DC Machines

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  - separate excitation
  - shunt excitation
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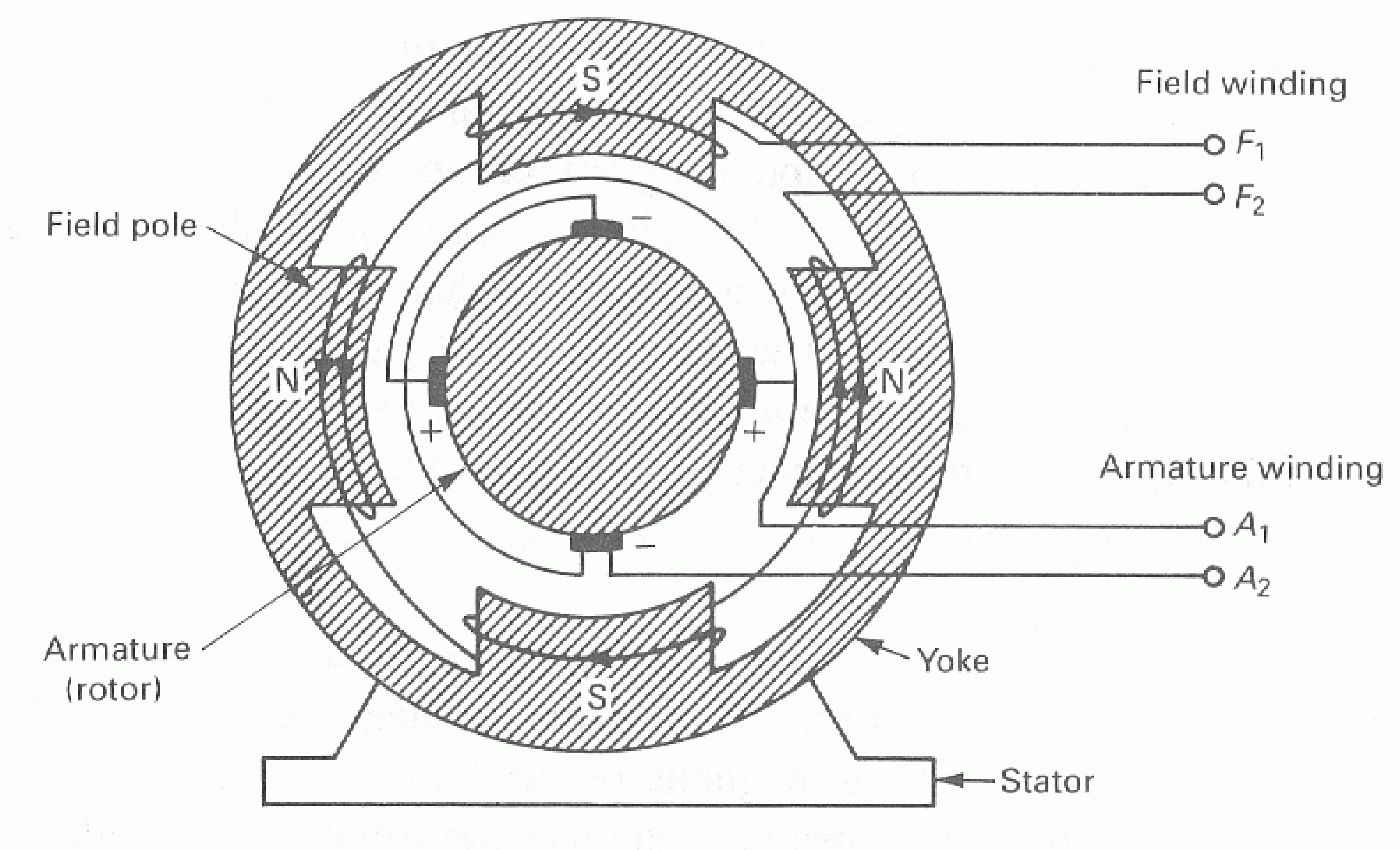
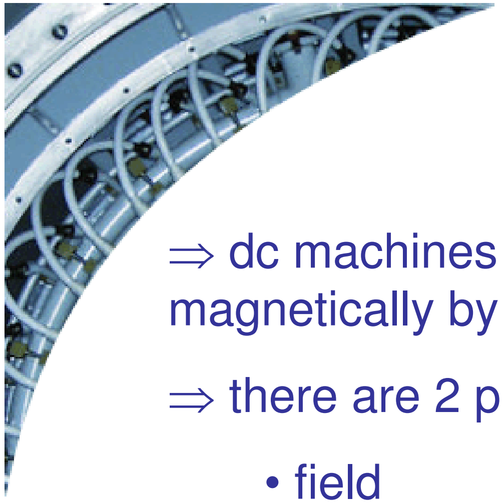
Introduction



4-pole dc machine



Introduction

⇒ dc machines consist of 2 or more sources of magnetic excitation coupled magnetically by means of a magnetic system

⇒ there are 2 principal excitations (hence doubly exited machine), i.e.

- field
- armature

Field System

⇒ function is to supply energy to establish a magnetic field in the magnetic circuit

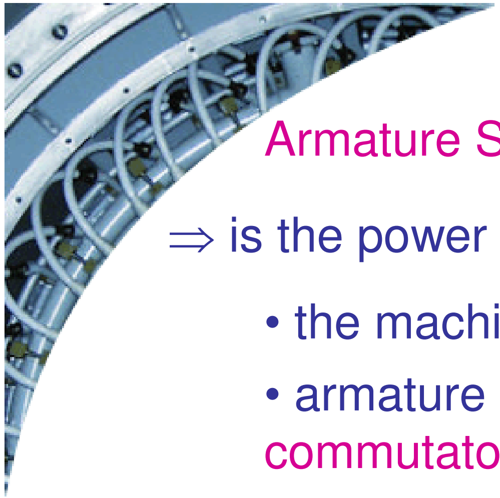
⇒ use of electrical field winding gives great DIVERSITY and VARIETY of performance characteristics that typify dc machines

⇒ permanent magnet excitation may be employed

∪ _is often less costly & occupies less space

∪ _eliminates need for separate source of energy

∩ _limited power for large machines (limited to few 100 W, until recently)



Armature System

⇒ is the power winding of a dc machine

- the machine's electromagnetic torque is a function of armature current
- armature terminals are connected to the external power source/use through commutator / brush system

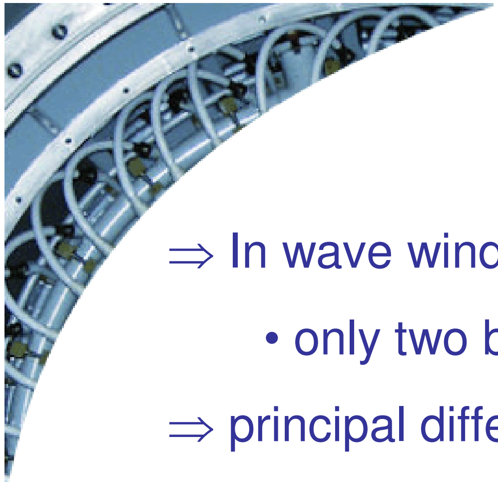
⇒ commutator / brush system acts a mechanical switching device between the external circuit and the armature winding within the machine

⇒ external connection of the armature winding are made through the brushes resting on the commutator

- brushes are held in stationary fixed positions
- commutator rotates with the rotor
- brushes are one pole-pitch apart

⇒ In lap winding:

- a number of brush positions equal to number of poles is required
- half the positions are +ve, half are –ve; positive and negative groups are paralleled through external electrical connections



⇒ In wave winding

- only two brush position are required: one +ve and one –ve

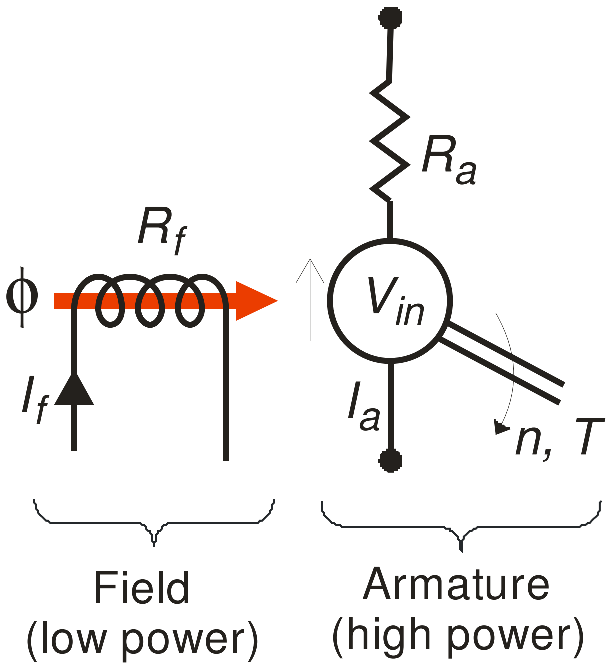
⇒ principal difference between lap and wave concerning electrical performance:

- the number of parallel electrical paths through the winding between +ve and –ve terminals of the armature

⇒ designate c for number of parallel paths between armature winding terminals

- lap: $c = 2p$
- wave: $c = 2$

Equivalent circuit of DC machine



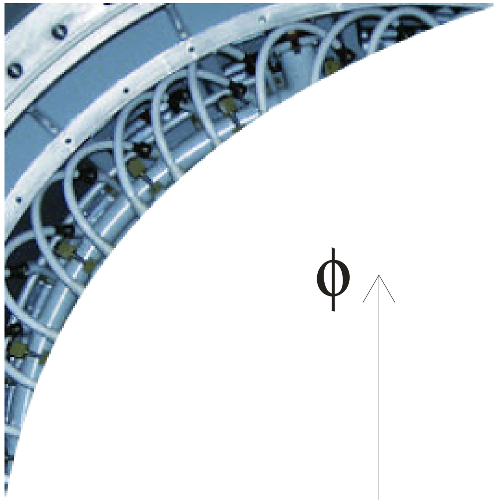
Losses

1. Copper Loss:

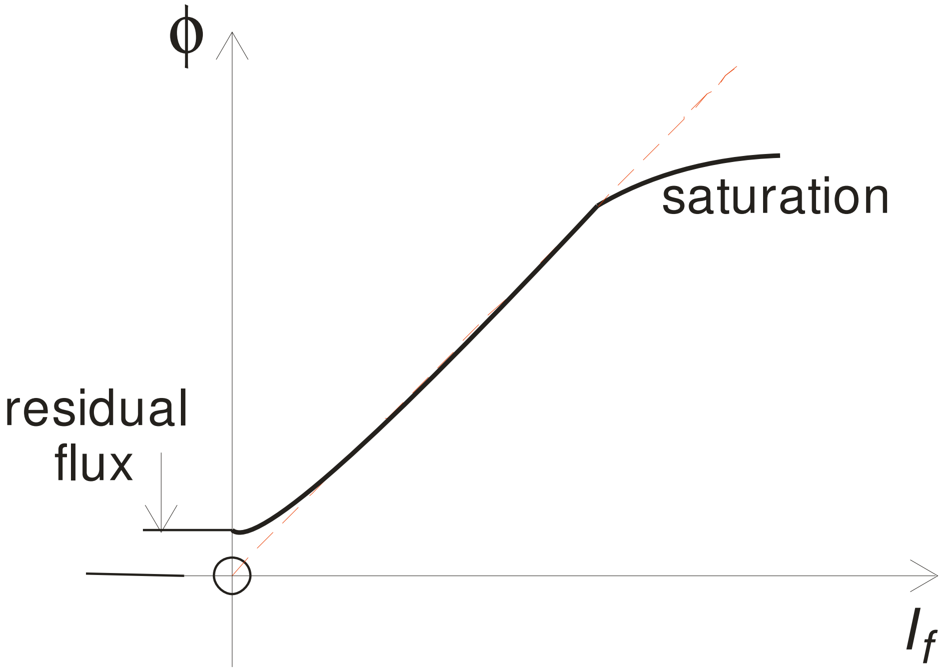
- armature $\longrightarrow$ $I_a^2 R_a$
- field $\longrightarrow$ $I_f^2 R_f = V_f I_f = \dfrac{V_f^2}{R_f}$

2. Mechanical loss

- iron loss
- friction
- windage

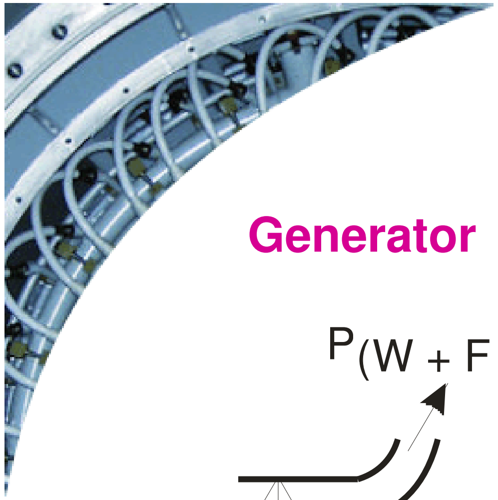


Production of flux



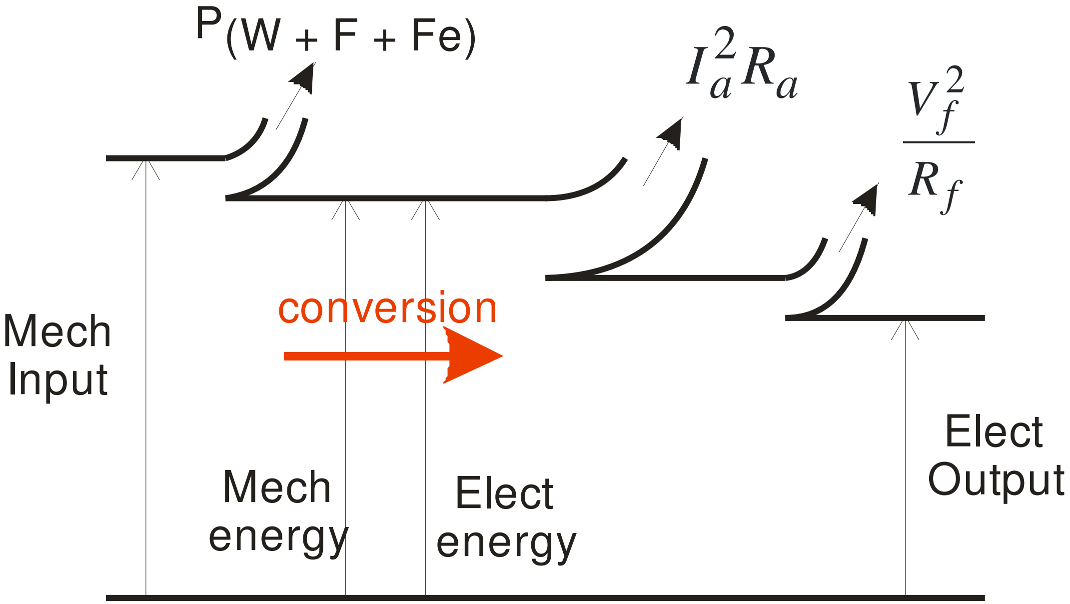
$$\phi = \frac{F}{S} = \frac{N_f I_f}{S}$$

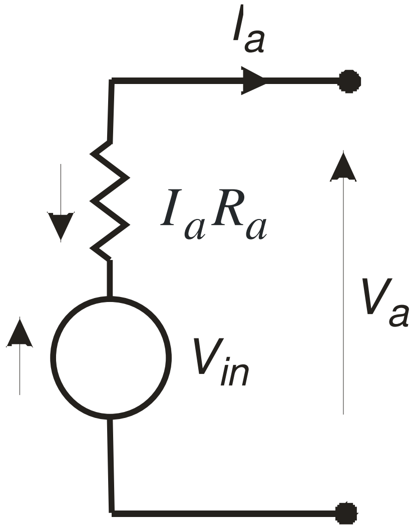
- it is a linear relationship between ϕ and I_f, if S is assumed constant
- deviation occurs because saturation appears when ϕ increases



Power flow diagrams

Generator

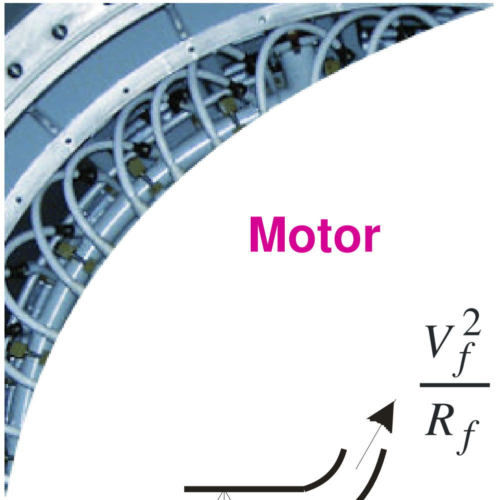




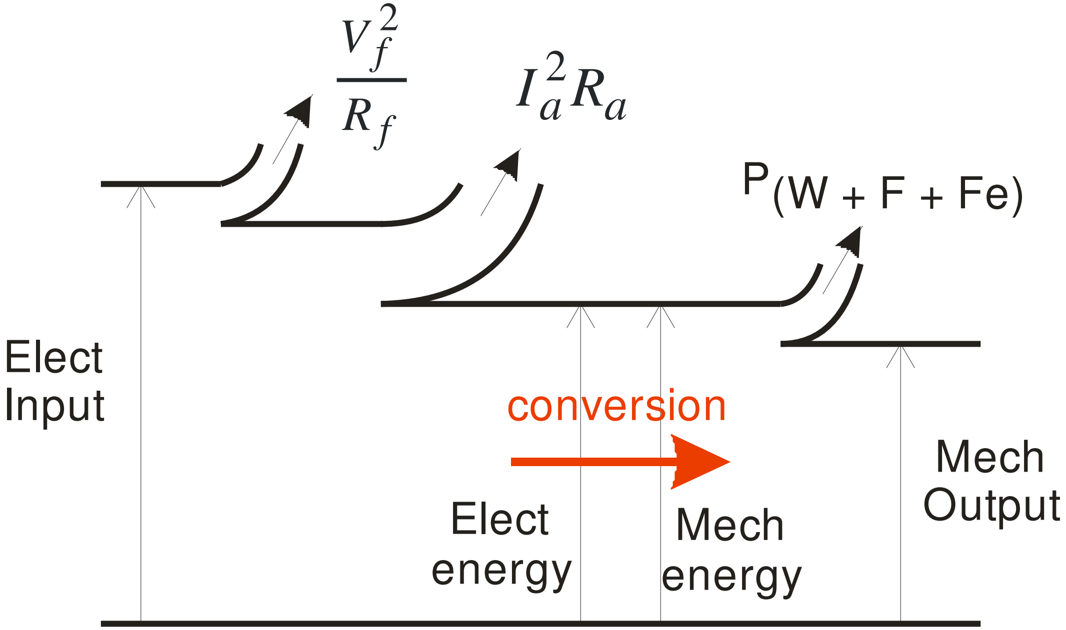
$$\eta = \frac{\text{elec. output}}{\text{mech. input}}$$

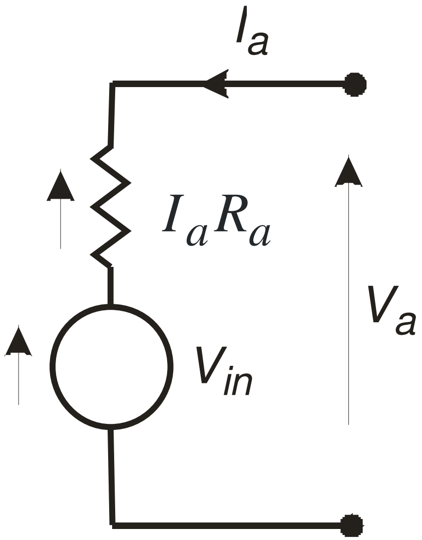
$$V_{in} = \left(\frac{2pZ}{c}\right) n\phi$$

$$V_a = V_{in} - I_a R_a$$



Motor

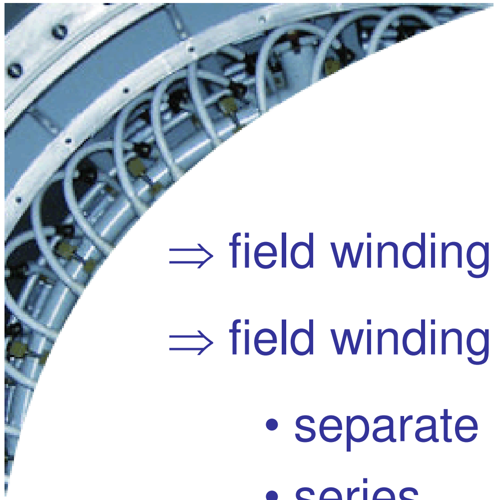




$$\eta = \frac{\text{elec. output}}{\text{mech. input}}$$

$$V_{in} = \left(\frac{2pZ}{c}\right) n\phi$$

$$V_a = V_{in} + I_a R_a$$



DC machine configurations

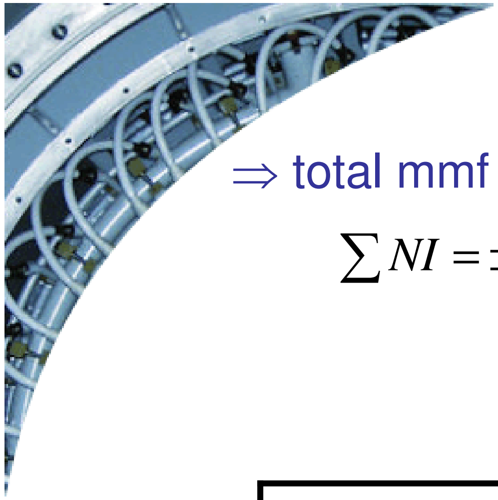
⇒ field winding connection determines the type of dc machine arrangement

⇒ field winding can either be connected in

- separate
- series
- shunt
- compound

- a winding in dc machine is designated as:

winding	**BS4999 pt3 (1977)**	**BS8222 pt 6 (1964)**
armature	A1 – A2	A – AA
separate	F1 – F2	X – XX
series	D1 – D2	Y – YY
shunt	E1 – E2	Z – ZZ

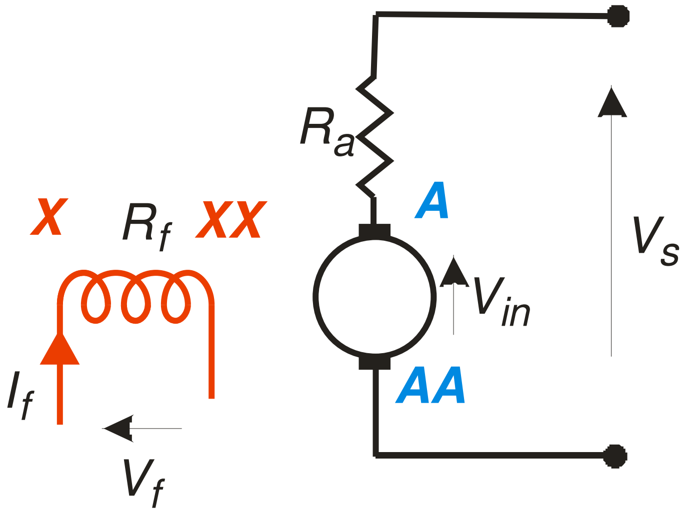


⇒ total mmf on *d*-axis is

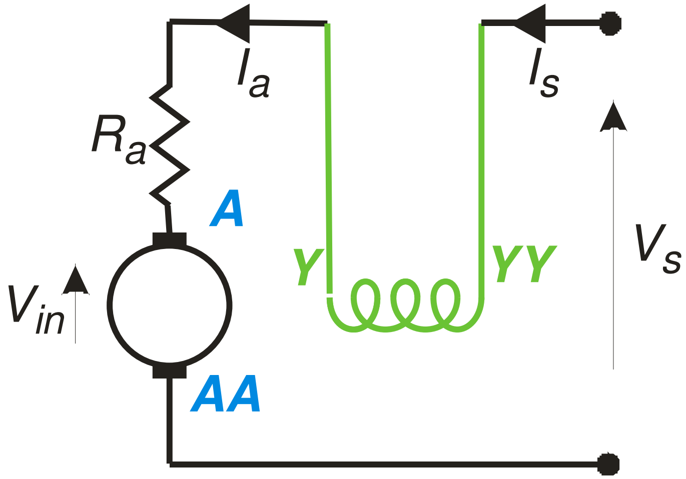
$$\sum NI = \pm N_X I_X \pm N_Y I_Y \pm N_Z I_Z$$

Field	**$\sum NI$**	
separate	$\pm N_X I_x + 0 + 0$	
series	$0 \pm N_Y I_Y + 0$	
shunt	$0 + 0 \pm N_Z I_Z$	
Compound (cumulative)	$0 + N_X I_x + N_Z I_Z$	$0 - N_X I_x - N_Z I_Z$
Compound (differential)	$0 + N_X I_x - N_Z I_Z$	$0 - N_X I_x + N_Z I_Z$

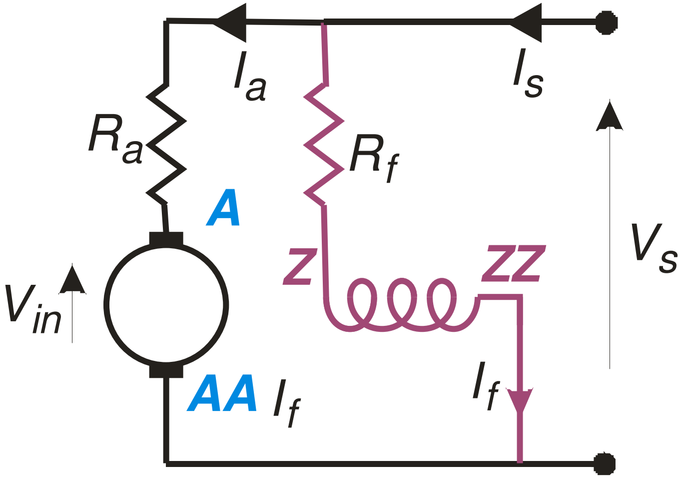
separate



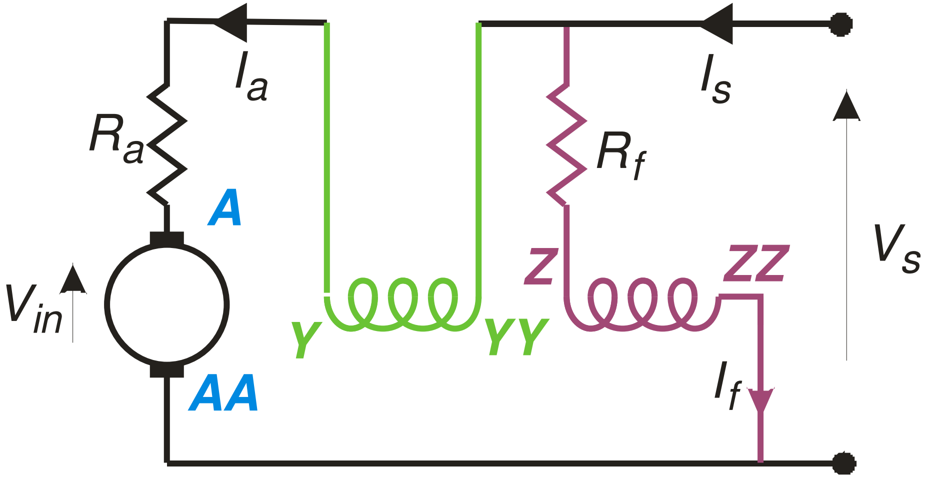
series

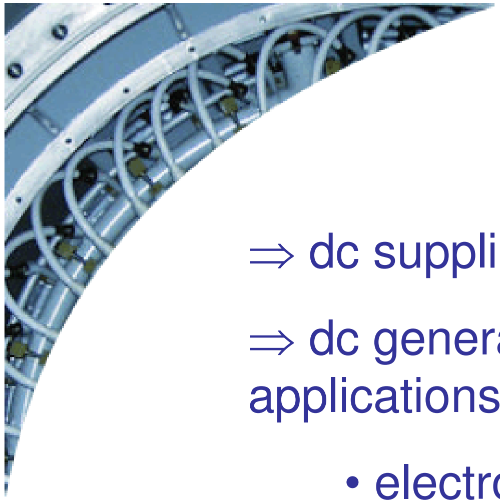


shunt



compound



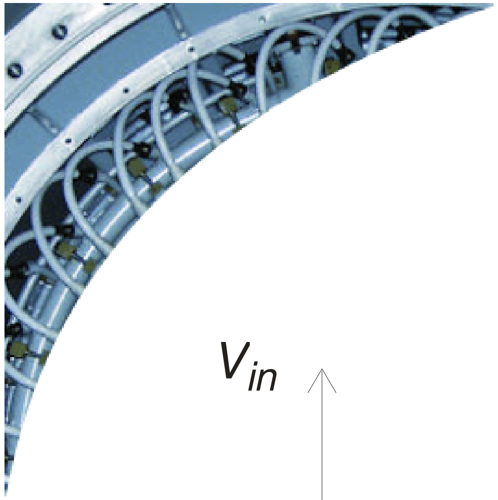


DC Generator

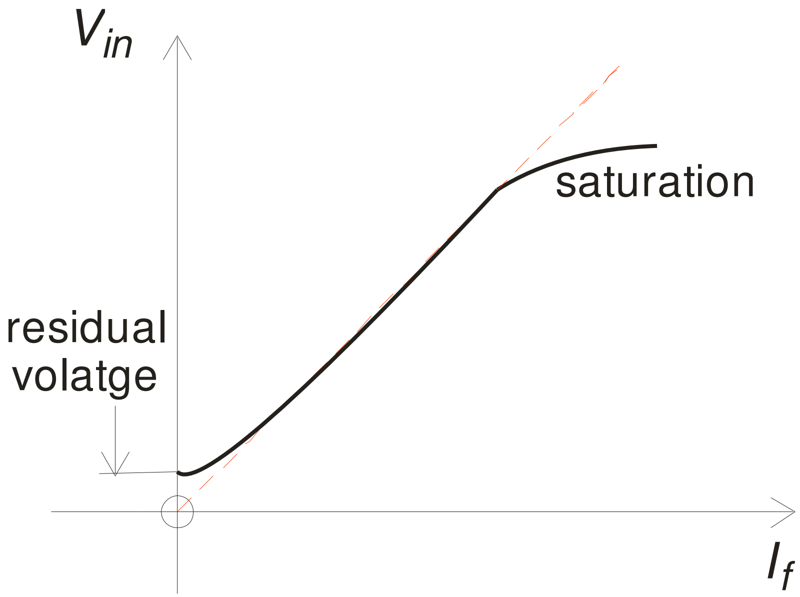
⇒ dc supplies are commonly derived from ac supplies by rectification

⇒ dc generators are built with outputs of a few W to several MW for applications in

- electrochemical plants for electro deposition and metal refining
- battery charging for standby or emergency supply
- diesel-electric locomotives
- synchronous machine excitation
- automatic control systems
- etc



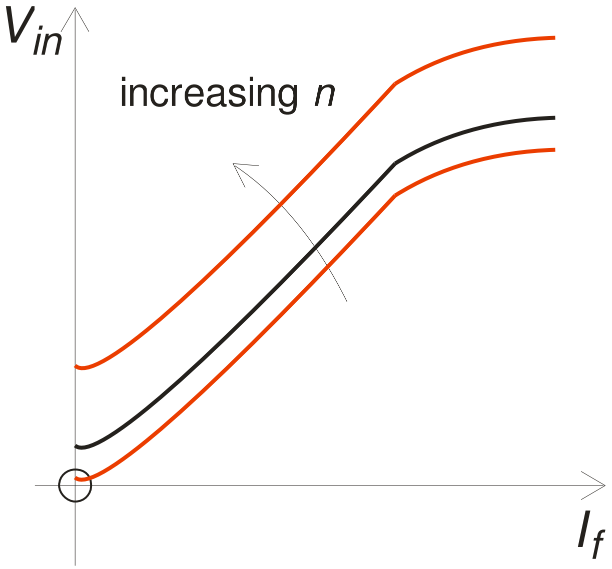
Saturation curve



$$V_{in} = \left(\frac{2pZ}{c}\right) n\phi$$

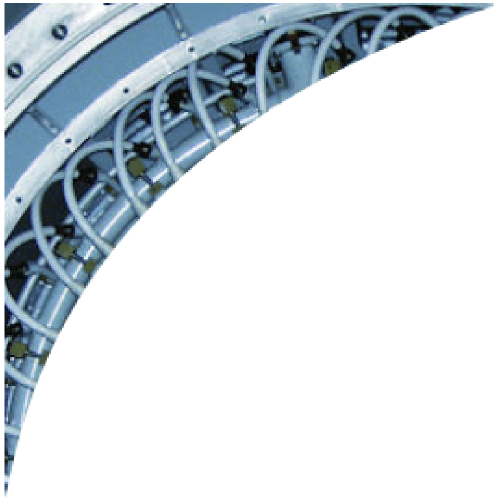
$$V_{in} \propto \phi \quad (n \ \text{const.})$$

$$V_{in} \propto n \quad (I_f \ \text{const.})$$

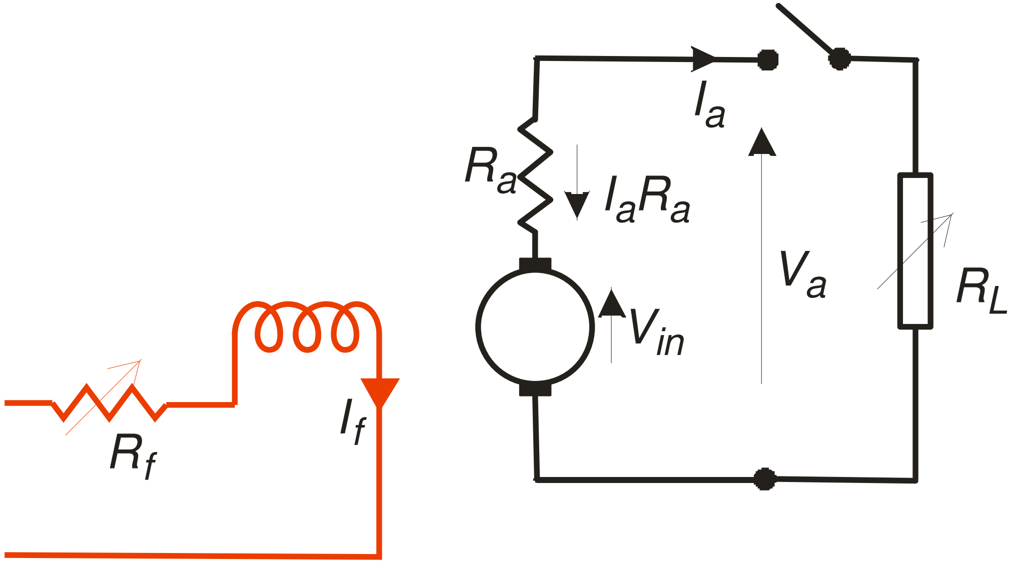


⇒ the no-load saturation curve a dc machine is a curve of induced armature emf V_{in} versus field current I_f for the machine running at rated speed on no-load

⇒ a.k.a. open-circuit characteristic or magnetisation curve

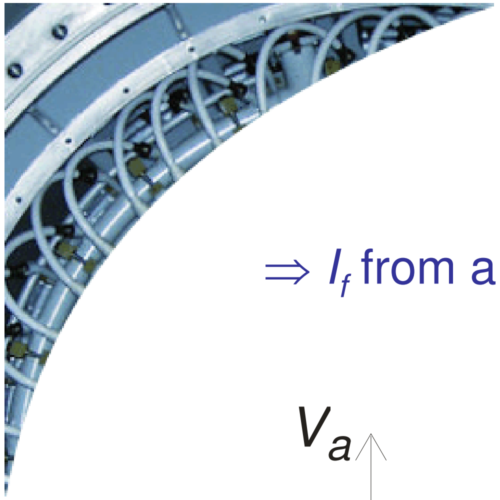


DC generator equivalent circuit



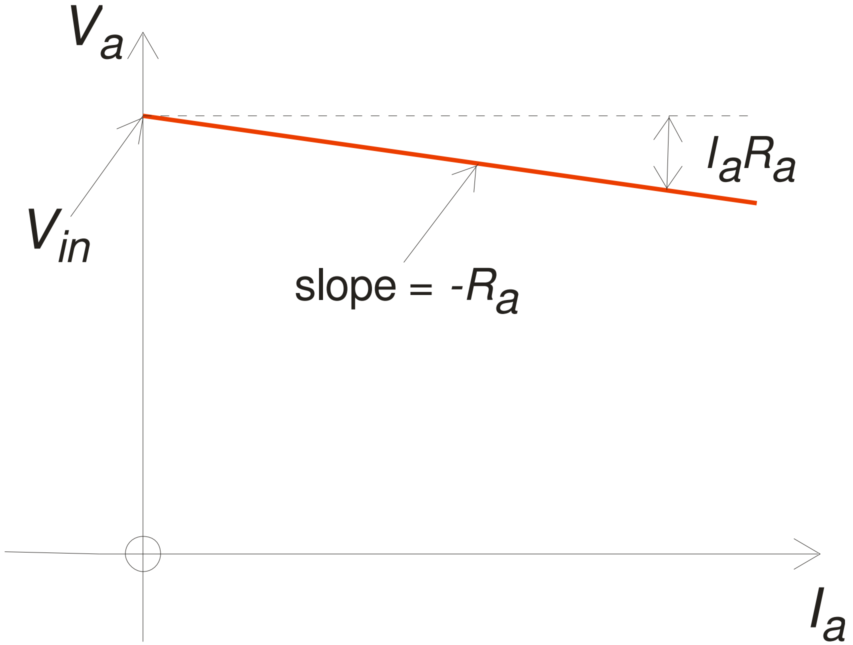
$$V_{in} = \left(\frac{2pZ}{c}\right) n\phi$$

$$V_a = V_{in} - I_a R_a$$

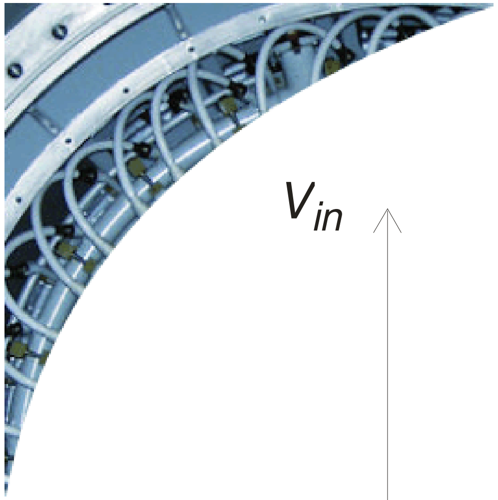


Separate excitation

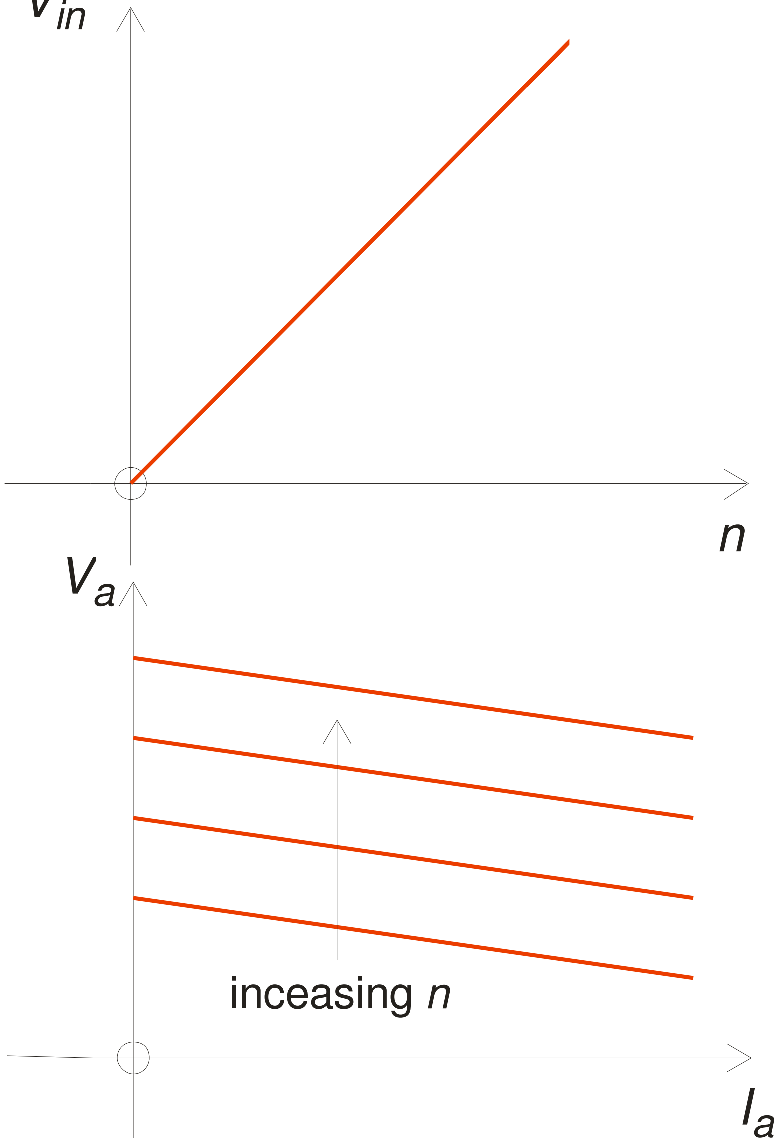
- ⇒ I_f from a separate source (external)



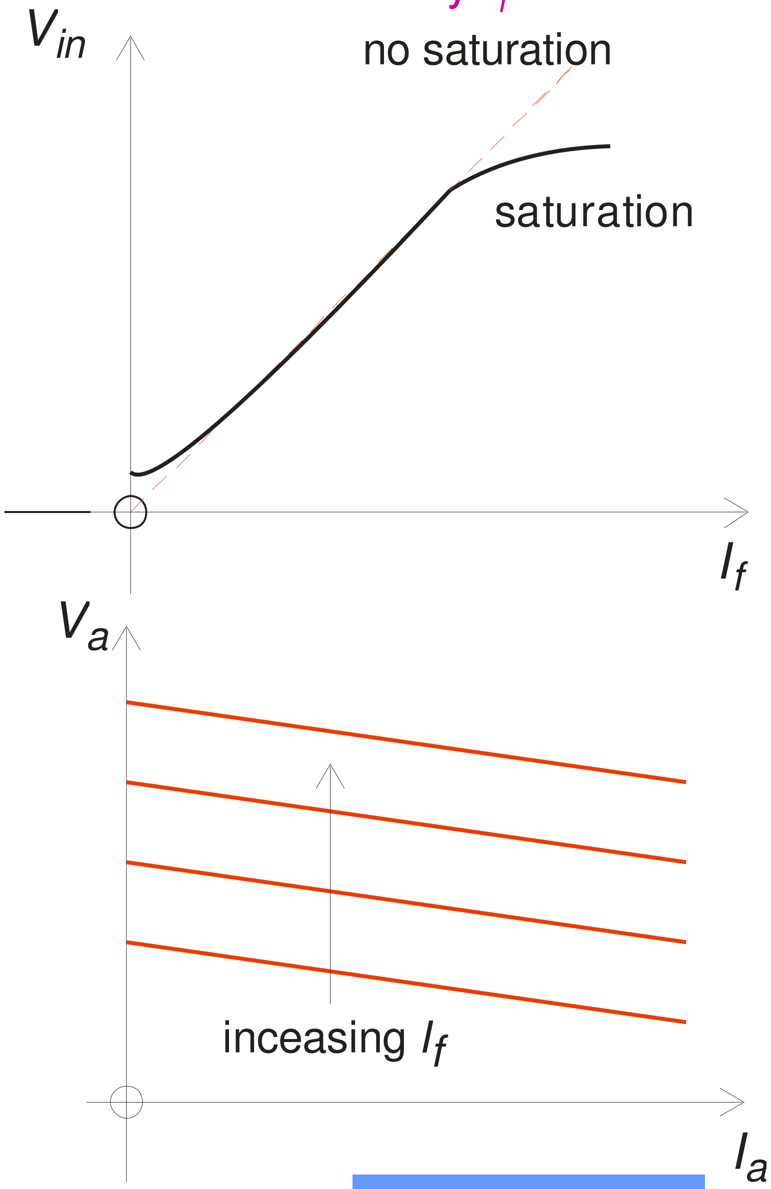
$$V_a = V_{in} - I_a R_a$$

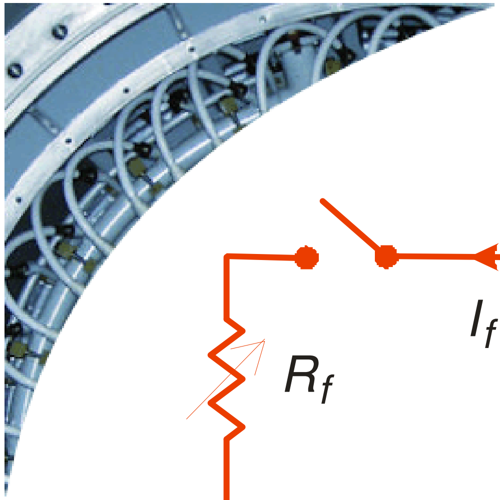


Vary n

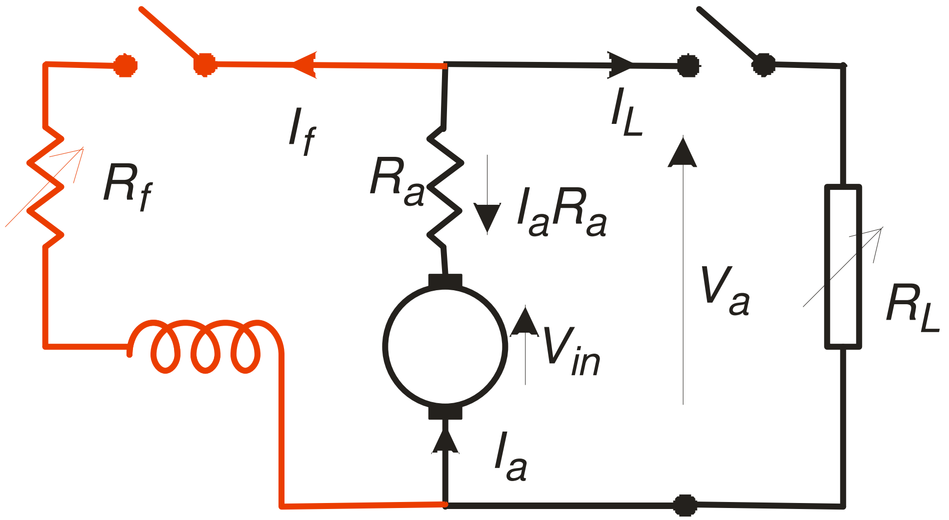


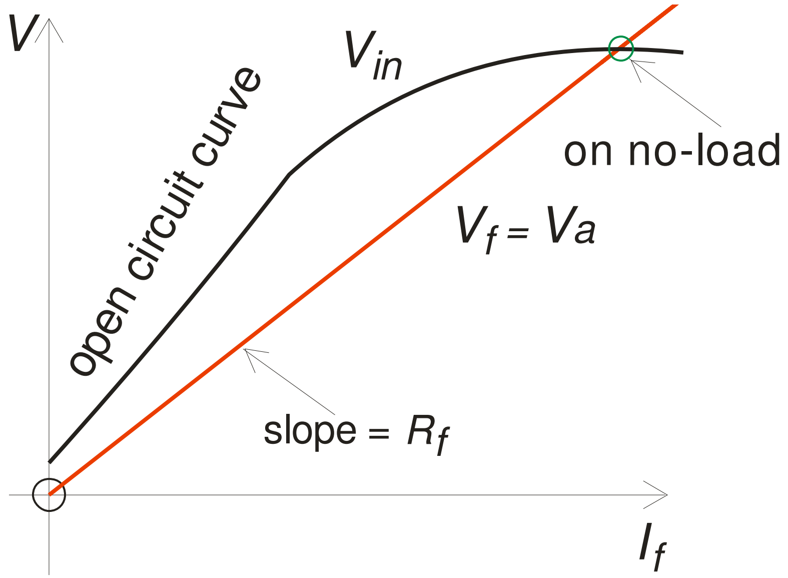
Vary I_f





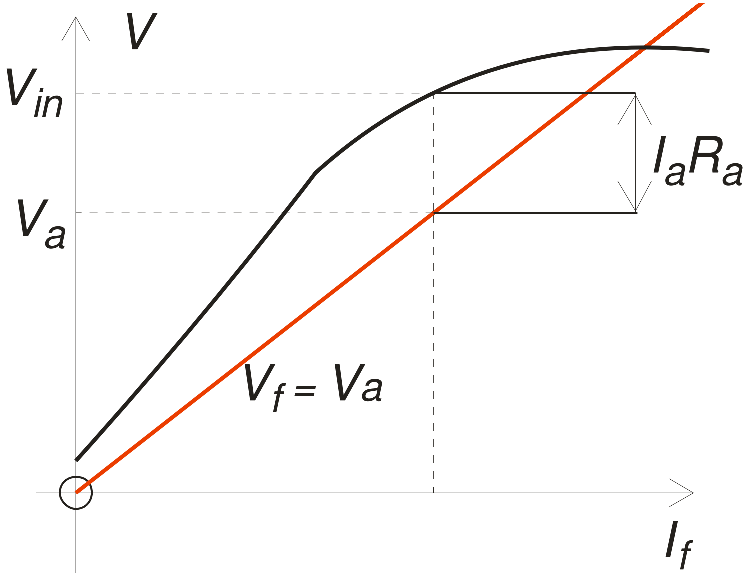
Shunt excitation



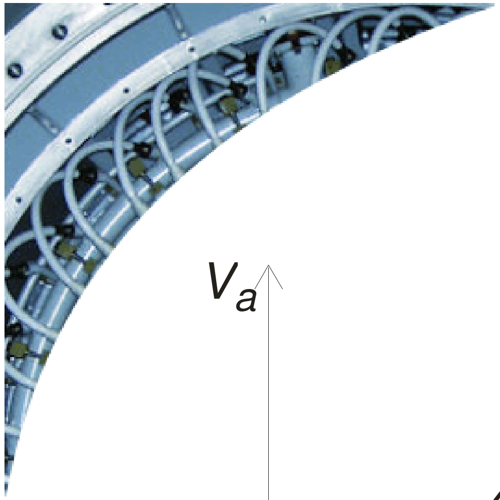


⇒ close field switch, then

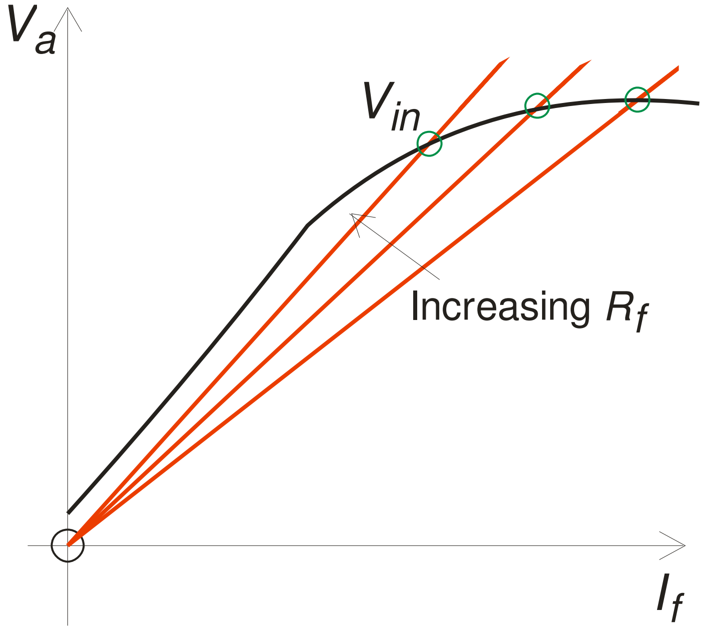
$$V_f = V_a$$



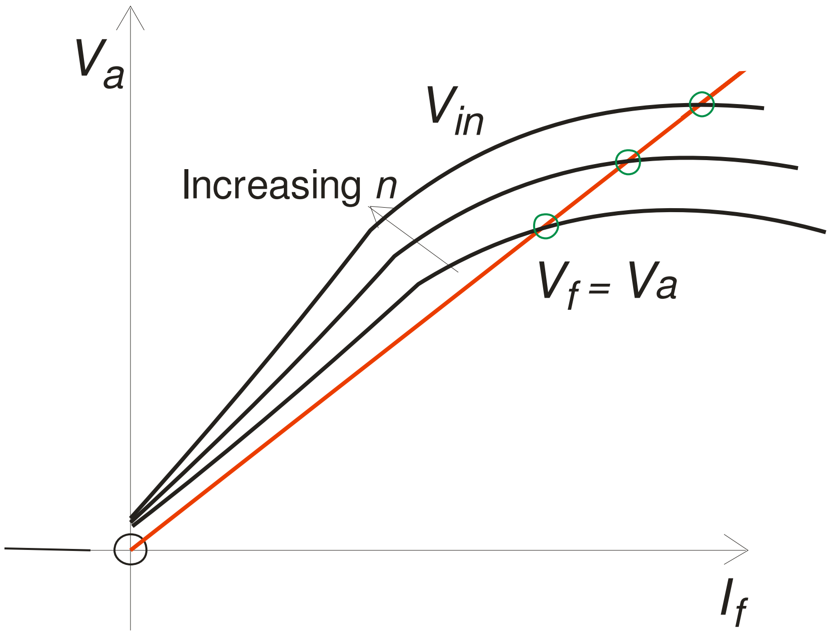
⇒ on load with load switch closed



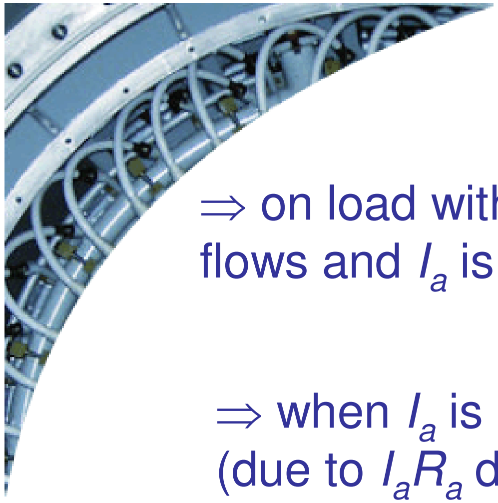
Why shunt generator may fail to self-excite



Too high R_f



Too low n



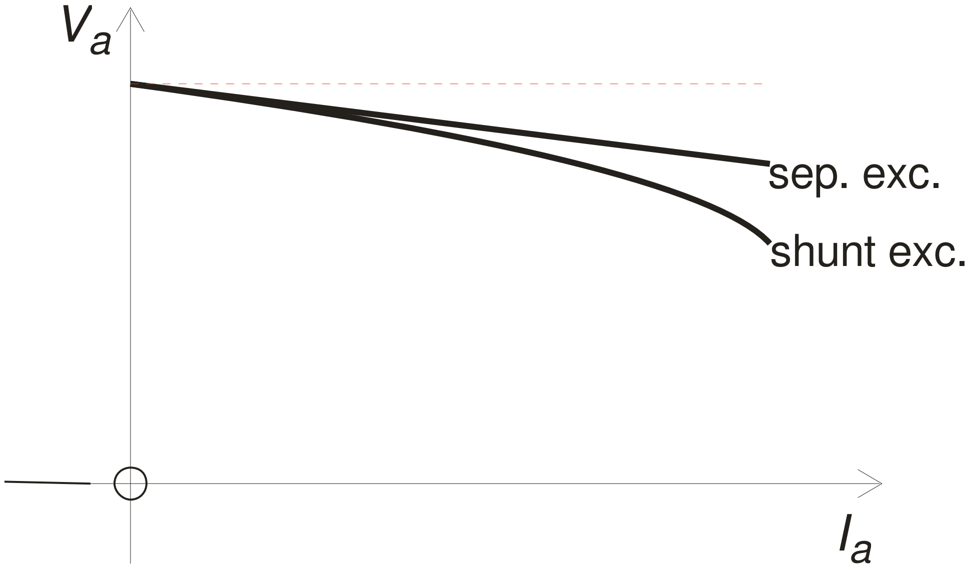
⇒ on load with load switch closed, I_L flows and I_a is significant

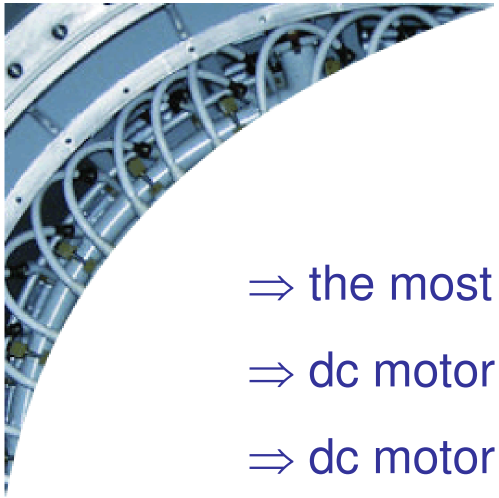
⇒ when I_a is increased, V_a reduces (due to I_aR_a drop), as in the case of separate excitation

⇒ V_f reduces, I_f reduces, ϕ reduces (unlike in separate excitation

⇒ $\therefore$ V_{in} reduces

⇒ V_a reduces even further





DC Motors

⇒ the most common industrial workhorse is the ac cage induction motor

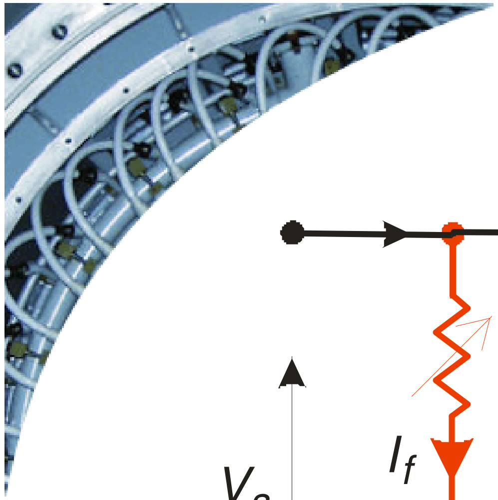
⇒ dc motor is more complex and more costly

⇒ dc motor has advantage of

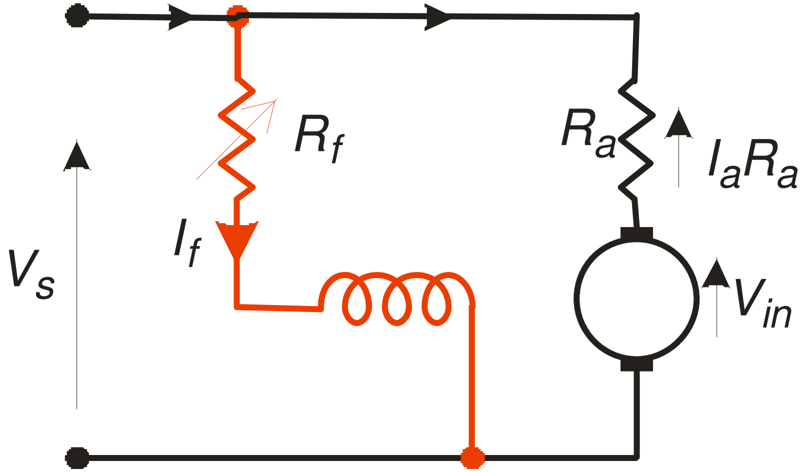
- a wide variety of torque-speed characteristics
- economical speed control

⇒ relationship between speed and torque corresponds to relationship between voltage and current for a generator

⇒ speed at which motor will run depends on the balancing point of the electromagnetic torque T_e and the mechanical load torque T_m



DC shunt motor



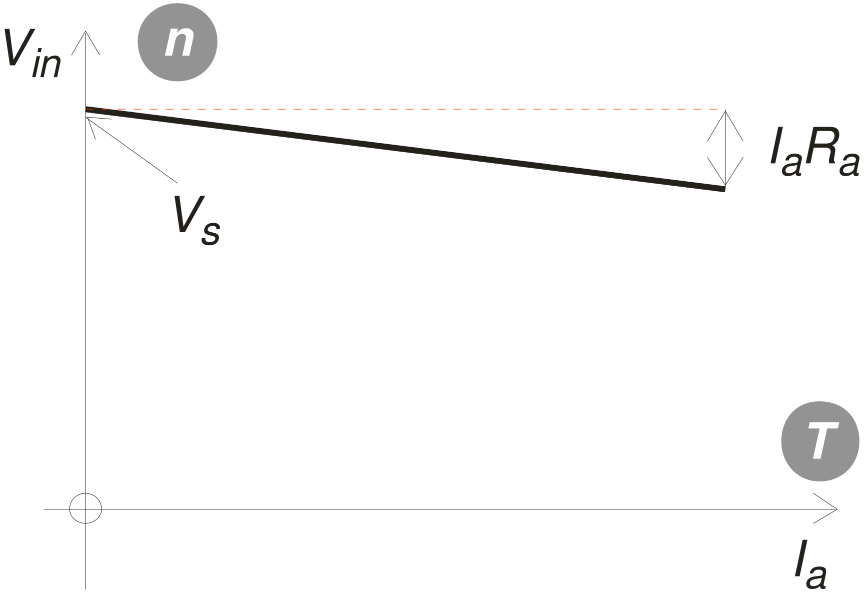
$$V_s = V_{in} + I_a R_a$$

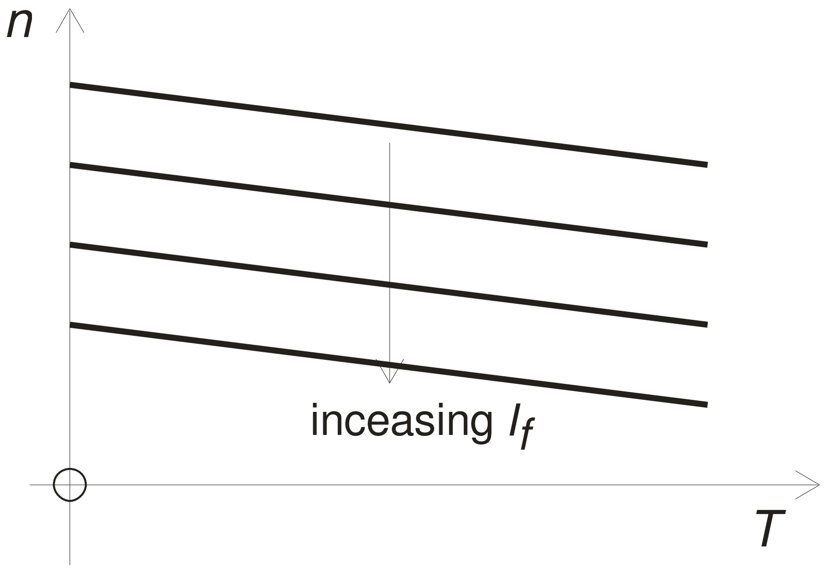
$$T = \frac{1}{2\pi}\left(\frac{2pZ}{c}\right)\phi I_a$$

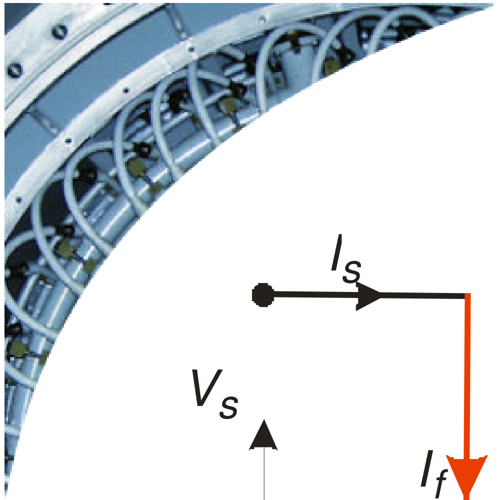
⇒ at const. I_f (∴ const. ϕ),

$$V_{in} \propto n$$

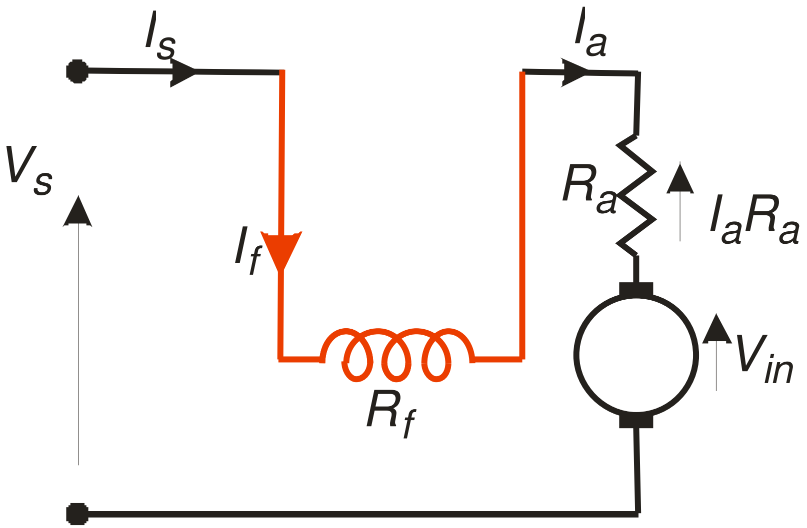
$$T \propto I_a$$







DC series motor



$$V_s = V_{in} = \left(\frac{2pZ}{c}\right)n\phi$$

$$\therefore n \propto \frac{1}{\phi} \propto \frac{1}{I}$$

$$T = \frac{1}{2\pi}\left(\frac{2pZ}{c}\right)\phi I_a$$

$$T \propto I^2$$

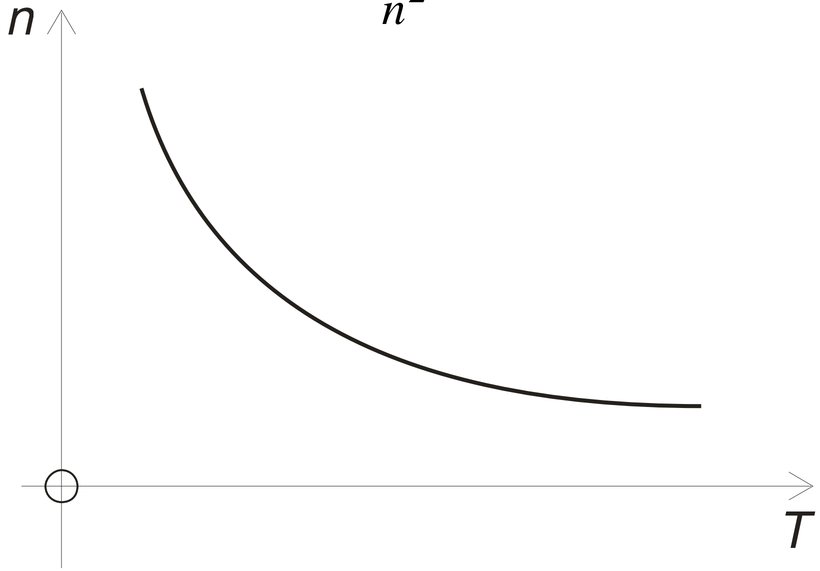
$$T \propto \frac{1}{n^2}$$

$$I_s = I_a = I_f = I$$

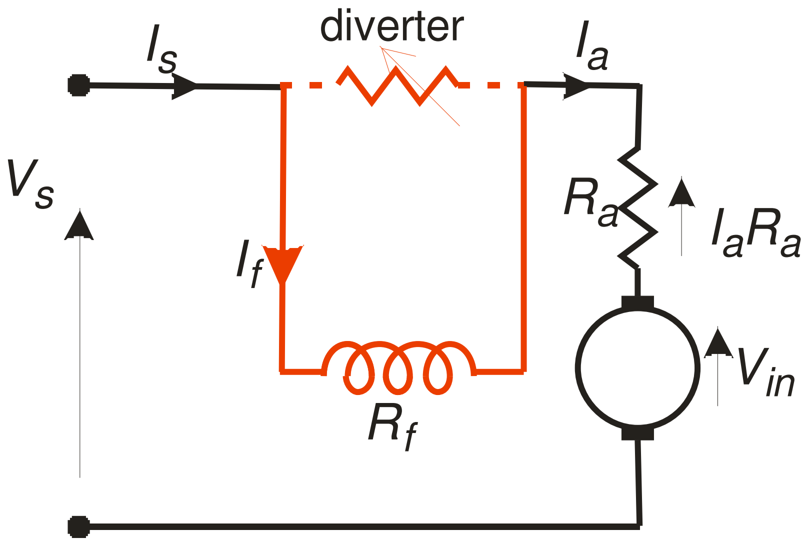
⇒ 2 assumptions

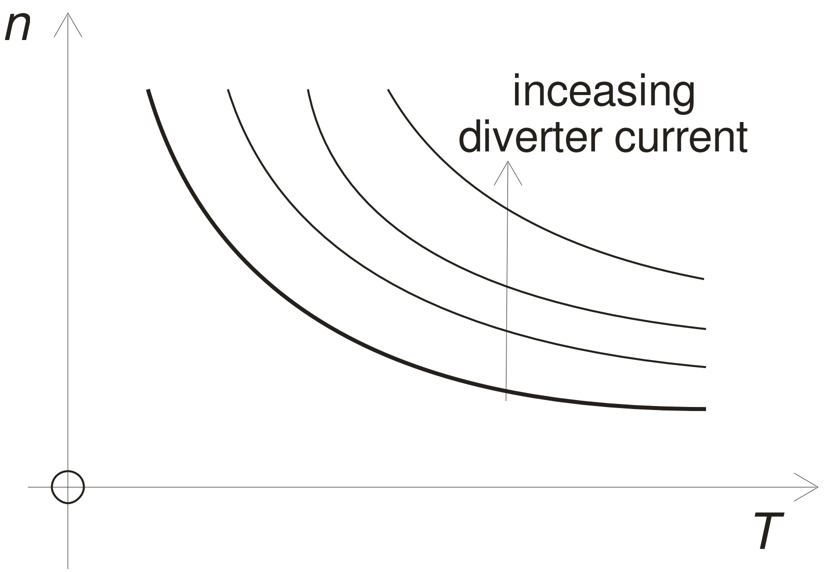
- neglect "*IR*" drops
- neglect saturation, so

$$\phi \propto I$$

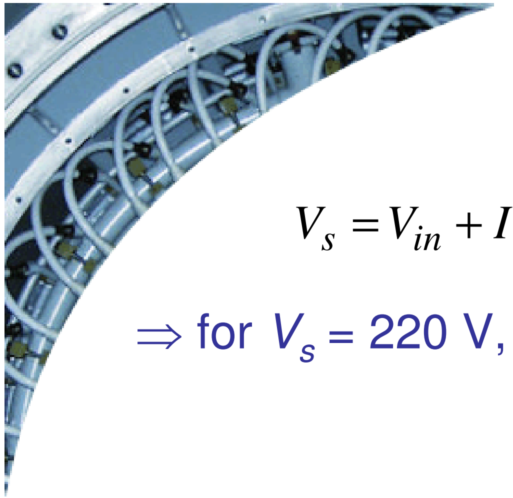


Using current diverter





⇒ gives a family of T-n curves



Starting DC motors

$$V_s = V_{in} + I_a R_a$$

⇒ for V_s = 220 V, R_a = 1 Ω (e.g.)

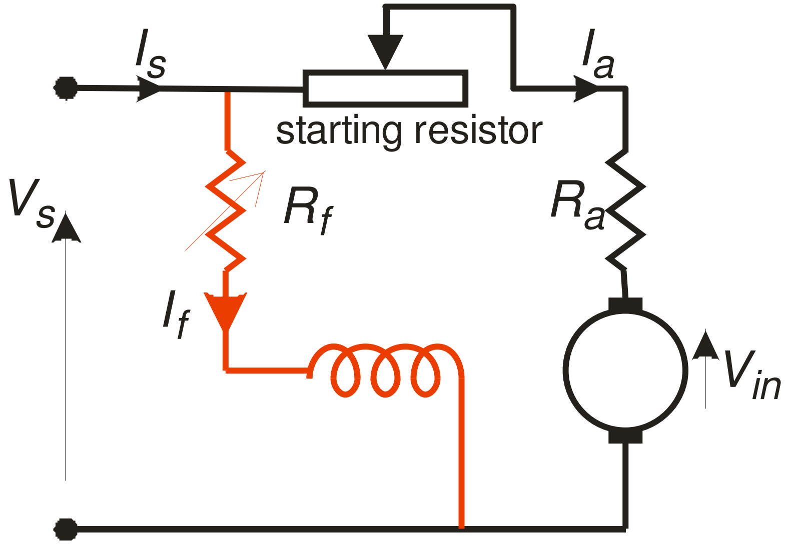
	I_a	V_s	=	V_{in}	+	$I_a R_a$
Full-load	10 A	220	=	210	+	10 x 1
No-load	1 A	220	=	219	+	1 x 1
Starting	?	220	=	0	+	? x 1

⇒ for an assumed no-load I = 1 A and full-load I = 10 A, starting current is 220 A!

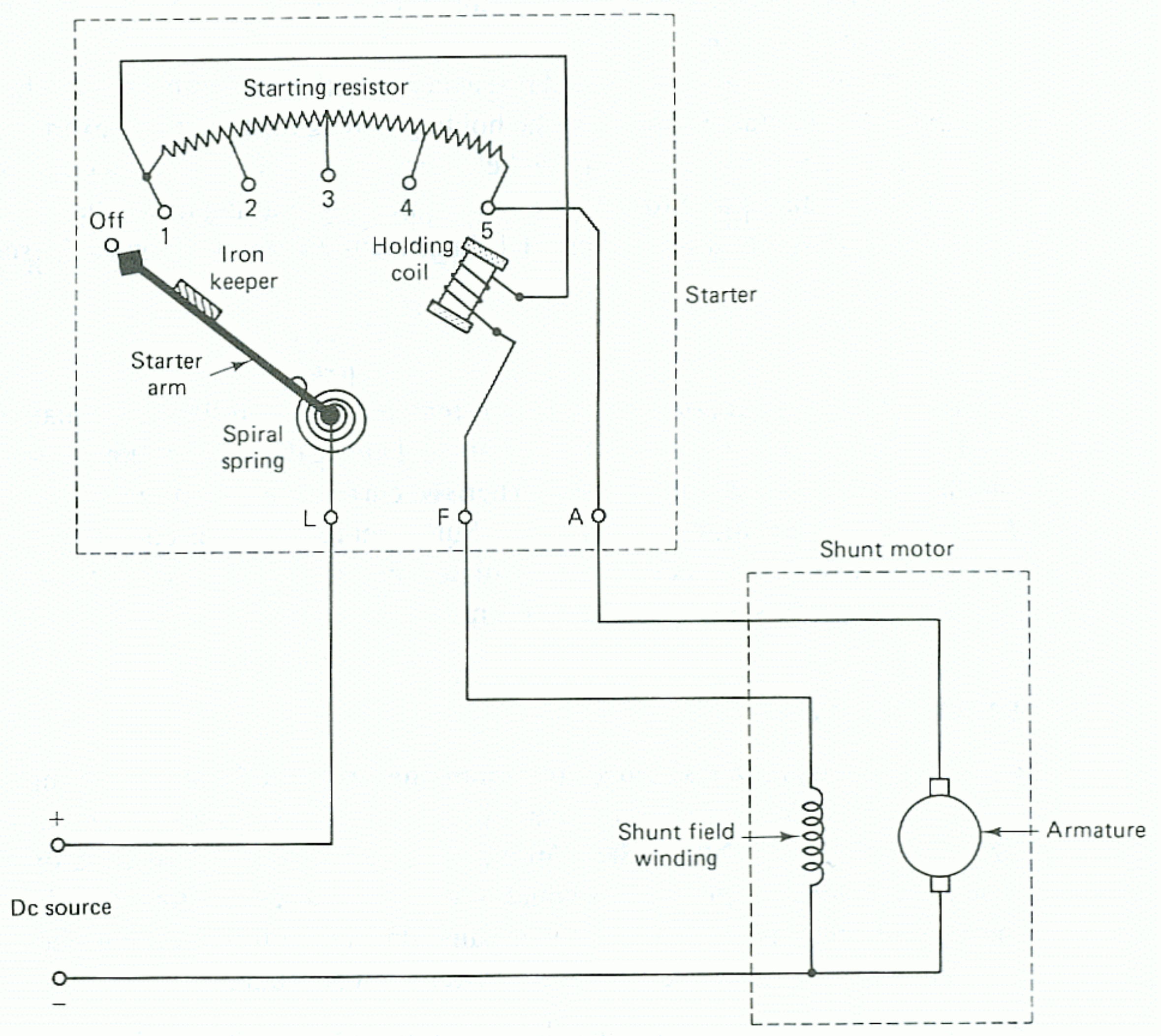
⇒ this is unacceptable

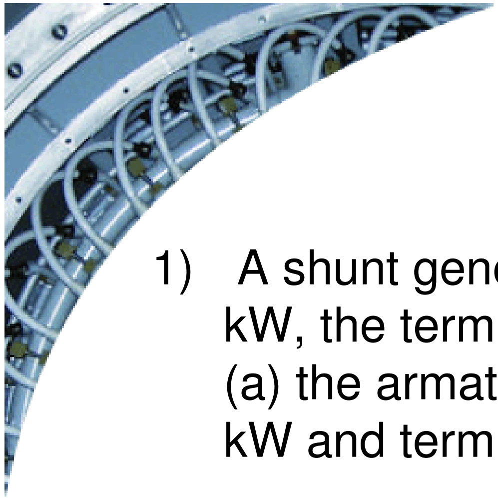
$\Rightarrow$ to limit the starting current we include a temporary resistor in the armature

$\Rightarrow$ this starting resistance is gradually reduced to zero as the machine speeds



A practical manual starter





Examples

1) A shunt generator has a field resistance of 60 Ω. when the generator delivers 6 kW, the terminal voltage is 120 V., while the generated EMF is 133 V. Determine (a) the armature circuit resistance and (b) the generated EMF when the output is 2 kW and terminal voltage is 135 V.
2) A DC motor operates at 1680 r/min when drawing 28 A from a 230-V supply. If the armature resistance is 0.25 Ω, and assuming all losses are neglected, calculate (a) the no-load speed, (b) the developed power under loaded conditions and (c) the torque developed under the given load.
3) A 240-V shunt motor has an armature resistance of 0.25 Ω. Under load, the armature current is 24 A. Suppose the flux is suddenly decreased by 2.5%; (a) what would be the immediate effect on the developed torque? (b) if the motor was running at 640 r/min before the field was adjusted, determine the new steady-state speed after the field has been decreased.
4) A 240-V shunt motor runs at 800 r/min when the armature current is 70 A. The armature circuit resistance is 0.10 Ω. Calculate the required resistance to be placed in series with the armature to reduce the speed to 650 r/min when armature current is 50 A.