Notes on DC Machines

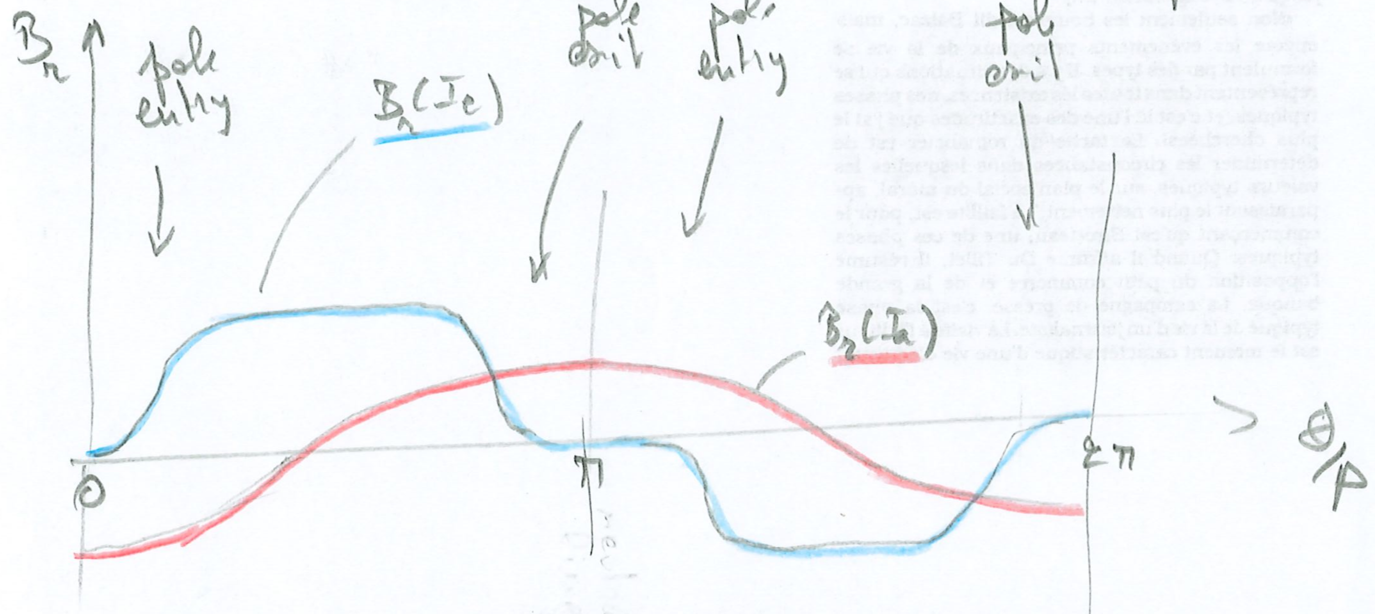
Types

Slide 2 ... each time the conductor

Slide 9 $\Psi(\bar{I}_a) = \psi(\bar{I}_a) + R_a I_a$

Armature reaction (Slide 4)

1 pole pair represented



One represents the (radial) component of the B field in the air gap

I_a weakens the field at pole entries

reinforces — exits

For each rotor conductor

$$\bar{e} = \bar{v} \times \bar{B} \Rightarrow e = v B_r = \dot{\theta} R B_r$$

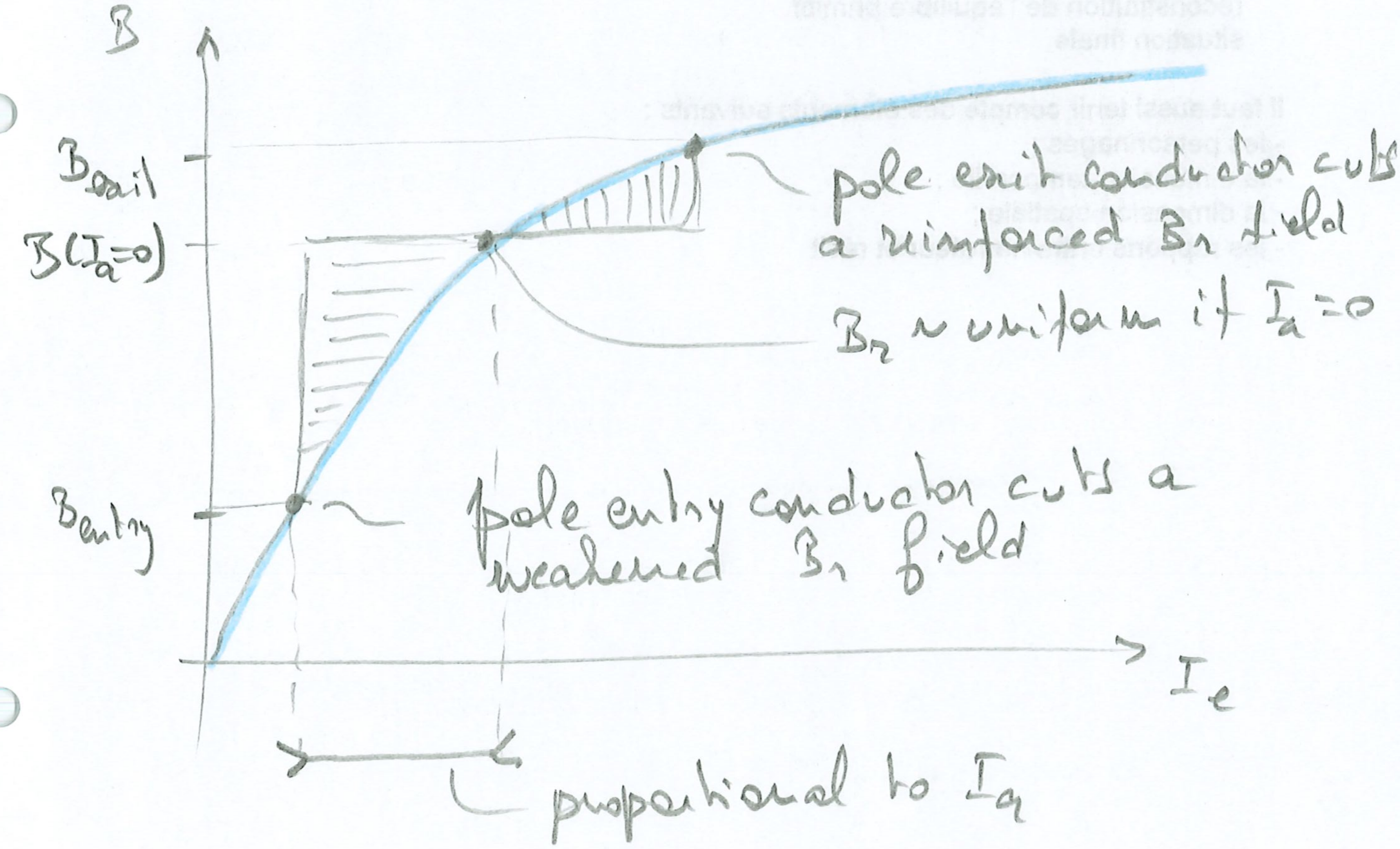
neutral line: line where B_r changes sign in the air gap.

$e<0$ for conductors on the left of the neutral line

$e>0$ ——— right ———

Brushes should be placed on the neutral line

$$emf = \sum_k e_k \propto \sum_k (B_r)_k$$



The gain of flux at the pole exit side is smaller to the loss of flux at the pole entry side $\Rightarrow \Delta\Phi(I_a)$

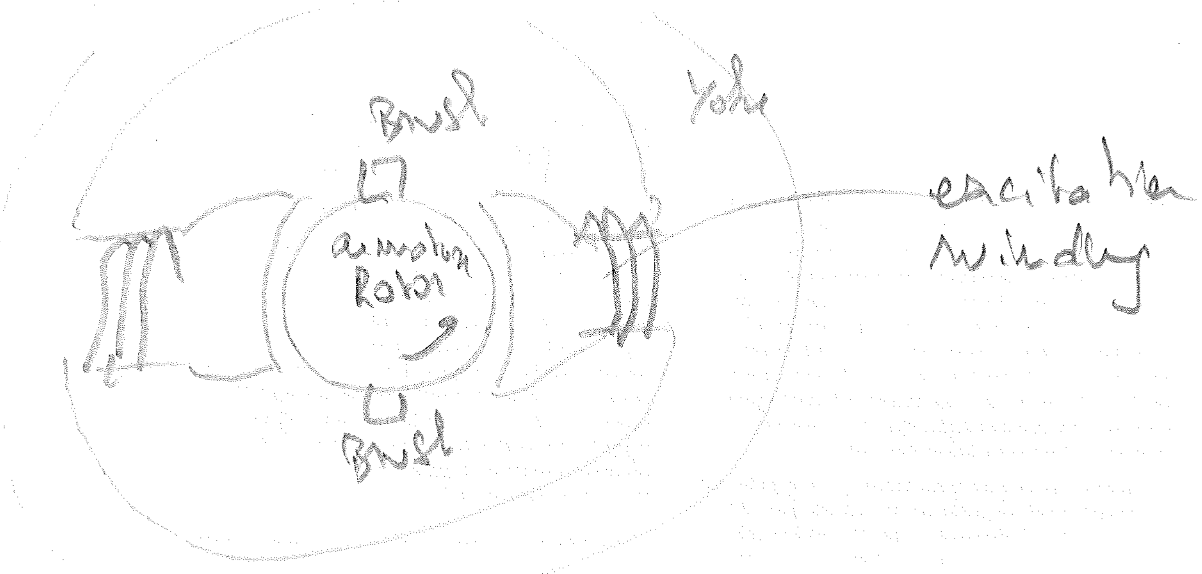
$$\Psi(I_a) = k_E \dot{\theta} \Delta\Phi(I_a)$$ armature reaction

→ Slide 5

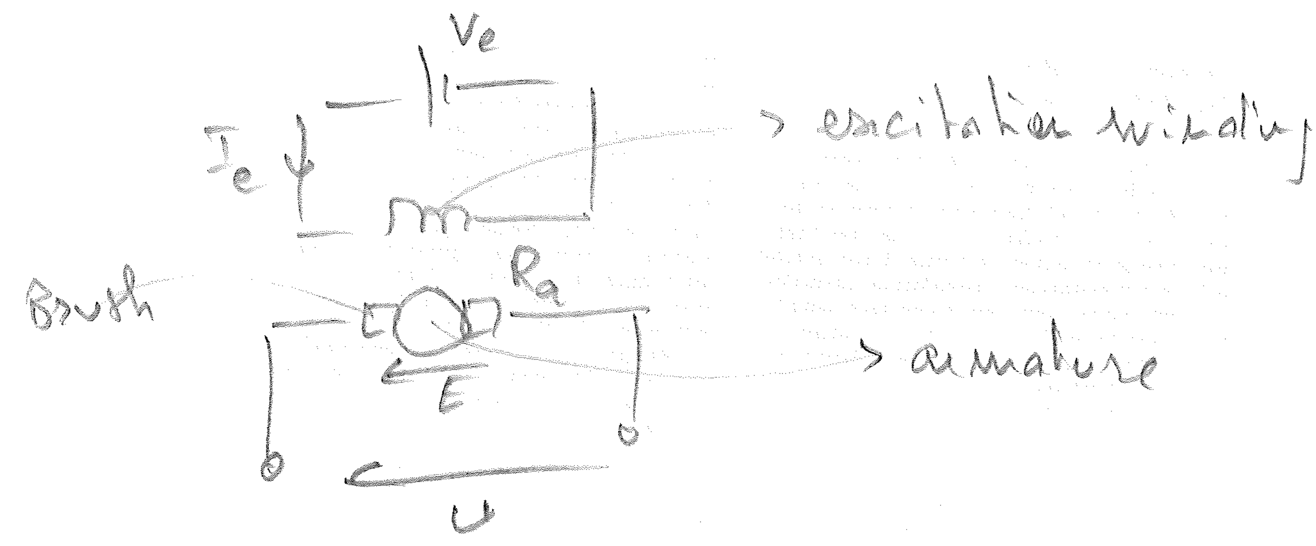
Compensation windings (Slide 5)

- conductors in the pole heads
- in series with the armature ⇒ carry the current I_a
- designed to produce approximately the opposite of the "armature field" depicted on slide 4
  ⇒ Total field = Inductor field
- fully compensated armature reaction but additional conductors / losses
  ⇒ loss of efficiency.

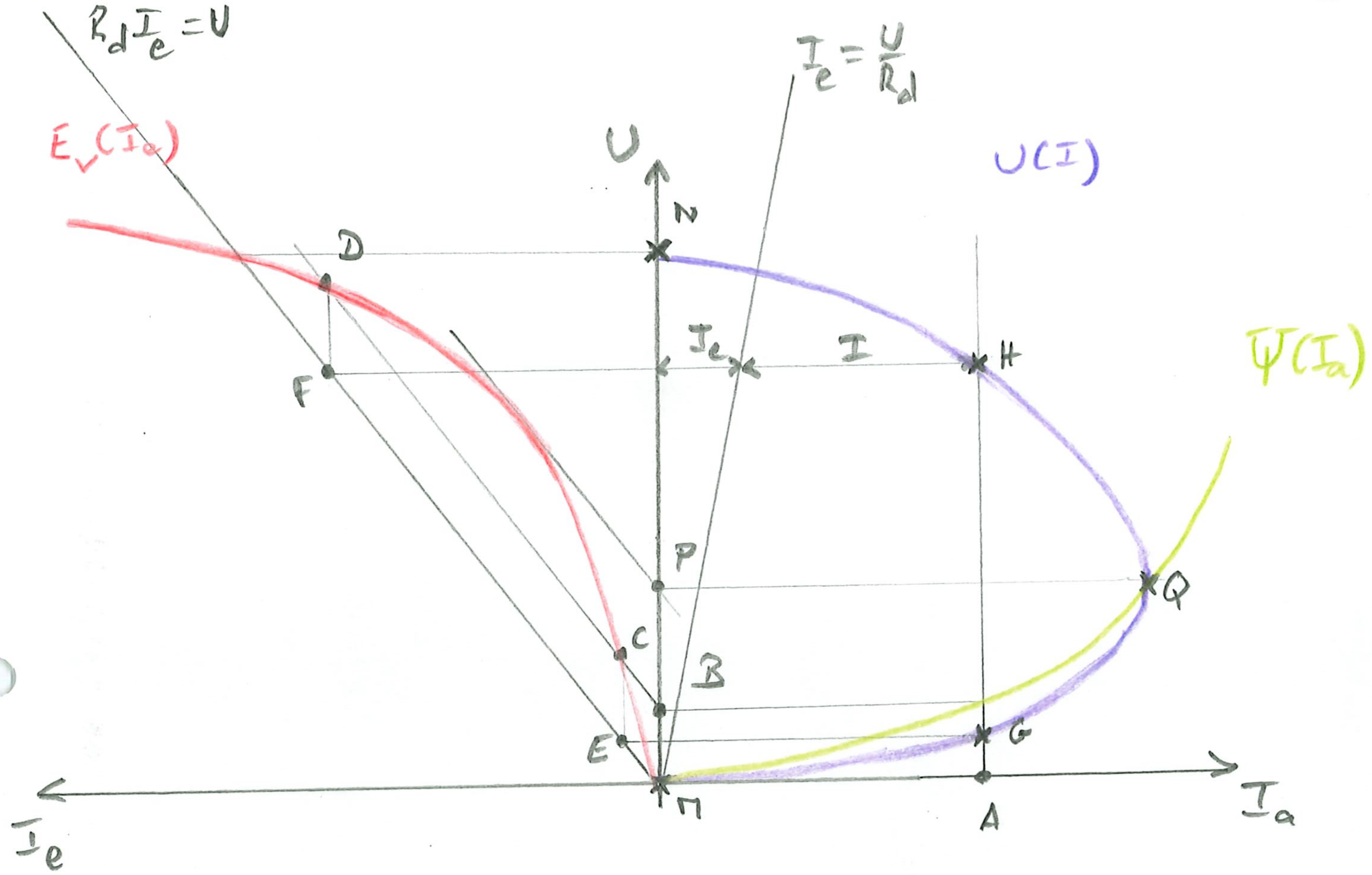
Excitation types (Slide 6)



Becomes (independent excitation case)



The representation above is realistic and complicated. In practice, it is enough to use the conventional representation (below) where the electric quantities are represented.


$R_d I_e = U$
$I_e = \frac{U}{R_d}$
$E_v(I_a)$
U
$U(I)$
$\Psi(I_a)$
N
D
I_e
I
H
F
P
Q
C
B
E
G
M
A
I_e
I_a

Picou construction (Slide 9)

- $E_v(I_e)$, $U = R_d I_e$ and $\Psi(I_a)$ are known and can be drawn on the figure.

- Choose I_a → point A
- Report $\Psi(I_a)$ on the vertical axis → point B.
- Draw the line $\Psi(I_a) + R_d I_e$.
- It intersects $E_v(I_e)$ in two points: C and D

For those points, the identity

$$E_v(I_e) = \Psi(I_a) + R_d I_e$$

holds.

- Withdraw $\Psi(I_a)$ to obtain the points E and F. The ordinates of E and F are two values of U corresponding to the chosen I_a. Report them on the vertical line in A → the sought points G and H that are on the $U(I)$ characteristic.

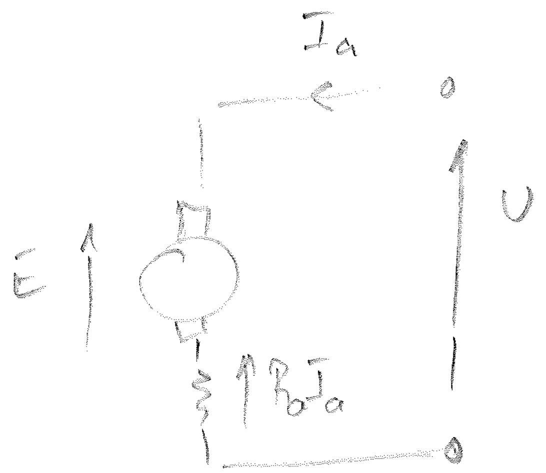
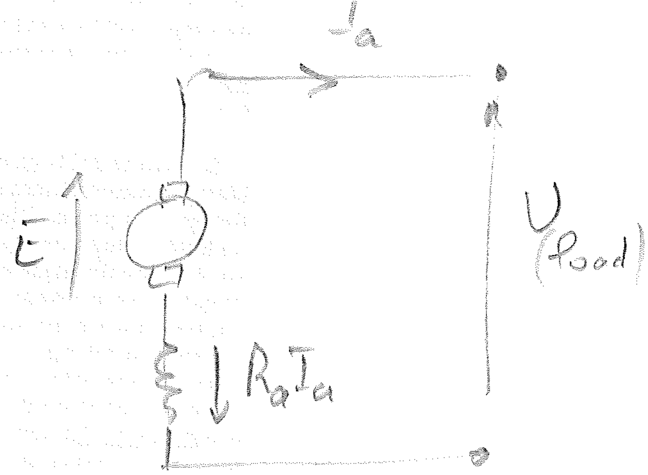
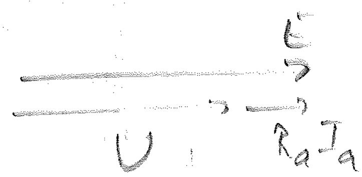
- This construction can be repeated for different values of I_a to build point by point the $U(I)$ characteristic of the shunt generator.

- The ordinates of the intersections of the line $R_d I_e$ with $E_v(I_e)$ are the voltages corresponding to $I_a = 0$ → point M and N of the U(I) characteristic.
- Intersect the parallel to $R_d I_e$ that is tangent to $E_N(I_e)$ with the vertical axis → point P
  Report this point on $\Psi(I_a)$ to obtain the rightmost point of the U(I) characteristic → point Q
- M, N, G, H and Q are 5 points on the sought U(I) characteristic of the shunt generator. Complete it with free-hand drawing → purple curve
- Draw the line $I_e = \frac{U}{R_d}$ using the vertical U axis as abscissa to decompose I_a into I_e and I
  $$I_a = I_e + I$$
  → done for point H in the figure.

Fundamental equations of DC machine

Basic equations : $E = k\phi\dot{\theta}$ $\quad C = k\phi I_a$

$E I_a = C\dot{\theta}$

MOTOR	GENERATOR
	
passive convention	active convention
	
$U = E + R_a I_a$	$E = U + R_a I_a$
$U I_a = E I_a + R_a I_a^2$	$E_a I_a = U I_a + R_a I_a^2$
Supplied mech Joule	Mech output Joule

Now

- $\phi(I_e) = B(I_e)S = \mu H(I_e)$ subjected to saturation / hysteresis
- armature reaction $\quad E = E_v(I_e) - k\,\Delta\phi(I_a)\,\dot{\theta}$
- Different excitation types

Slide 13

The shunt generator, because it can auto-excite, does not need any source of electric power to be operated. A source of mechanical power (e.g. a combustion engine) is enough. Very useful if you are in the desert or in case of black-out!

Slide 17 Pelm

The name "electromagnetic" power might be a bit misleading. It is indeed the power converted from mechanic to electromagnetic or vice versa.

Slide 19 : Shunt motor

Use the fundamental equations of DC machines to first understand the general shape of the $\dot{\Theta}(C)$ characteristic of the motor.

Shunt excitation $\Rightarrow$ $I_e = \frac{U}{R_d}$ = constant

$$\begin{cases} \dot{\Theta} = \dfrac{E}{k\phi} = \dfrac{U - R_a I_a}{k\phi} = \dfrac{U - \frac{R_a}{k\phi} C}{k\phi} \\ C = k\phi I_a \propto I_a \end{cases}$$

Then, note that, due to the armature reaction, $\phi \searrow$ when I_a (and then C) $\nearrow$

Slides 20, 21, 23

Controlling U and I_e with variable resistances (rheostats) belongs to the past. Lossy solutions are nowadays forbidden for the sake of energy efficiency.

The tendencies indicated in the graphs are however correct, irrespective of whether the control is made with resistances or power electronics.

Slide 22 What does "No Load" mean?

No Load → $C \ll$ → $I_a \ll$

$$\rightarrow \quad U = \underbrace{k\,\phi(I_a)}_{\ll}\ \underbrace{\dot{\theta}}_{\gg} \quad \rightarrow \text{runaway}$$

The series motor must rotate very fast to produce a back-emf E equal to the imposed U.

Slide 26 What does "Start-up" mean?

- Start-up → $\dot{\theta} \ll$ → $E \ll U$

$$I_a = \frac{U - E}{R_a} \cong \frac{U}{R_a} \gg$$

- R_a is small because:
  in a motor, one wants large C → large I_a
  but one also want small losses $R_a I_a^2$
  ⇒ R_a must be small ($\sim 0.1\,\Omega$)
- Start up rheostat (i.e. variable resistance) also belongs to the past but has to do something equivalent with power electronics.