Design and material aspects in small electromagnetic energy transducers

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Permanent magnets play a predominant role in designing small electromagnetic energy transducers in general and in particular when dealing with electric motors. Due to Ampere's law, the magnetic field that can be generated using electromagnets becomes too small to be useful when the designs become smaller (J: current density, limited due to heating restrictions; S surface; H field strength):

$$\oint \vec{H} d\vec{l} = \iint_S \vec{J} d\vec{S} \tag{1}$$

In order to produce sufficient torque and/or forces, in very small dimensioned machines, it is advantageous to use permanent magnet materials to produce the field, as the flux density of these magnetic sources is independent of their size. Therefore, in small and extra small motors, being dc, brushless dc or synchronous, permanent magnets are extremely common. An other advantage is the decrease of the losses. Although it might seem that this is less important for small motors than for larger ones, this is often not true. Small motors are very much used in portable and battery supplied applications (audio, toys, notebooks, etc.). For a given amount of batteries, i.e. for a given weight of the system, the autonomy increases dramatically as the efficiency of the motor improves. In the new walkman DCC (Digital Compact Cassette) one third of the energy consumption is due to the motor, indicating e.g. the importance of this part of the system.

The design of such small motors is very difficult. Classic design methods are not possible due to the odd geometry's, used to incorporate the motor in its application. With the inset of high energy permanent magnets the ferromagnetic parts of the machine will be highly saturated. To solve this type of non-linear problem with complex geometry finite elements can be used. A three dimensional approach is indispensable, as for machines with radially oriented flux density distribution the length to diameter ratio is too small to allow a two-dimensional model. In axial flux designs, which are very common for small motors, a three dimensional analysis is always necessary.

The calculation of the flux density distribution has to account for the geometrical lay-out of the motor. For a somewhat larger motor (diameter 45 mm, length 15 mm), a cylindrical rotor with permanent magnet material is used. The poles constitute a four pole arrangement. Using this symmetry, the model may be limited to only one quarter of the actual motor. Binary constraints, allowing to impose these symmetry conditions to the machine, yields a considerable reduction in computing time.

Due to the cylindrical rotor, the geometry does not alter as the rotor rotates. If the magnets are divided in several pieces, it is sufficient to alter the orientation of the pole of each piece in order to simulate the rotation of the machine. The field can be calculated for different rotor position without the need to produce a new three dimensional mesh, thus gaining a lot of computing time. The air gap field as a function of the rotor position is used to calculate both, the induced voltage by the differentiation of flux linkage with respect to time or with the angle. If the machine is rotating at constant speed the induced voltage can be given.

$$V_{in-p} = -4 \cdot \frac{d\Psi_W}{d\theta} \cdot 2\pi n \tag{2}$$