"Neo" Magnets Raise the Efficiency of Electric Motors

Higher-efficiency motors reduce the load on the alternator and improve a car's fuel economy. Neodymium-iron-boron magnets are shown to provide these benefits to key electric motors in the vehicle.

The growing number of electro-mechanical devices employed in today's automobiles places an increasingly severe load on the alternator. For this reason, car manufacturers are seeking to increase device efficiencies, thereby reducing the current drawn from the alternator. An added benefit of using higher-efficiency motors and actuators is an improvement in fuel economy. Car manufacturers estimate the improvement in fuel efficiency attributed to electric current drain to be about 0.024 litres/100 km per amp. Of all the motors employed in today's automobile, the engine cooling fan (ECF) blower motor has the greatest full-duty power consumption, drawing over 20 amps at 12 volts. This DC brush motor employs ferrite arc magnets.

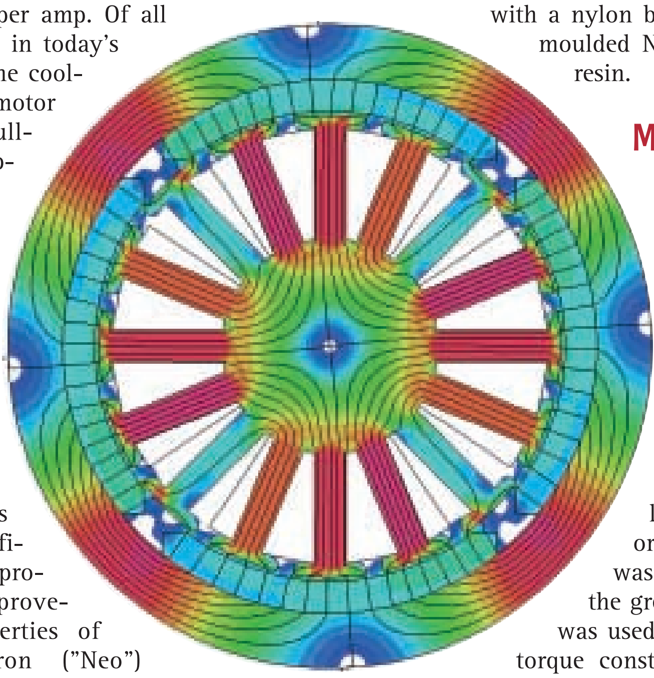

Figure 1: Flux distribution in the ECF motor with compression-moulded Neo magnets.

Bonded Neo versus Ferrite

Higher-energy permanent magnets allow for higher-efficiency motors to be produced. Recent improvements in the properties of neodymium-iron-boron ("Neo") magnets have made the replacement of ferrite magnets attractive in certain applications. While the development of Neo magnets has had a significant impact on the electric motor industry, these advancements have been slow to gain acceptance from the automotive sector because of the higher cost of Neo compared to ferrite. Continual price reductions in Neo magnets are finally enabling the replacement of ferrites in many high-volume applications. The cost difference between a Neo and ferrite magnet solution is narrowing.

In order to quantify the benefits of replacing ferrite magnets with Neo, a 2000 model year Ford Taurus as a common vehicle that would provide a representative ECF motor was selected. Its ECF assembly has dual identical 4-pole, 16-slot blower motors, each with an outer diameter of 104 mm. The measure of a magnet's performance is demonstrated by its demagnetisation characteristic, examples of which are shown in Figure 3. The ferrite magnet currently used in the Taurus' ECF motor clearly has the lowest magnetic properties, compared to the two different types of bonded Neo magnet employed in the redesign, which are injection-moulded Neo with a nylon binder and compression-moulded Neo blended with epoxy resin.

Motor Performance Improvements

With injection-moulded Neo magnets, a direct substitution for the existing ferrite magnets can be made. This allows the use of the existing motor housing and armature laminations. When the original Taurus ECF motor was modified in this way, the greater flux now available was used to increase the motor's torque constant Kt and reduce the armature resistance R, so as to reproduce as closely as possible the original ferrite motor's torque versus speed characteristic. This was accomplished by rewinding the armature with fewer turns of slightly thicker wire. The net result was a reduction in current draw and an increase in efficiency. Figure 2 is a photograph of the disassembled ECF motor, with four new injection-moulded Neo arcs installed, and the armature winding removed in preparation for rewinding.

While the ECF motor with injection-moulded Neo was built and tested, another design iteration using the compression-moulded Neo material was analysed using finite element analysis (FEA). Figure 1 shows

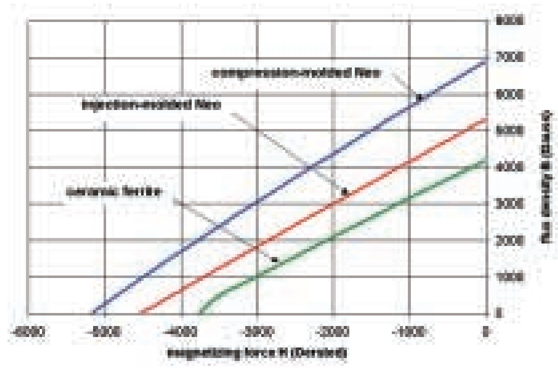

Figure 3: Demagnetisation curves of candidate ECF motor magnets at 25 °C.

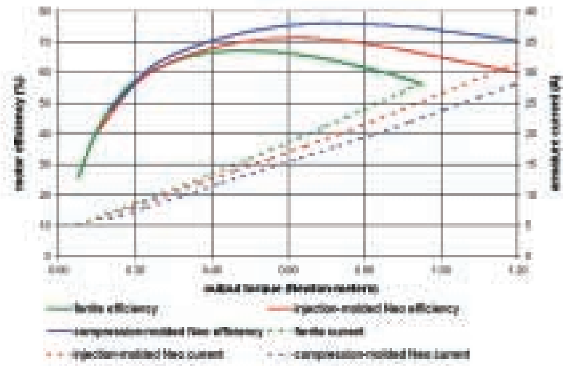

Figure 4: Efficiency and current vs. torque for the ECF motor with ferrite and bonded Neo magnets.

the flux density distribution calculated by FEA. Since compression-moulded Neo is far superior to ferrite, it was not practical for direct replacement in the ECF motor because its higher energy would drive the housing and armature well into saturation. The saturation is alleviated by adjustments to the magnet and housing thickness, as well as to the lamination spoke width and the rotor hub.

As shown in Figure 4, the replacement of ferrite with Neo reduced the current draw and raised the efficiency of the ECF motor. Table 1 summarizes the motor performance improvements afforded by the two bonded Neo materials selected. At the motor's normal continuous operating torque of 0.7 Nm, a 2.0 A (10 %) reduction in current is achieved by replacing ferrite with injection-moulded Neo, and a 4.4 A (21 %) drop in current is achieved by using compression-moulded Neo. At the 1.0 Nm peak operating torque, the current saving rises to 3.0 amps and 5.6 amps with injection-moulded and compression-moulded Neo magnets respectively.

In addition to this, ferrite magnets are brittle and require careful handling and attachment within the motor. The injection-moulded and compression-moulded Neo magnets we have described allow for greater flexibility in the manufacturing of the motor.

Improved Fuel Economy

Estimating the improvement in fuel efficiency attributed to electric current drain to be about 0.024 litres/100 km per amp, and assuming two ECF motors and a similarly-sized HVAC motor per vehicle, the use of injection-moulded Neo will improve the vehicle's fuel economy by 0.14–0.21 litres/100 km. With the compression-moulded Neo magnets, the fuel savings increase to 0.30–0.38 litres/100 km. There are many more electric motors in the vehicle whose redesign with Neo magnets could add to these savings.

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Figure 2: ECF motor with bonded Neo arcs and armature in the process of reworking.

Parameter	*Unit*	*Ferrite*	*Injection-moulded Neo*	*Compression-moulded Neo*
Remanence, Br	*Gauss*	*4200*	*5300*	*6900*
Intrinsic coercivity, H_{ci}	*Oersted*	*4000*	*9500*	*9000*
Torque constant, K_t	*Nm/amp*	*0.038*	*0.040*	*0.044*
Winding resistance, R	*Ohms*	*0.177*	*0.143*	*0.113*
Motor constant, K_m	*Nm/sqrt(W)*	*0.085*	*0.105*	*0.132*
Max. motor efficiency	*%*	*66.7*	*71.3*	*76.2*
Current draw @ 0.7 Nm	*Amperes*	*21.0*	*19.0*	*16.6*
Current draw @ 1.0 Nm	*Amperes*	*29.5*	*26.5*	*23.9*

Table 1: Summary of the comparison of ferrite versus bonded Neo ECF motor designs.