Magnetic material impact in electric vehicle motors with small amount of magnets

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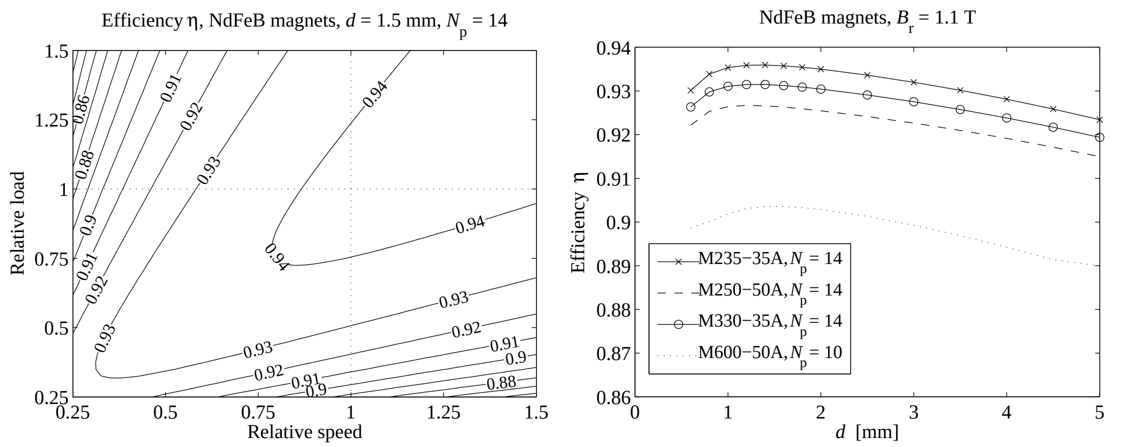
As the price of rare earth magnets increases, permanent magnet synchronous motors (PMSM) with small amount of magnets become interesting, on condition that their efficiency and power density remains high. In electric vehicles, a wheel drive with a reduction needs less magnetic material than a direct drive configuration. Therefore, we design a light high speed PMSM with outer rotor. We investigate the impact of the magnetic material and the amount of magnets on the torque and efficiency. The machine has 80 mm outer diameter, 12 concentrated stator windings, 2 kW power and 4500 rpm nominal speed. The number of poles N_p is optimized.

An analytical reluctance network model is made [1], and the copper and iron losses are computed. The iron losses are computed based on the loss separation theory. The coefficients in the loss equation are fitted by using Epstein frame measurements on the different materials.

The analytical model computes the efficiency for a wide range of operating points, so that an efficiency map can be made: fig. 1a. The average efficiency over this range is shown in fig. 1b, for several magnet thicknesses and several soft magnetic materials. As the air gap is fixed (0.55 mm), very thin magnets are not optimal because the air gap induction is too low. As the outer machine diameter is fixed, very thick magnets are not optimal either because the increased rotor thickness causes a smaller air gap diameter, hence a bad torque-per-Ampere ratio.

Concerning the material influence, the M250-50A results in lower efficiency than the M330-35A, because of the high nominal frequency (525 Hz if N_p=14). The optimal number of poles is 14 except for the 'high loss' M600-50A material: a lower N_p causes a lower frequency and lower iron loss, but the average efficiency remains about 3% lower than for machines with M235-35A.



(a) (b)

Figure 1: (a) Efficiency map of a PMSM with M250-50A and d = 1.5 mm; (b) Average efficiency of a PMSM in the speed range 0.25–1.50$\times N_\mathrm{nom}$ and torque range 0.25–1.50$\times T_\mathrm{nom}$, as a function of the magnet thickness d and the material grade. The number of poles is optimized.

[1] A. Tariq, C. Nino-Baron, and E. Strangas, IEEE Trans. Magn. **46** (2010), 4073-4080.