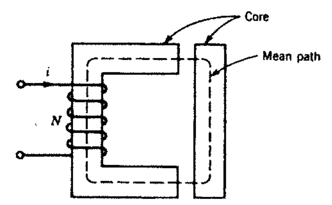
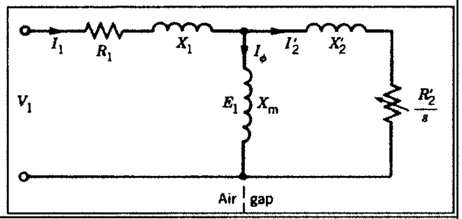
1. Explain the following concepts, use drawings and equations when adequate.
   a) Describe the stator and rotor constructions and the principle of operation of a **separately excited DC-machine**. (Hint: field and armature, forces on conductors and torque, induced voltage, commutator and brushes, etc…) (3p.)
   b) Explain the three running modes of operation of an induction machine by drawing the Torque-Speed (or Slip) curve and give the range of the slip for each mode of operation (3 p.)
   c) Draw the complete single-phase equivalent circuit of a transformer and explain what each of its component represents (3 p.)
   d) Explain the static stability limits of a synchronous machine. What are these limits? Why they are important? What happens if any of them exceeds? (hint: use drawing in the PQ plan) (3 p.)

2. The magnetic relay in the figure has a coil of 500 turns currying a current $I_{dc} = 4{,}19$ A. The mean core path length is $l_c = 360$ mm and the air gap is $l_g = 1{,}5$ mm. The relative permeability of the core is $\mu_c = 1250$ and its cross-section is $A_c = 100$ mm$^2$. Neglect flux fringing in the air gaps.
   a) Draw the equivalent magnetic circuit of the relay and calculate its parameters, (MMF and reluctances) (2 p.)
   b) Calculate the flux density in the air gap (use the circuit in (a)) (2 p.)
   c) Calculate the total force acting on the moving part (2 p.).




*Simplified magnetic relay.*

3. A three phases, 250 kW, 460 V, 60 Hz, eight poles, star-connected induction machine is connected to a 460 V infinite bus and is running as a generator at a slip $s = -2{,}5\,\%$. The equivalent circuit of the machine, in the figure, has the following parameters
   $R_1 = 0{,}015\Omega;\; R_2^{'} = 0{,}035\Omega;$
   $X_1 = 0{,}145\Omega;\; X_2^{'} = 0{,}145\Omega;\; X_m = 6{,}5\Omega$
   a) Determine the speed of the rotor (2 p.)
   b) Determine the power delivered to the infinite bus and the power factor (2 p.)
   c) Determine the efficiency of the generator. The rotational and core losses are 3 kW (2 p.)




*IEEE-recommended equivalent circuit of an induction machine.*

4. A 2-pole DC-motor connected to 345 V supply draws 39 A current and produces 11 kW mechanical power at 1500 rpm.
   a) Calculate the mechanical torque and resistive losses in armature winding ($R_a$=0,8706 Ω) (2 p.)
   b) Calculate the input power of the motor and its efficiency (neglect field winding losses) (2 p.)
   c) Calculate the back electromotive force $E_a$ when the flux factor at nominal field current is $k_\Phi$=1,895 Vs/rad (2 p.)

Evaluation:

| Grade | Lower limit | Upper limit |
|---|---|---|
| 0 | 0 | 13 |
| 1 | 14 | 16 |
| 2 | 17 | 19 |
| 3 | 20 | 22 |
| 4 | 23 | 26 |
| 5 | 27 | 30 |

Some useful formulas and drawings:

Magnetic reluctance: $\mathfrak{R} = \dfrac{l}{\mu A}$

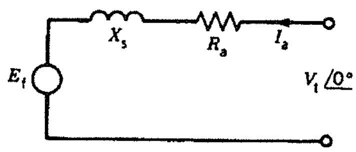
Magnetomotive force: $F = Ni$

Force pressure: $F_m = \dfrac{B_g^2}{2\mu_0}$

Speed of AC-machine: $n = \dfrac{120f}{p}$ ($p$ is the number of poles!)

Slip of induction machine: $s = \dfrac{n_s - n}{n_s}$

Equivalent circuit of a synchronous motor:




Convention: lagging reactive power positive -- > phase angle of current negative

AC active power: $P = 3V_{ph}I_{ph}\cos\phi = \sqrt{3}VI\cos\phi$

Magnetic permeability: $\mu = \mu_r\mu_0$; $\mu_0 = 4\pi 10^{-7}\ Hm^{-1}$