3.15

Transformers and DC motors

C.A. Ross, DMSE, MIT

References:

Braithwaite and Weaver, Electronic Materials, sections 3.2 and 3.3
(Jiles, Introduction to Magnetism and Magnetic Materials 4.3.3 & 12.1.7)

How do transformers work?

Two coils wrap around a soft magnetic core. The input side has a varying current i_m through n turns of wire.

Ampere: $\oint H.dl = ni_m$

Within the core, $B = \mu_o \mu_r H$

(Soft magnet: large, nearly constant μ_r)

Put a secondary coil around the core: n' turns

Faraday $V = -n' \, d\Phi/dt$

where $\Phi = B.A$ (A = coil area)

Now we draw a current from the secondary: current i_s induces a current i_p back in the primary. Now primary current is $i_m + i_p$.

Power transferred $V_s i_s = V_p i_p$, where $V_s/V_p = n'/n$

Properties of the core:
- easy to magnetize to have a high B
- high B_s
- low hysteresis
- resistive to avoid eddy currents.

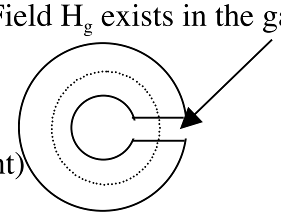
Soft magnetic materials

	T_c/ K	B_s /T	Hc / A/m	μ_r	W, J/m^3
Fe	1043	2.2	~4	200,000	30
Fe-3%Si	1030	2.1	~12	40,000	30
a-FeBSi	630	1.6	~0	>100,000	15

How do DC motors work?

We characterize hard magnets by the $(BH)_{max}$ product in the hysteresis loop.

For the magnet to be able to do some useful work, it needs to produce some external flux, e.g. at the gap of a ring-shaped magnet with a cut made in it. Field H_g exists in the gap.



Ampere: $l_m H_m + l_g H_g = 0$ around dotted line

also $B_m = B_g$

$B_m = \mu_o \mu_r H_m$ (negative since in second quadrant)

$B_g = \mu_o H_g$

hence $H_m = -l_g B_m / l_m \mu_o$

This linear relation intersects the hysteresis loop and defines uniquely the operating point.

The amount of work that can be done by the magnet is proportional to $l_g H_g B_g$ so scales with the $(BH)_{max}$ product.

In a permanent magnet motor: a current i runs through a wire length *l* in a B field.
Force $F = Bil$ (use Fleming's left hand rule)
This gives a force perpendicular to the wire and to B.

- A radial B is produced by two permanent magnets called the stator.
- The wire is wrapped round a vertical piece made of a soft magnet (the rotor). The purpose of the soft magnet is to concentrate the flux lines through the coil, giving maximum B.
- Current is supplied by a commutator (sliding contact).

Desirable properties of the permanent magnets: must stay magnetized despite their shape, and the fields produced by the wire, hence a high coercivity. Must produce large B, hence a high B_s i.e. high $(BH)_{max.}$
Efficiency of motor is maximized if we can reduce the resistive losses in the wire. So minimize $\rho i/ABv$, where ρ is resistivity, A is wire x-section and v is rotation velocity.

Hard magnetic materials

	T_c/ K	B_r /T	Hc / kA/m	$(BH)_{max}$, kJ/m^3
Alnico-5	1160	1.4	64	44
$BaO.(Fe_2O_3)_6$	720	0.4	264	28
SmCo5	1000	0.85	600	140
$Nd_2Fe_{14}B$	620	1.1	890	216
		remanence		