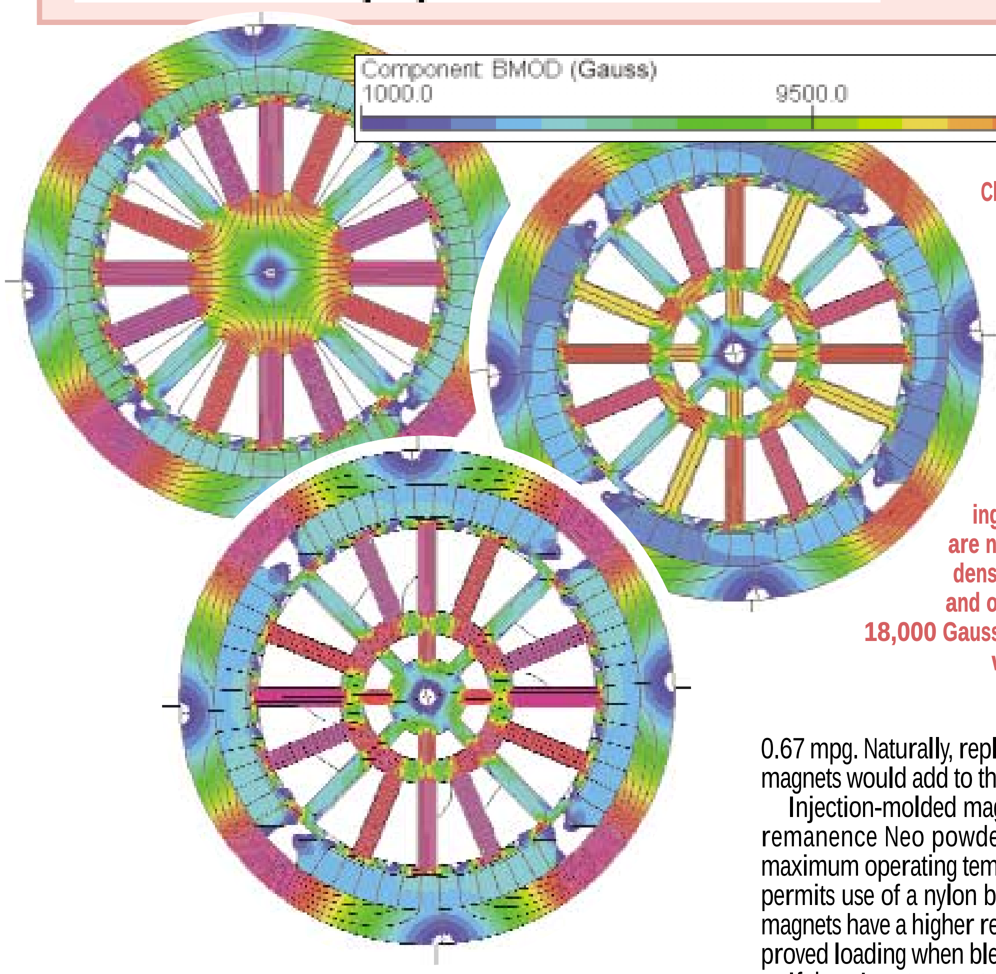
A dual ECF fan (dual motor) assembly on a 2000 Ford Taurus was used to test the replacement of ferrite with Neo magnets. The motor, which has an outer diameter a little over 4 in., is a four-pole, 16-slot brushed-dc machine with sintered ferrite-magnet arc segments. It operates within an ambient temperature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

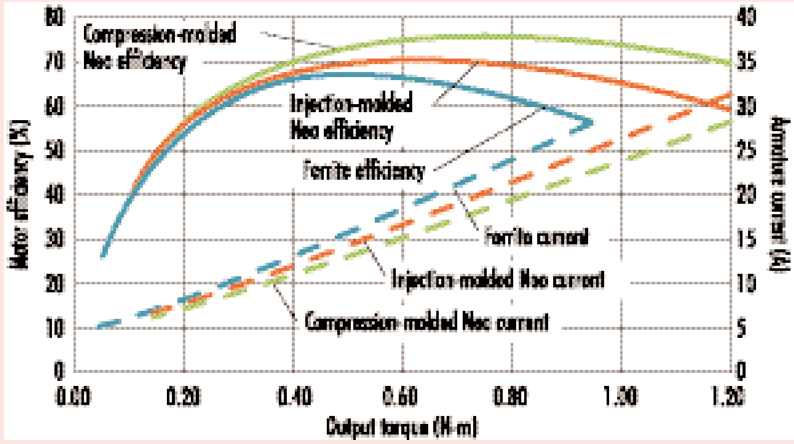


Clockwise, from the top, the graph shows typical flux-density distributions calculated by FEA at a motor current of 20 A for compression-molded Neo, ferrite, and injection-molded Neo. The color contours indicate that the flux-density levels both in the outer housing and in the armature teeth are nearing 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.