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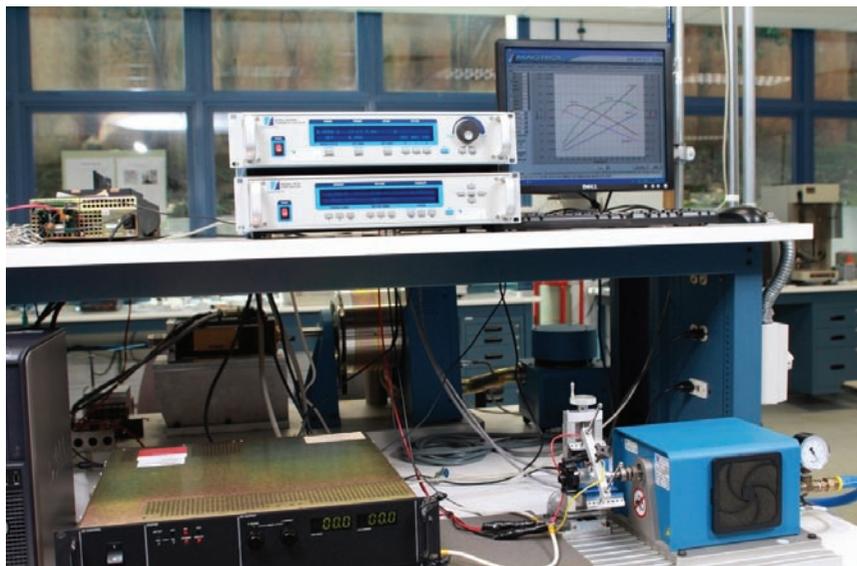
# Bonded neodymium magnets

Optimal use of higher-density bonded neodymium magnets is helpful in achieving weight and volume reduction in permanent magnet motors, resulting in raw material cost savings

The automotive sector requires the development of cost-effective smaller, lighter and more efficient accessories motors, either by innovative motor design or by optimised use of new and improved materials. At present automotive accessories motors are mostly permanent magnet brushed DC (PMDC) motors using ferrite arc magnets. Isotropic bonded NdFeB magnets provide higher magnetic energy and unique advantages, such as the ability to achieve very small thicknesses in the direction of magnetisation, tailored magnetisation profile and almost constant cost on a weight basis. These advantages of isotropic bonded neodymium magnets increase the trend to use them in automobile accessories motors.

Depending on the shape factor of the magnet, a typical compression bonded neodymium magnet has density in the range of 5.7-6.1g/cm<sup>3</sup>. For

Figure 1: Motor characteristics measurement using dynamometer



commercially available magnets with lengths of 20-30mm, the magnet density using conventional compaction techniques is 5.8-5.9g/cm<sup>3</sup>. However the theoretical density of a compound of magnetic powder and organic binders can reach 6.9g/cm<sup>3</sup> indicating that higher (BH)<sub>max</sub> could be obtained if density were increased during moulding<sup>1</sup>.

## Benchmarking existing motors

The performance of a commercially available automotive window lift motor used in a late model Toyota Prius and Harrier has been benchmarked by performing the following tests:

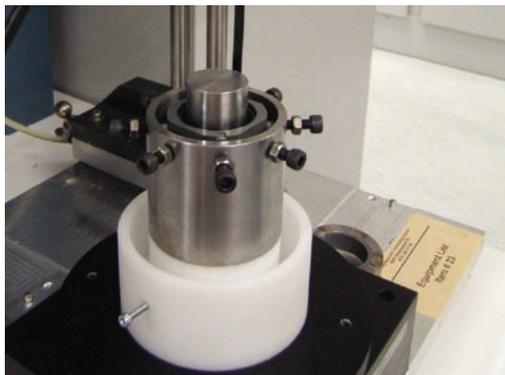
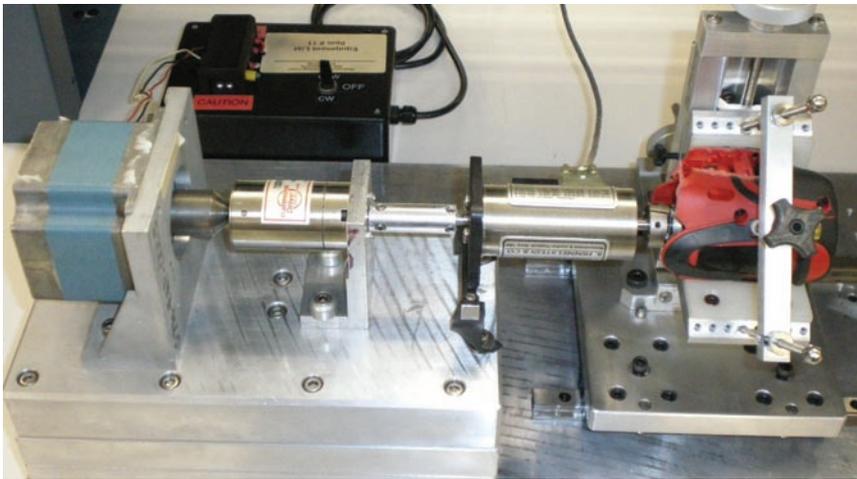
- Using a computer-controlled dynamometer as shown in Figure 1, the motor characteristics were measured for different load torques. No-load speed, no-load current and no-load power for the motor were also noted.
- The motor cogging torque was measured using the cogging torque measurement system. The set-up is shown in Figure 2 (top).
- The airgap flux scan was measured using the closed magnetic circuit, in which the armature is replaced with a solid iron core as shown in Figure 2 (bottom).

The motor was disassembled and key physical dimensions were measured, as were weights for the magnet, copper and soft iron materials.

## Redesign of the motor

After completing the benchmarking of the motor, new designs were developed using a 10MGOe isotropic bonded neodymium ring magnet. To demonstrate the advantage of higher-density bonded neodymium magnets two motors were designed using 8MGOe and 9MGOe magnets. The commercially available motor design software SPEED PC-DCM was used for the first-cut designs<sup>2</sup>, and the commercially available FE analysis software Opera 2-D<sup>3</sup> was used to fine-

Figure 2: Cogging torque and closed circuit airgap flux density measurement. Top: cogging torque measurement. Below left: airgap flux scan



tune the constants used in the design program of SPEED and to validate the design.

Some of the major considerations during the redesign are as follows:

- The length of the airgap in the redesigned motors was kept the same as that of the benchmarked motor to avoid any undue advantage due to a reduction in the airgap.
- The magnet thickness of the bonded neodymium rings was always selected to be as thin as possible without causing manufacturability problems.
- The armature conductor current density is kept less than or equal to the benchmarked motor value.
- Under extreme conditions the magnet operating point is prevented from operating below the knee point on the second quadrant characteristic of the magnet.
- For motors having different densities of bonded neodymium magnets, the slot fill factors have been kept the same as far as possible.

The assembly process cost is different for different manufacturers, so for the cost comparison of the benchmarked and redesigned motors the cost of only the major material used in

the electromagnetic circuit of the motor (i.e. the ferrite or bonded neodymium magnet, copper and soft magnetic iron) is considered.

### Comparison of the benchmark and redesigned motors

The benchmarked motor has a flat surface on the periphery, so the width at the flat surfaces adds an additional constraint on the maximum possible diameter of the redesigned motors. Table I gives the key physical dimensions for the benchmarked two-pole ferrite arc motor and for the redesigned motor with a 10MGOe isotropic bonded neodymium ring magnet.

### Performance of the motors for same dimensions and different magnet density

For the same dimension and cross section of the motor the effect of magnet density on the motor performance has been evaluated by varying the magnet  $BH_{max}$  from 8MGOe to 10MGOe for the redesigned motor given in Table I. Figure 3 (a) and (b) shows the motor performance for different  $BH_{max}$  values of the magnet, from which it is observed that motors with lower values of  $BH_{max}$  magnet require a bigger size envelope to achieve

Figure 3 (Below): Performance comparison of the benchmarked and redesigned motor with a 10MGOe magnet. (a) Torque-speed and torque-current characteristics. (b) Torque-efficiency and torque-power characteristics

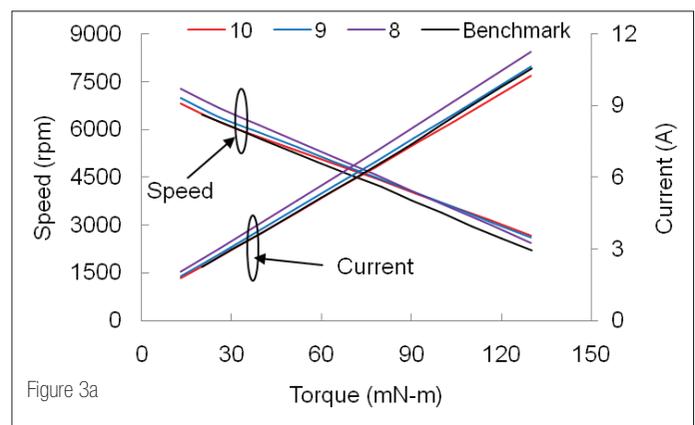


Figure 3a

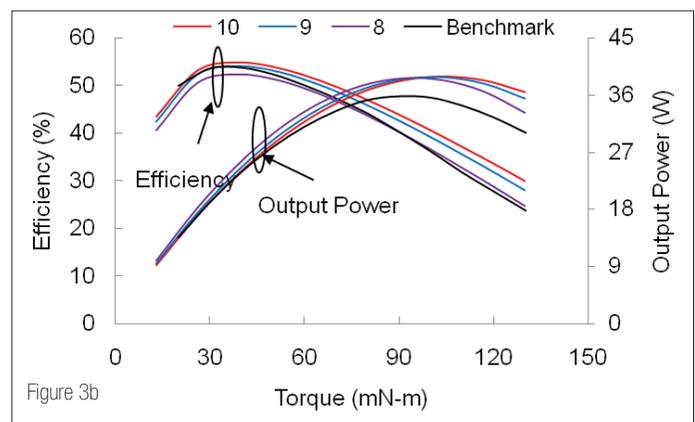


Figure 3b

the same performance as that of the motor with a 10MGOe magnet. This increase in size envelope may result in an increase in the overall cost of raw materials.

**Motors to achieve the same performance with different magnet density**

Different motors are designed to achieve the same performance as that of a motor with a 10MGOe isotropic bonded neodymium magnet. During design the slot fill factor for the different motors was kept the same as far as possible. Table II gives the magnet density for different values  $BH_{max}$ . Also listed are the corresponding values of no-load speed, maximum efficiency and stall torque.

Figures 4 (a) and (b) show the performance of the motor with 10MGOe and 8MGOe magnets. From this figure it can be observed that the performances of the two motors are a close match.

Figure 5 shows the comparison of key physical parameters and raw material cost for the benchmarked and redesigned motors. From this figure it can be observed that using isotropic bonded neodymium magnets with optimal motor design, the volume and weight of the motor can be reduced by about 50 percent. The optimal design also helps to achieve between eight percent and 15 percent reduction in the raw material cost. The magnet with density of  $6.07g/cm^3$  helps to achieve the highest saving in raw material cost.

**Conclusions**

An optimally designed motor with isotropic bonded neodymium magnets helps in reducing the motor weight and volume by 50 percent to 60 percent compared with the benchmarked ferrite motor. It is shown that though magnet cost on per kilogram basis is higher for the isotropic bonded neodymium magnets, an optimal design of the motor helps reduce the overall cost by eight to 15 percent with greater savings when higher density magnets are used. ■

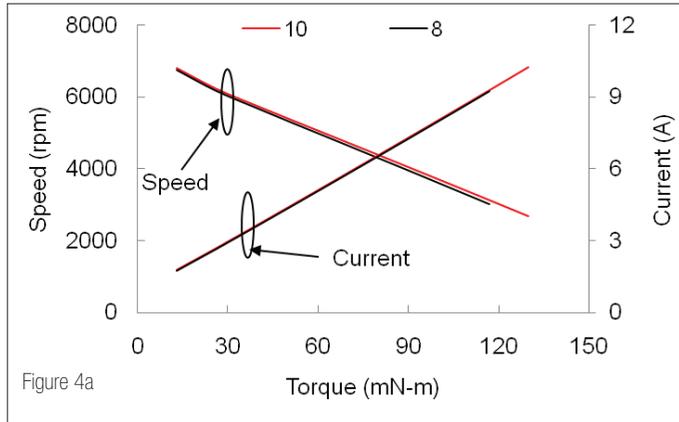


Figure 4a

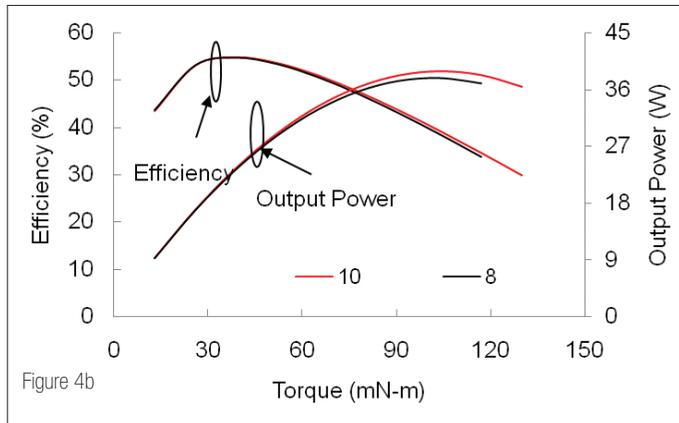


Figure 4b

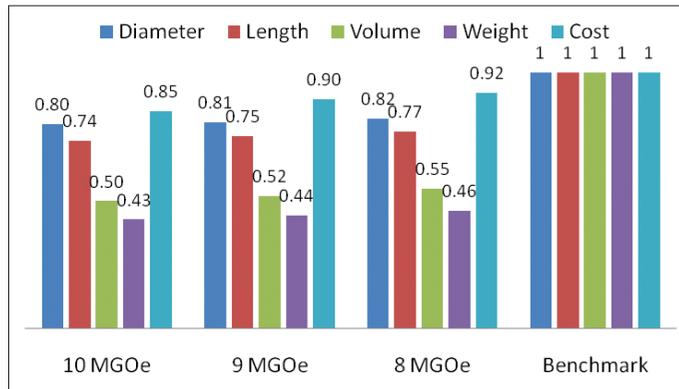


Figure 4 (top): Performance comparison of the redesigned motor with 10 and 8MGOe magnets. (a) Torque-speed and torque-current characteristics. (b) Torque-efficiency and torque-power characteristics

Figure 5 (above): Comparison of key physical dimensions and raw material cost for the benchmarked and redesigned motors

**References**

1. J. Herchenroeder et al, 'High performance bonded neo magnets using high density compaction', selected for publication in Journal of Applied Physics, April 2011.
2. <http://www.speedlab.co.uk>
3. <http://www.vectorfields.com>