Electric Machinery II

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Text: A. E. Fitzgerald, Charles Kingsley, Jr And Stephen D. Umans, *Electric Machinery*. Mc GrawHill, 7th Edition

Electrical Machine II Syllabus

1. Introduction

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2. Introduction to Rotating Machines

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3. DC Machines
    - Commutator Action
    - Electric-Circuit Aspects
    - Effect of Armature MMF (Armature reaction, Commutation and Interpoles and Compensating Windings)
    - Steady-State DC Machine Performance
    - Permanent-Magnet DC Machines
    - Series Universal Motors
    - DC Motor Starting
4. Induction Machines

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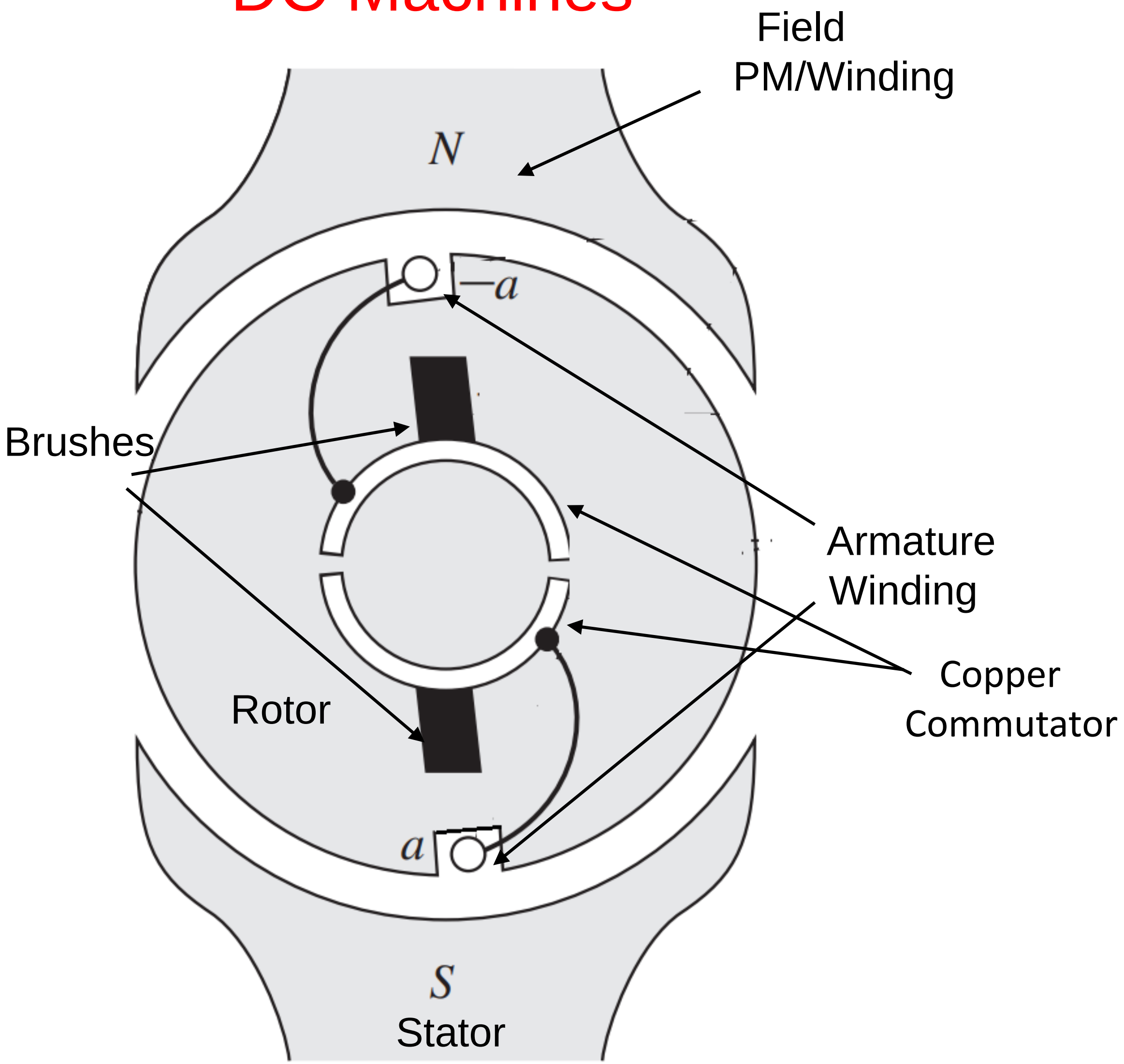
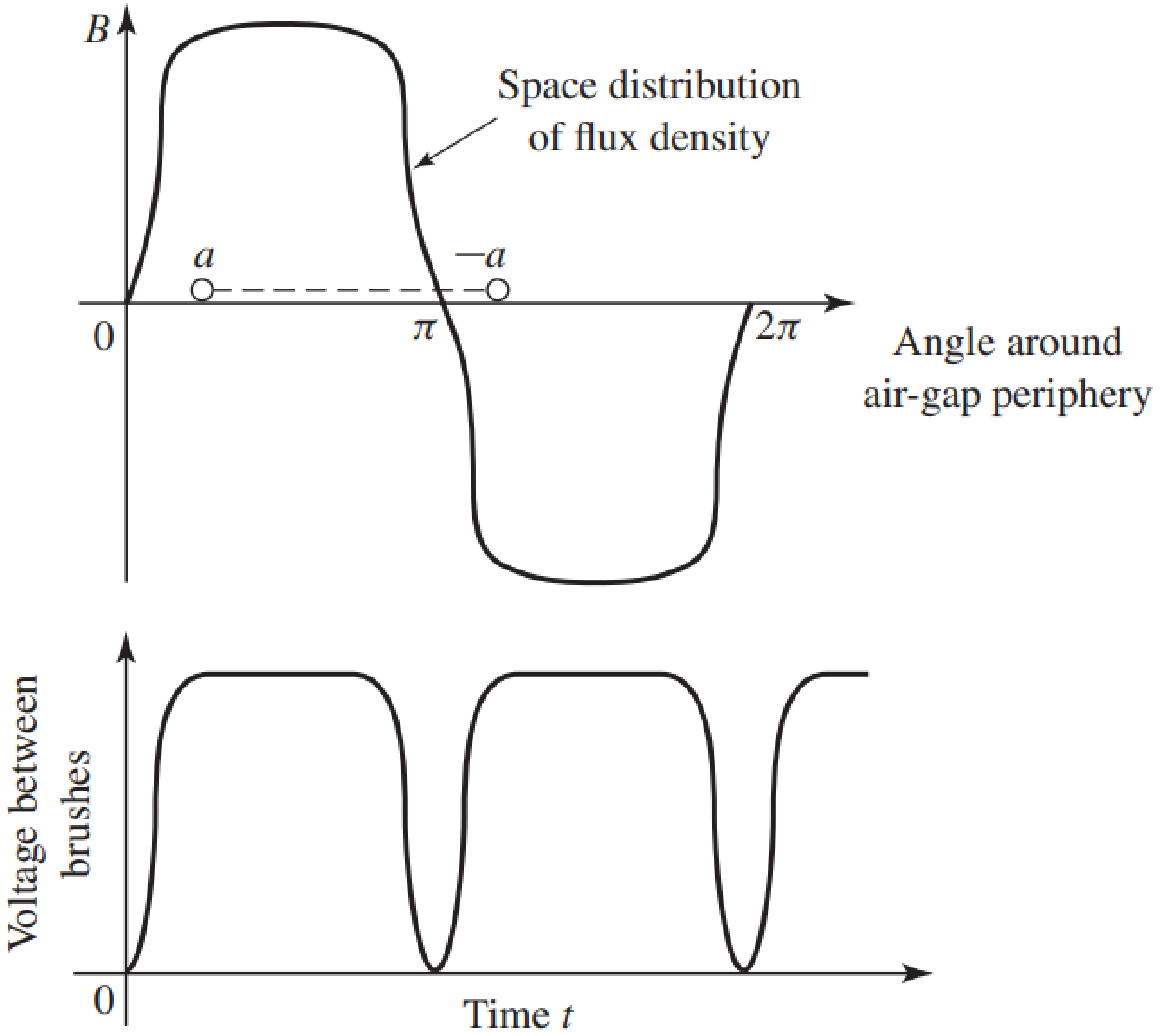
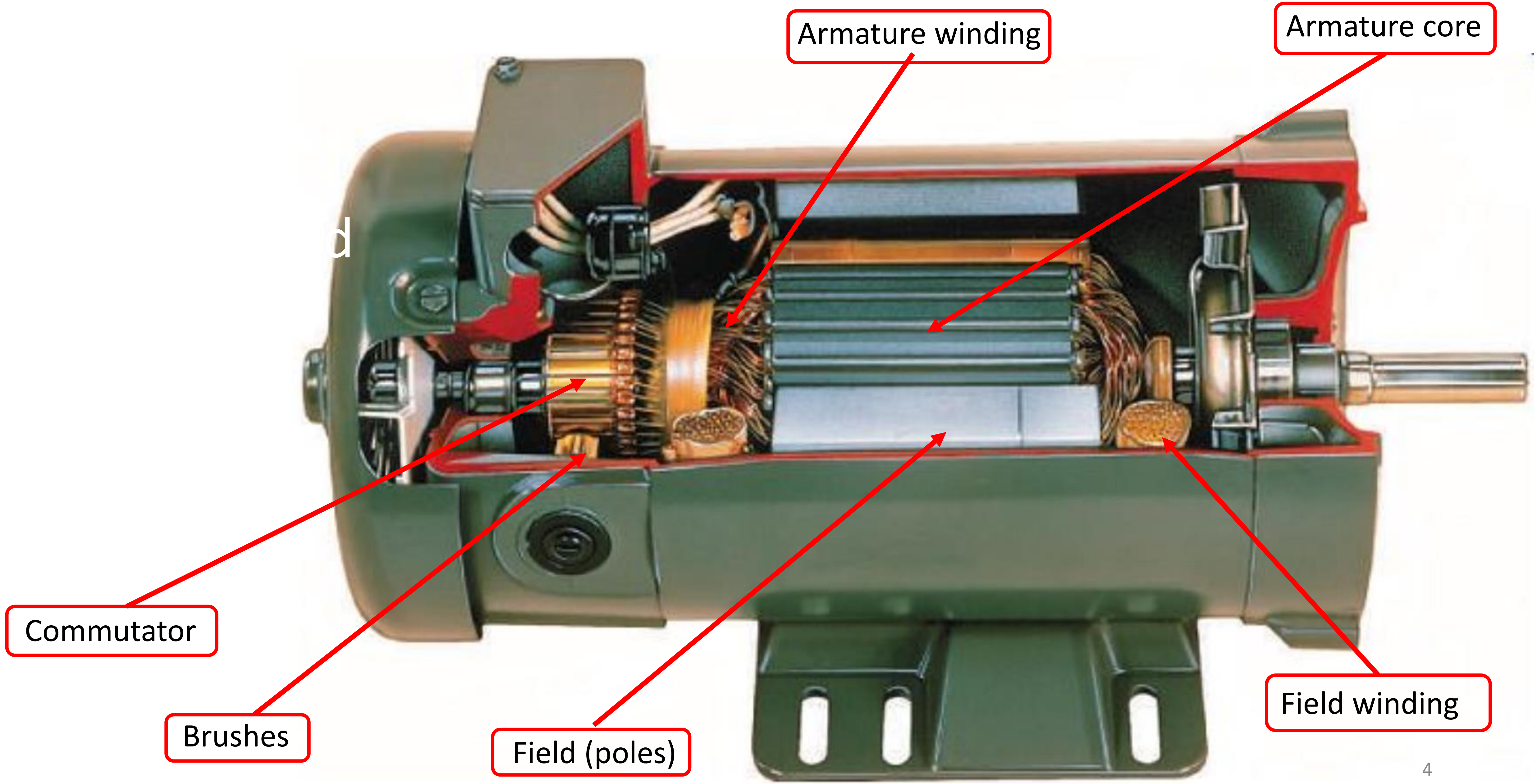
Voltage Generation in Electrical Machinery

DC Machines

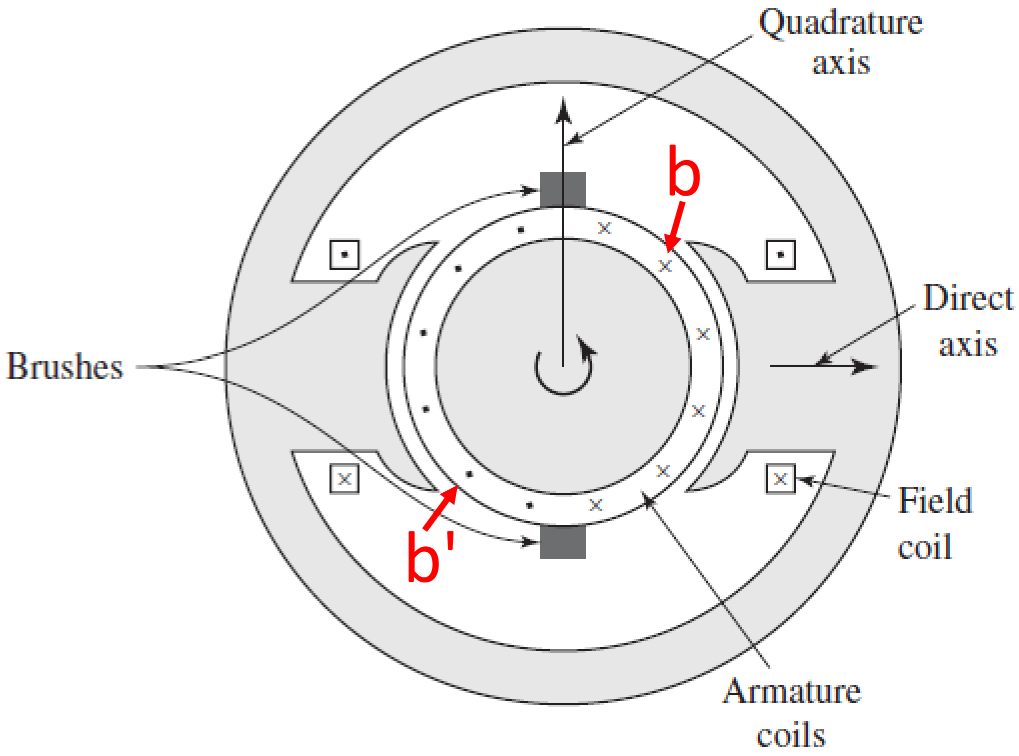


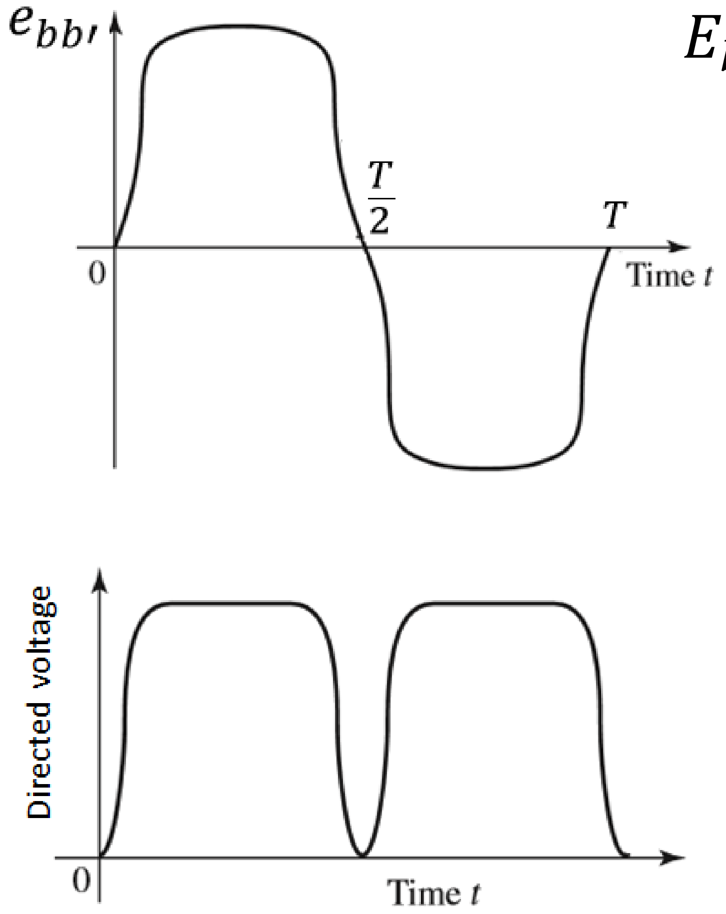



Armature winding
Armature core
Commutator
Brushes
Field (poles)
Field winding

Generated voltage in DC Machine$\left(\frac{d\varphi}{dt}\right)$

Schematic of a DC machine





$$E_{bb'} = \frac{1}{T/2}\int_0^{T/2} 1\frac{d\varphi}{dt}dt$$

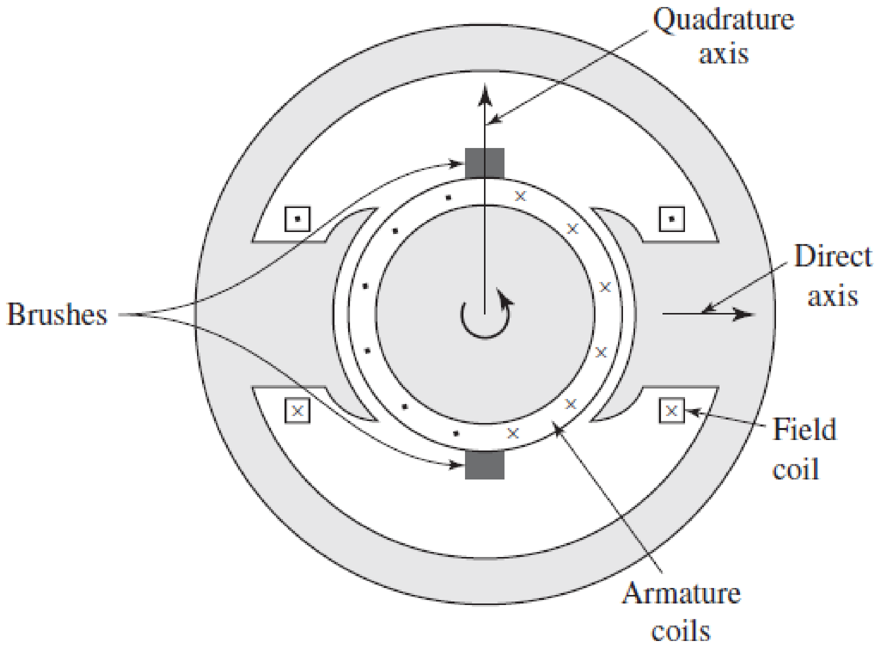
$$= \frac{2}{T}\int_0^{\frac{T}{2}} 1\frac{d\varphi}{dt}dt$$

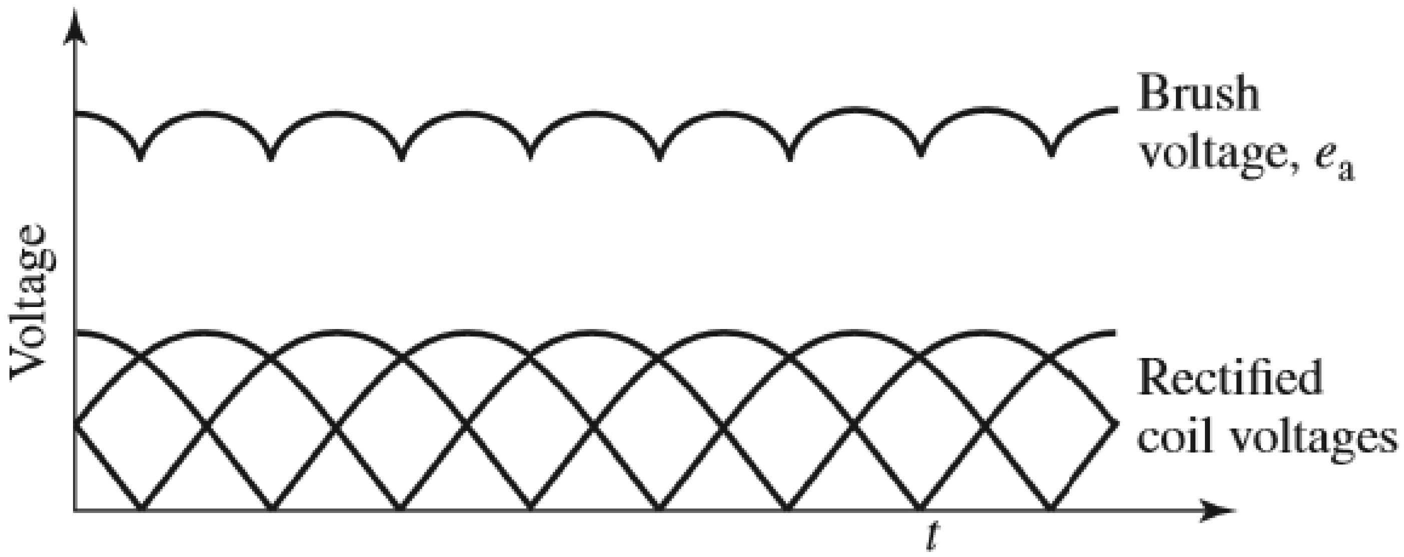
$$= \frac{2}{T}\left(\varphi\left(\frac{T}{2}\right) - \varphi(0)\right)$$

$$= \frac{4}{T}\varphi_d$$

$E_b = \frac{2}{T}\varphi_d$ Average generated voltage in one conductor

Generated voltage in DC Machine$\left(\frac{d\varphi}{dt}\right)$





$$E_b = \frac{2}{T}\varphi_d$$ Average generated voltage in one conductor

$$\omega_m = \frac{2\pi}{T_m} \qquad T_m = \frac{2\pi}{\omega_m} \qquad T = \frac{2T_m}{P} = \frac{4\pi}{P\omega_m}$$

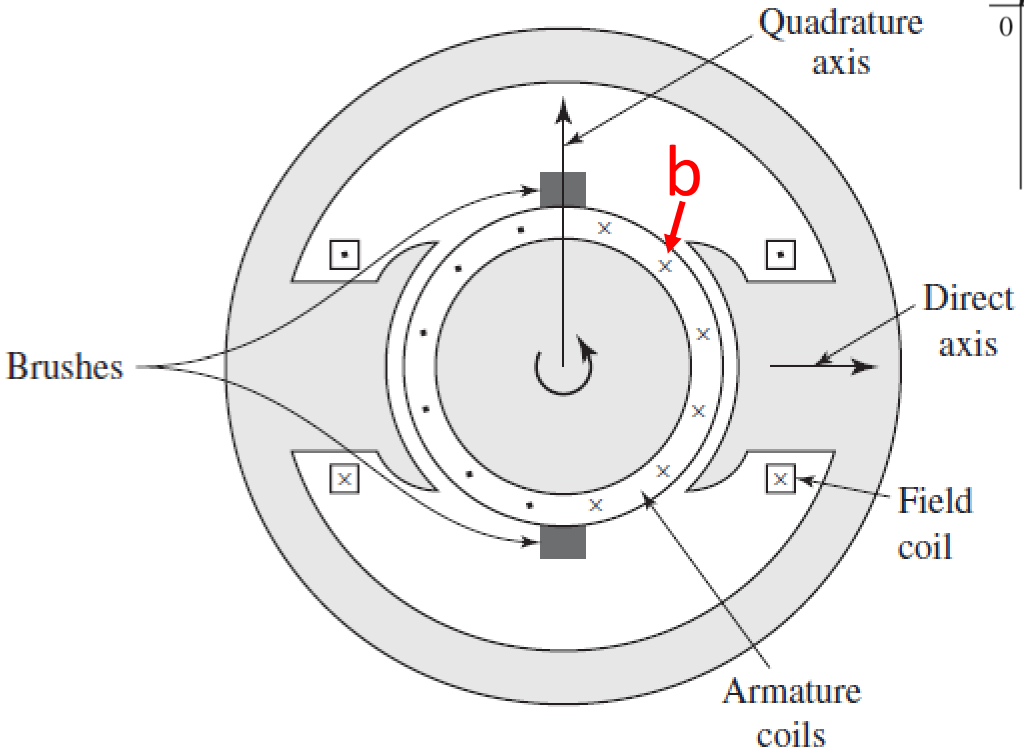
$$E_b = \frac{P}{2\pi}\varphi_d\omega_m$$

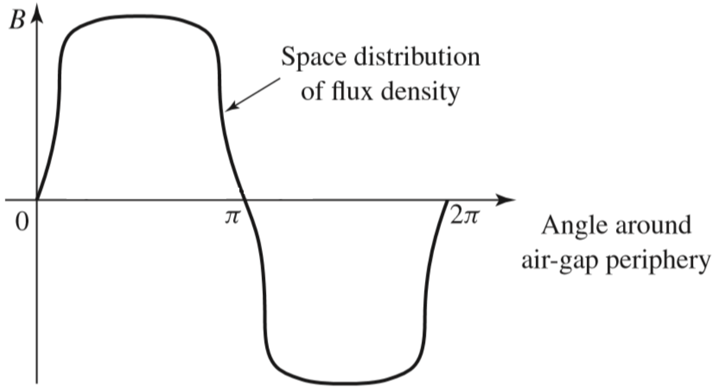
$$\boxed{E_a = \frac{C_a}{m}\frac{P}{2\pi}\varphi_d\omega_m = K_a\varphi_d\omega_m}$$

Average generated voltage in brushes

Generated voltage in DC Machine(Blv)

Schematic of a DC machine





$$e_b = Blv = Blr\omega_m$$

$$E_b = \frac{1}{\pi}\int_0^{\pi} B_{peak} l r \omega_m sin\theta d\theta$$
$$= \frac{1}{\pi} B_{peak} 2lr\omega_m$$

$$E_b = \frac{1}{\pi} \underbrace{B_{peak} 2lr \frac{2}{P}}_{\varphi_d} \frac{P}{2}\omega_m$$

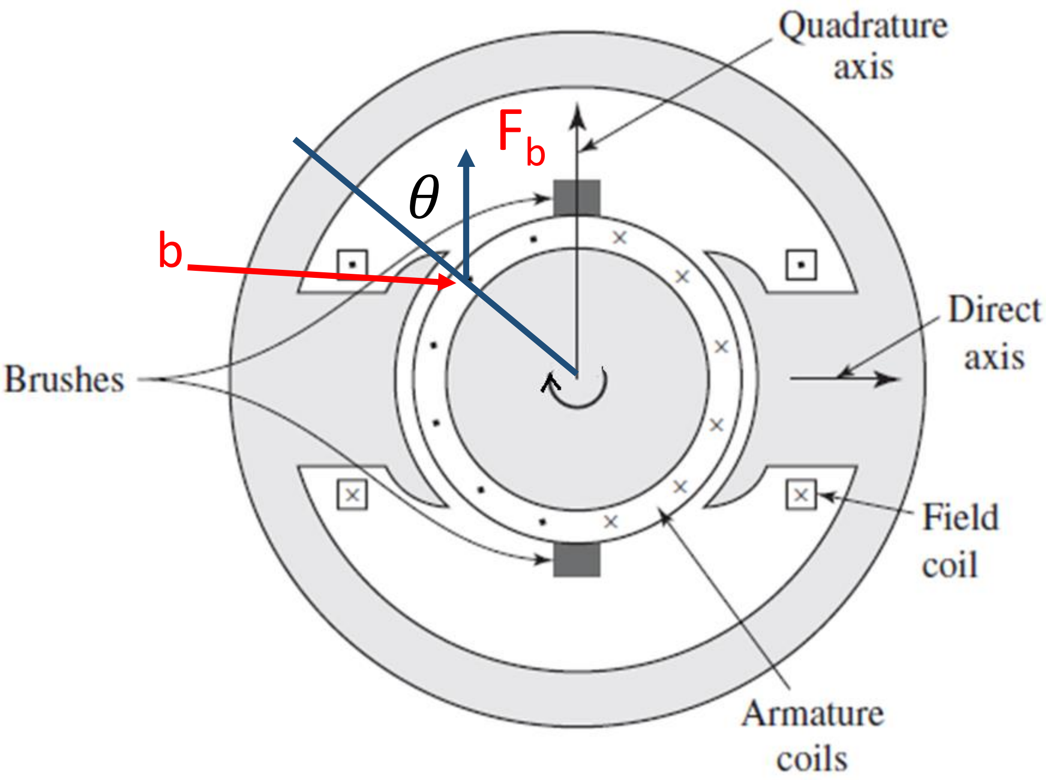
$$E_b = \frac{P}{2\pi}\varphi_d\omega_m$$

Average generated voltage in one conductor

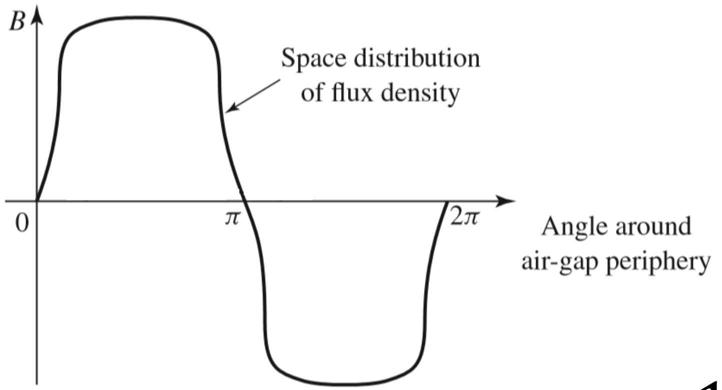
$$E_a = \frac{C_a}{m}\frac{P}{2\pi}\varphi_d\omega_m = K_a\varphi_d\omega_m$$

Average generated voltage in brushes

Torque production in DC Machine(Lorentz law)



Generated torque in one conductor(b)



$$F_b = lIB \quad = l\frac{I_a}{m}B$$

$$\tau_b(\theta) = rF_b \sin\theta$$

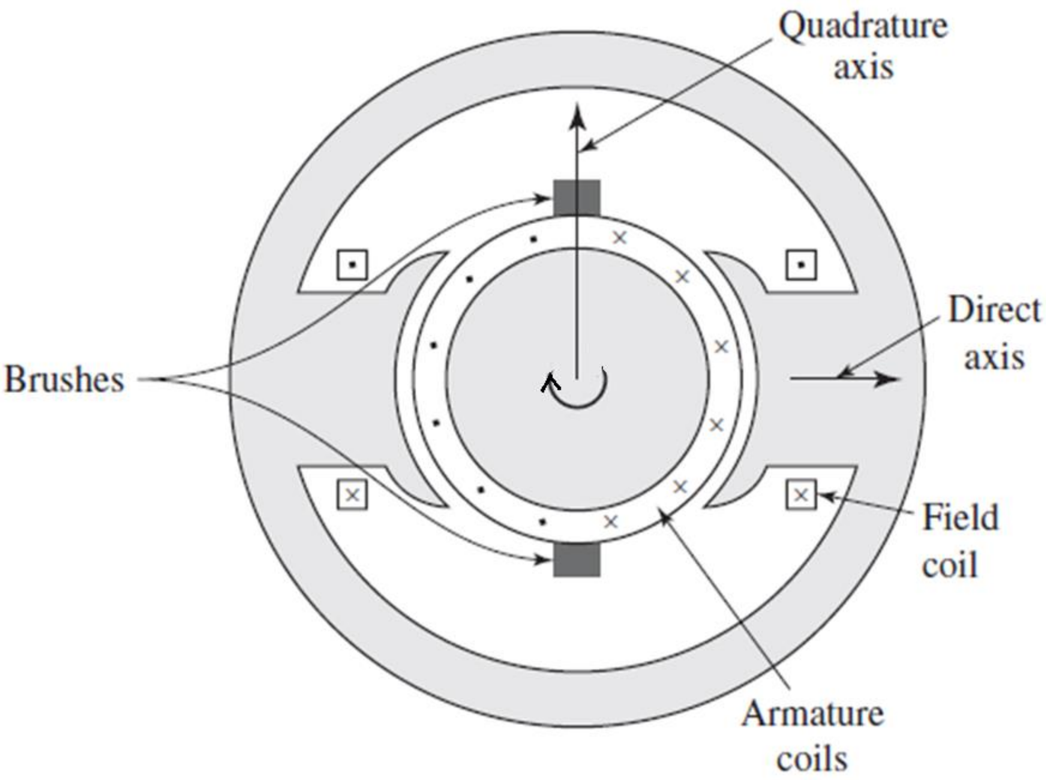
$$\tau_b = \frac{1}{\pi}\int_0^{\pi} rl\frac{I_a}{m}B\, sin\theta\, d\theta$$

$$\tau_b = \frac{1}{\pi}\frac{I_a}{m}2rlB\,\frac{2}{P}\frac{P}{2}$$

$$\varphi_d$$

$$\tau = \frac{P}{2\pi}\frac{C_a}{m}I_a\varphi_d \quad = K_a I_a \varphi_d$$

Torque production in DC Machine($power/\omega$)

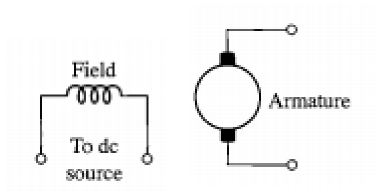


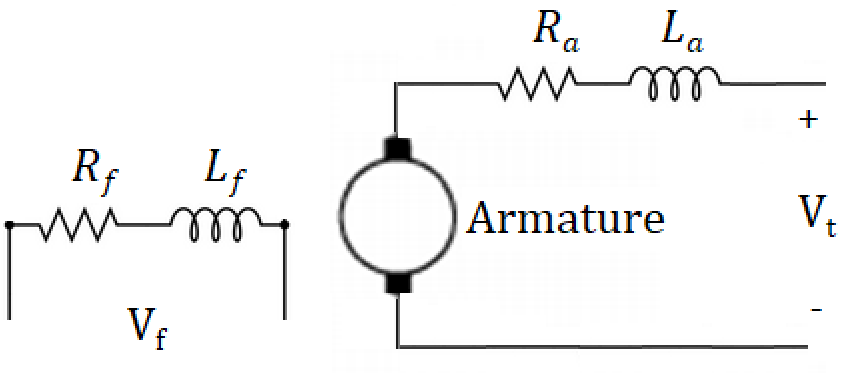
Generated torque in machine

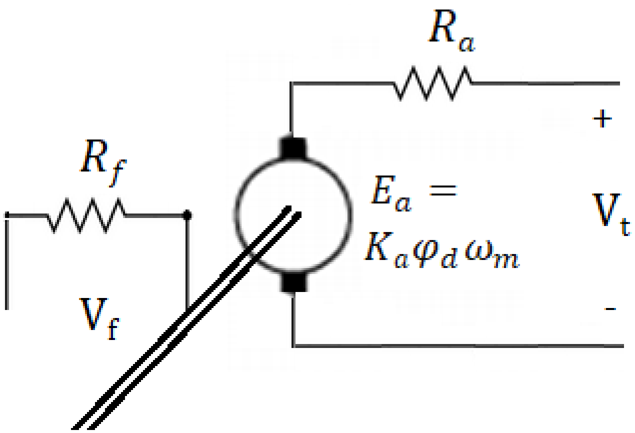
$$\tau = \frac{power}{\omega_m} = \frac{E_a I_a}{\omega_m} = \frac{K_a \varphi_d \omega_m I_a}{\omega_m}$$

$$\tau = K_a I_a \varphi_d$$

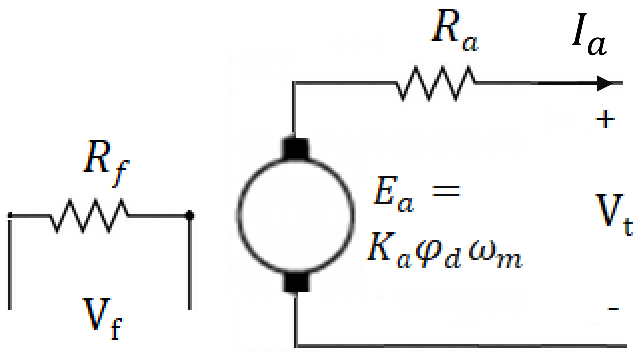
Equivalent circuit in DC Machine







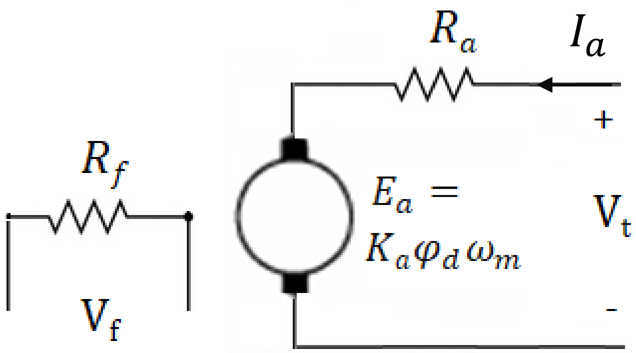
Equivalent circuit of DC generator



$$V_f = R_f \, I_f$$

$$E_a = V_t + R_a \, I_a$$

Equivalent circuit of DC motor



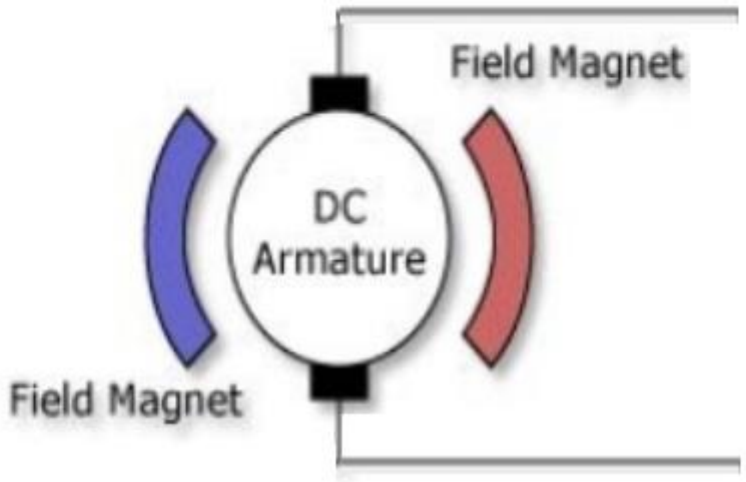
$$V_f = R_f \, I_f$$

$$V_t = Ea + R_a \, I_a$$

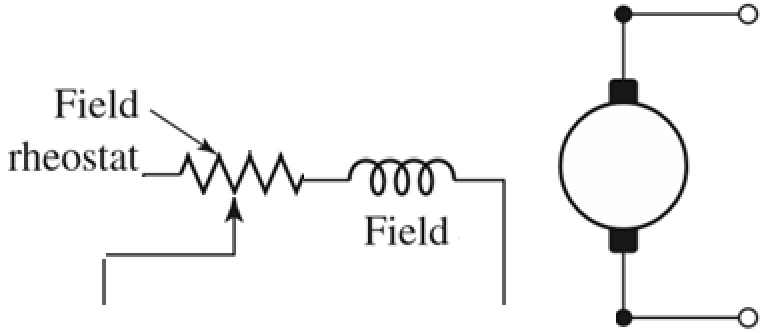
Field excitation in DC machines

How can we energize the field winding?

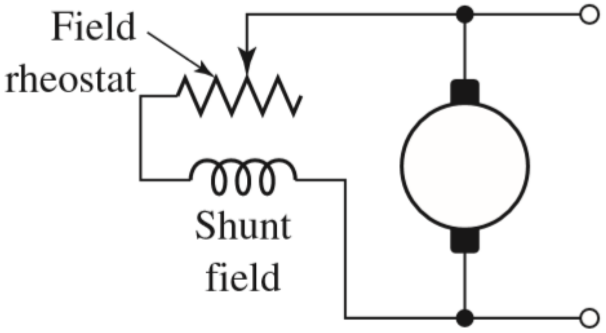
1-PM DC machines



2- Separate excitation DC machines



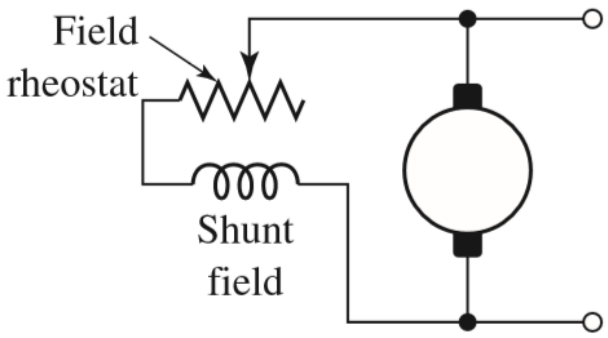
3- Self excitation DC machines



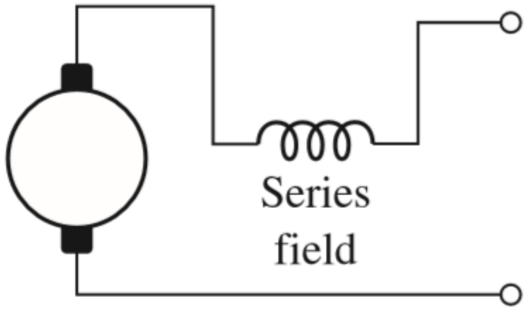
Field excitation in DC machines

Different types of self excitation DC machines

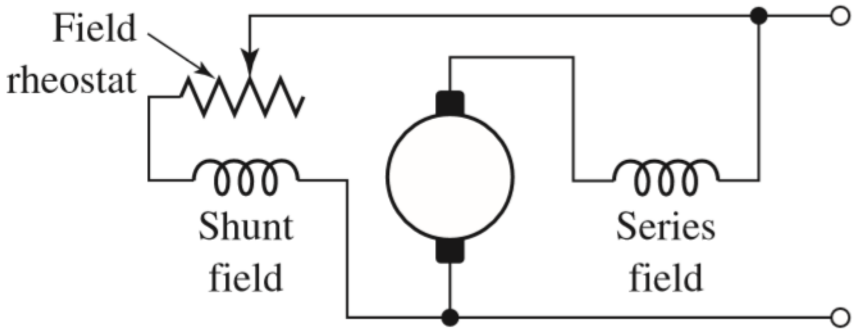
1- Shunt excitation



2- Series excitation



3- Compound excitation

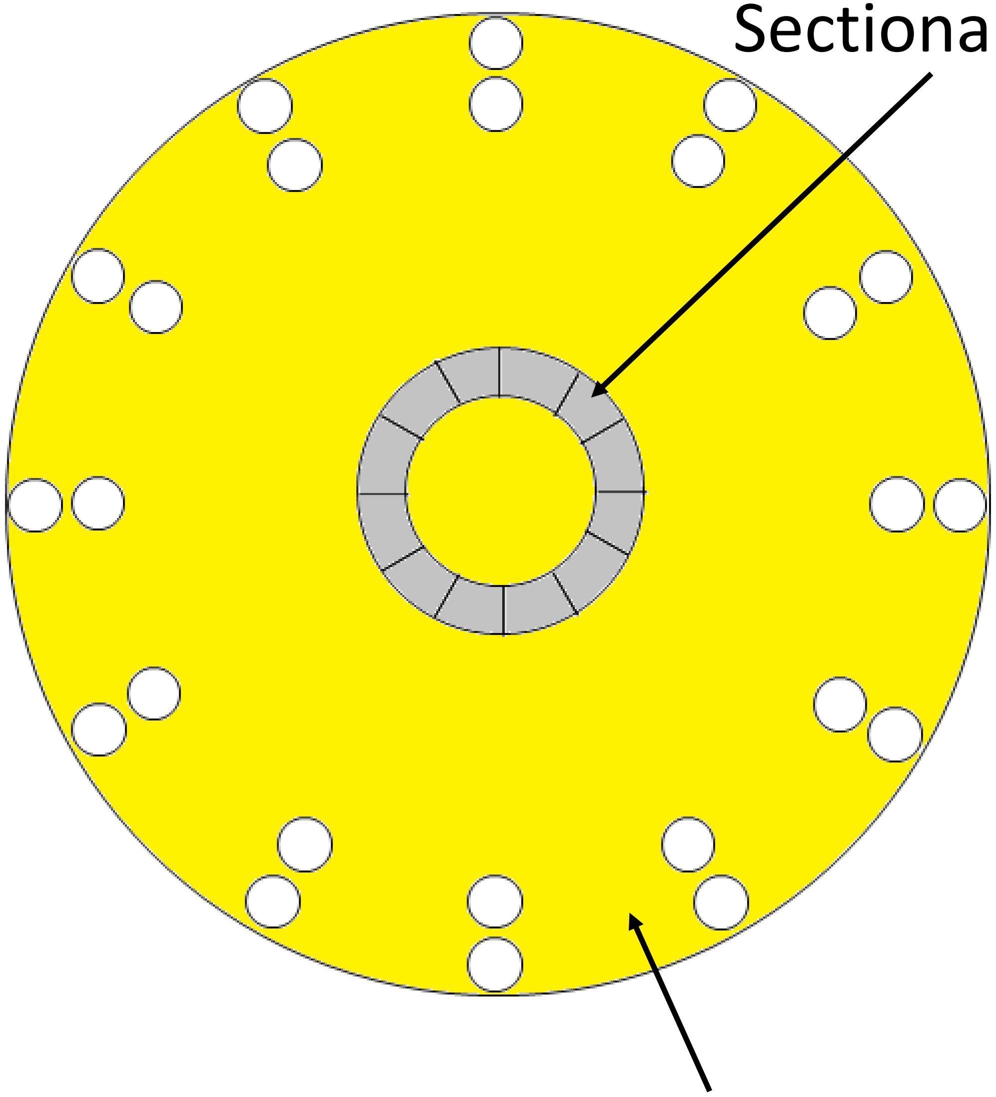


Different types of compound excitation (Short-Long-Cumulative-Differential)

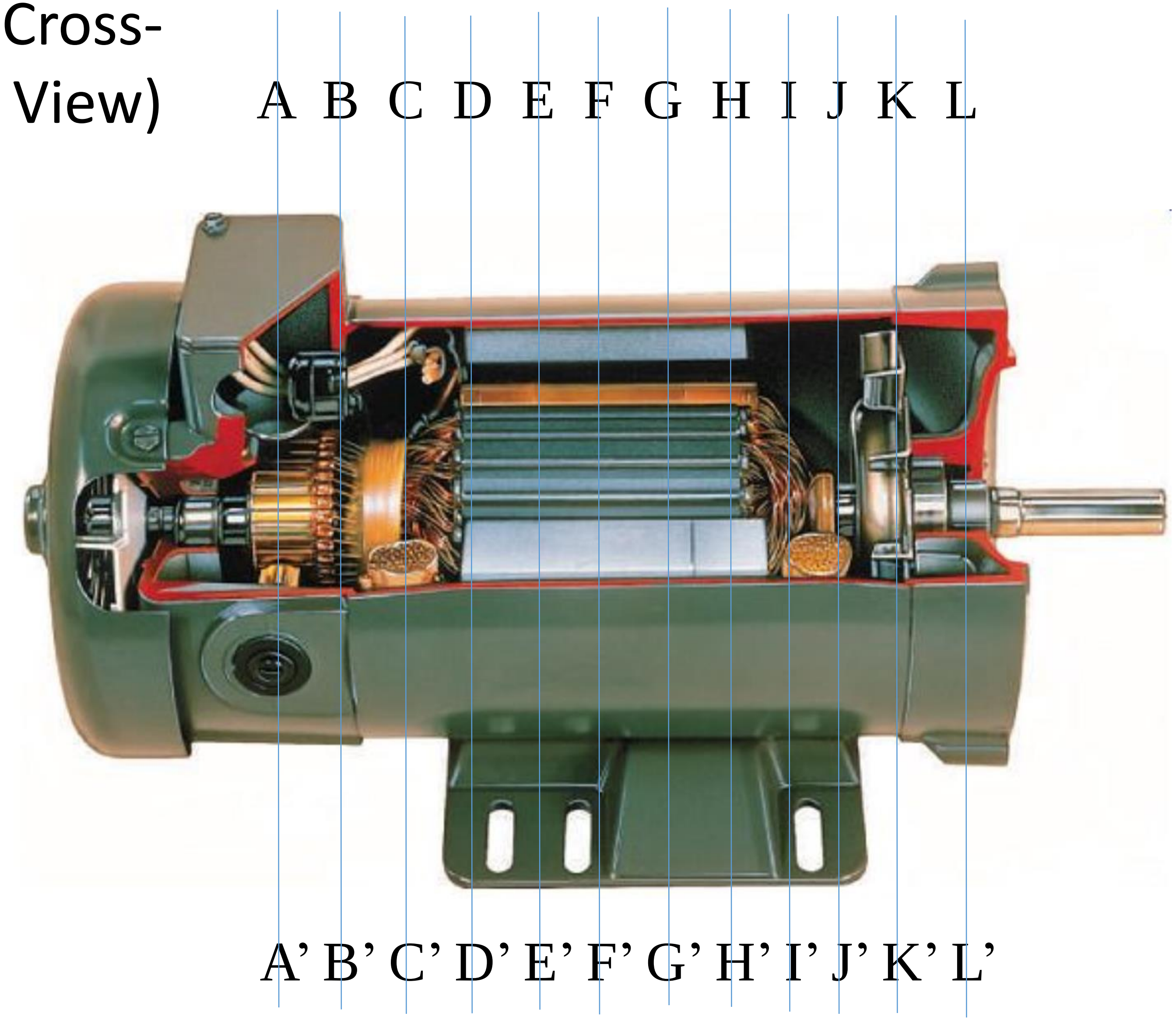
How to distinguish shunt winding from series winding?

DC Armature Winding

Commutator (AA’ Cross-Sectional View)

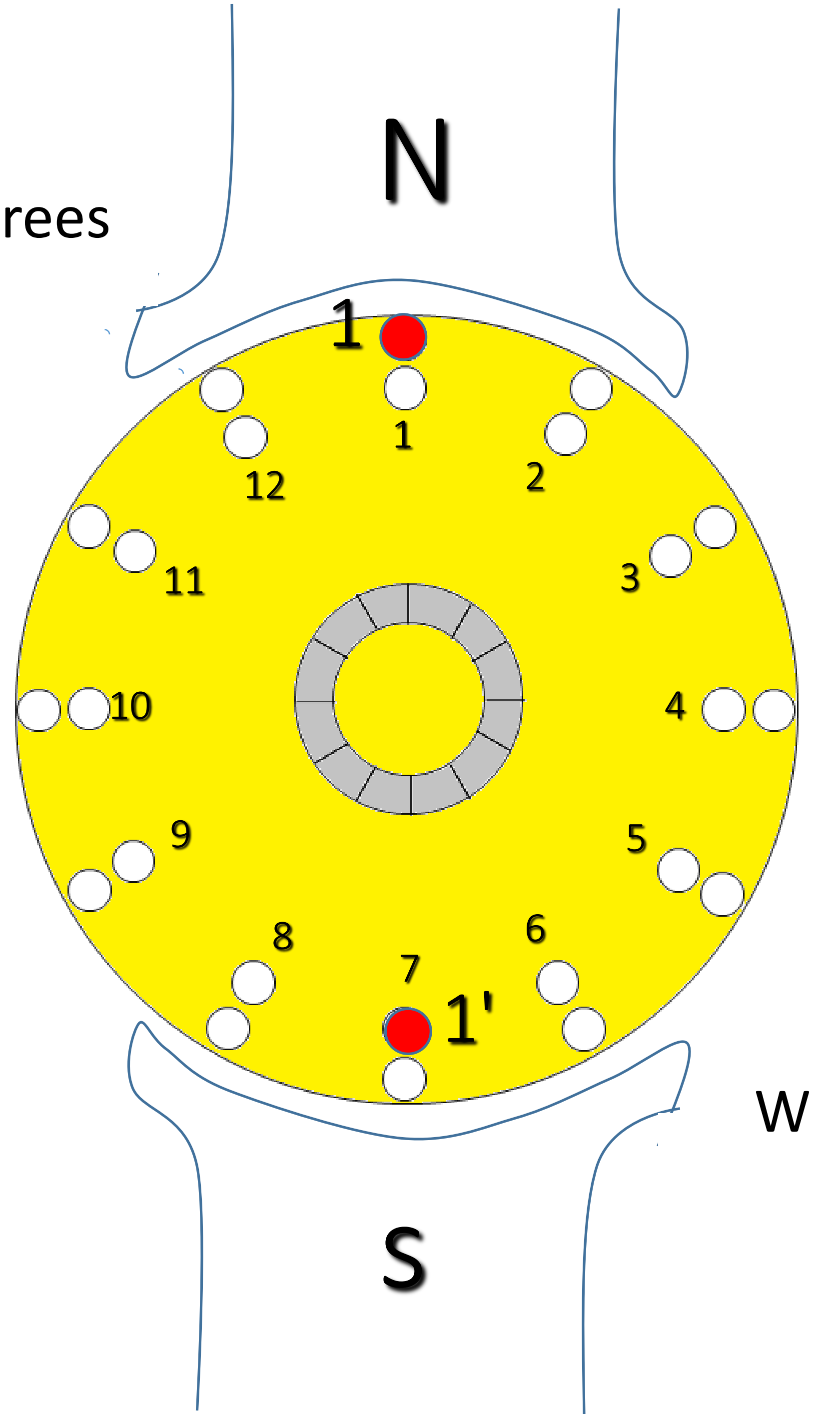


FF’ Cross-Sectional View

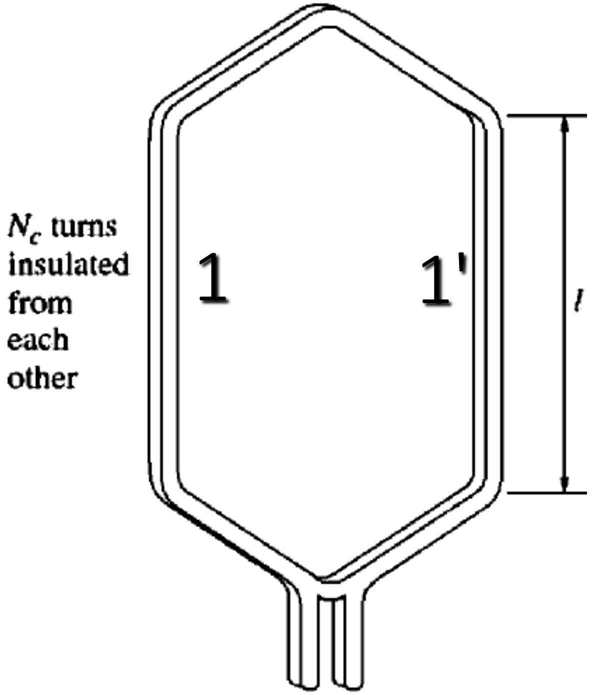


Winding Pitch = 180 Electrical Degrees

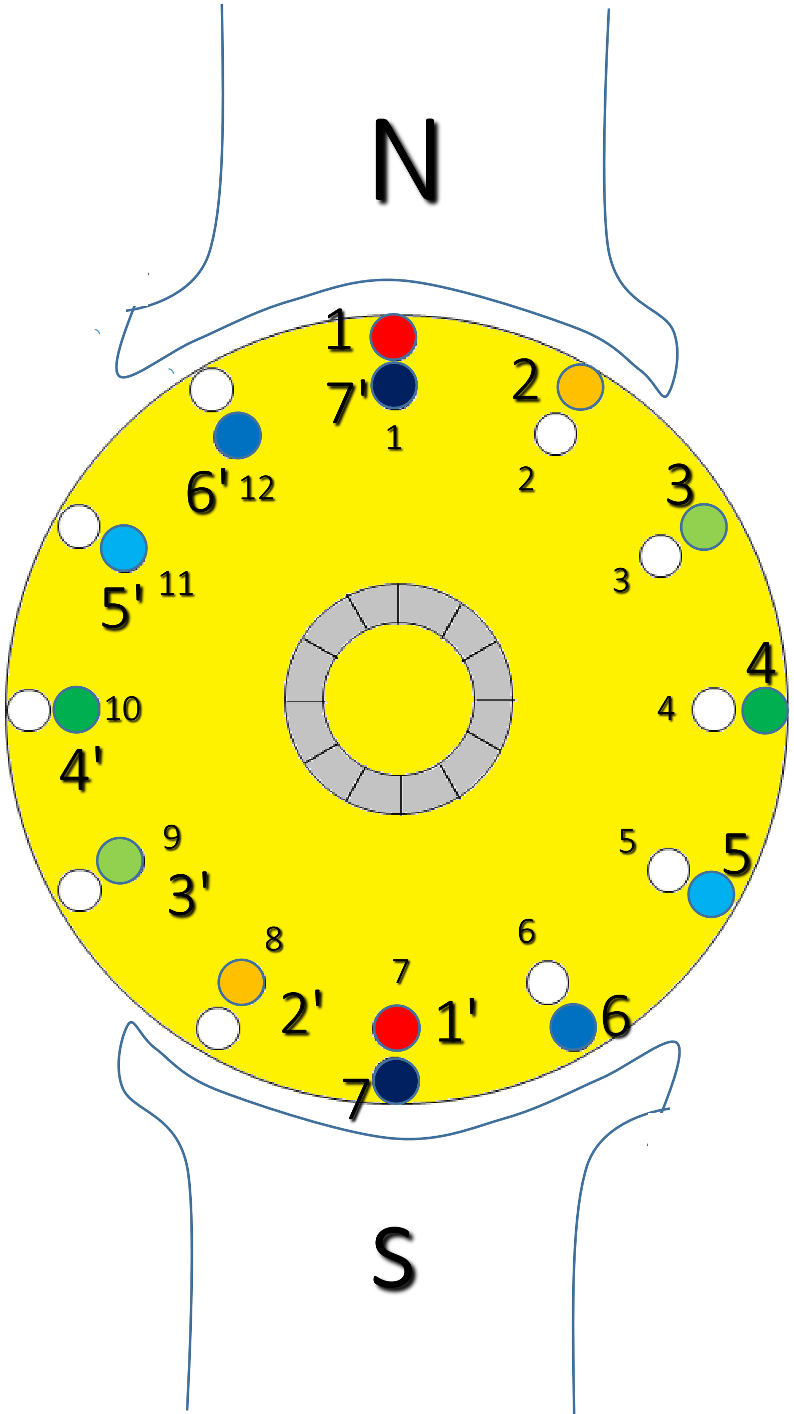
Slot Pitch = 6

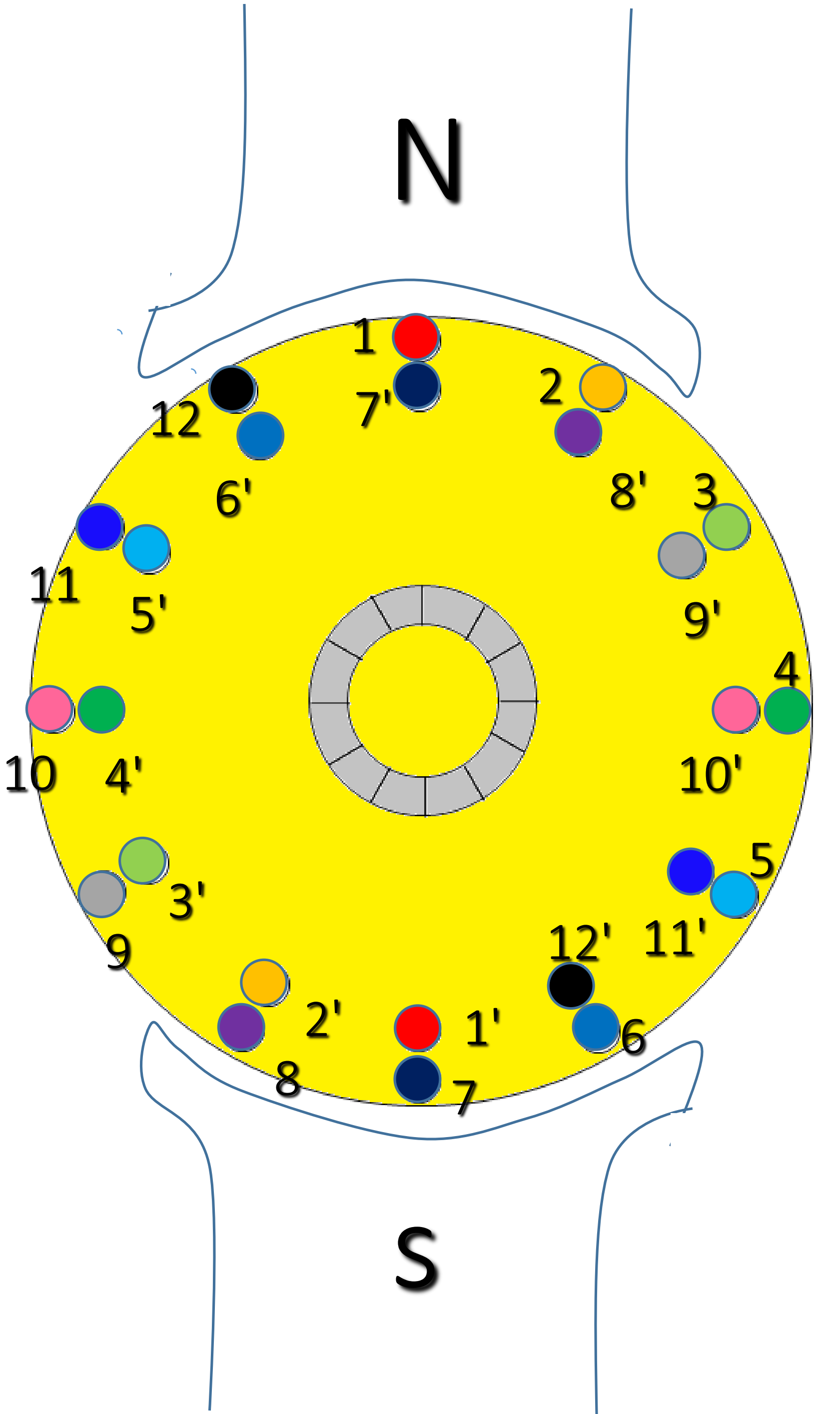


Part of the Armature Winding (Coil)



Where is the other side of the coil located?

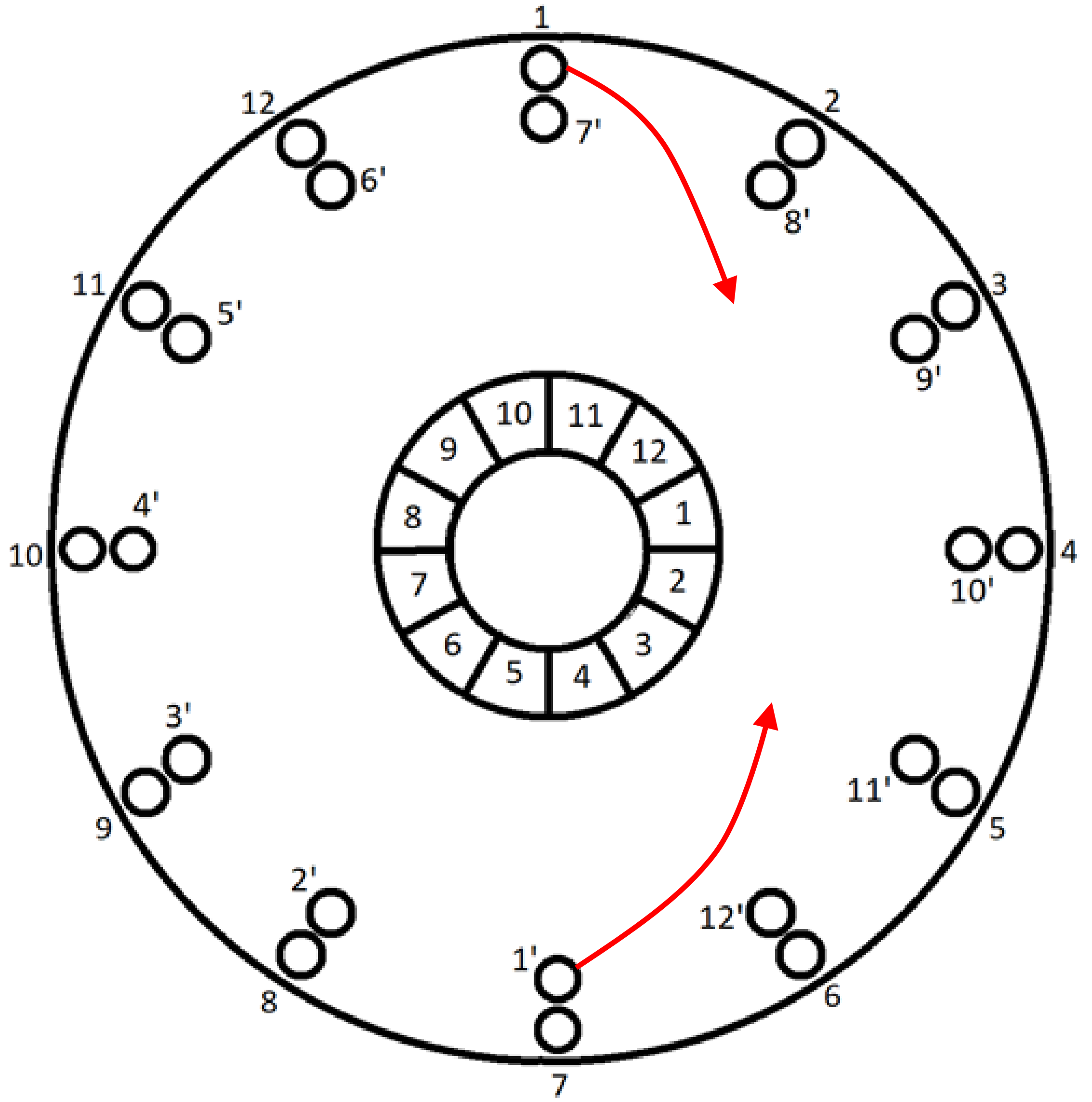

N
1
7'
1
2
2
6'
12
2
3
3
3
5'
11
4
4
4
10
4'
9
3'
5
5
8
6
7
2'
1'
6
7
S


N
1
7'
2
12
6'
8'
3
11
5'
9'
4
10
4'
10'
5
3'
9
12'
11'
2'
1'
6
8
7
S

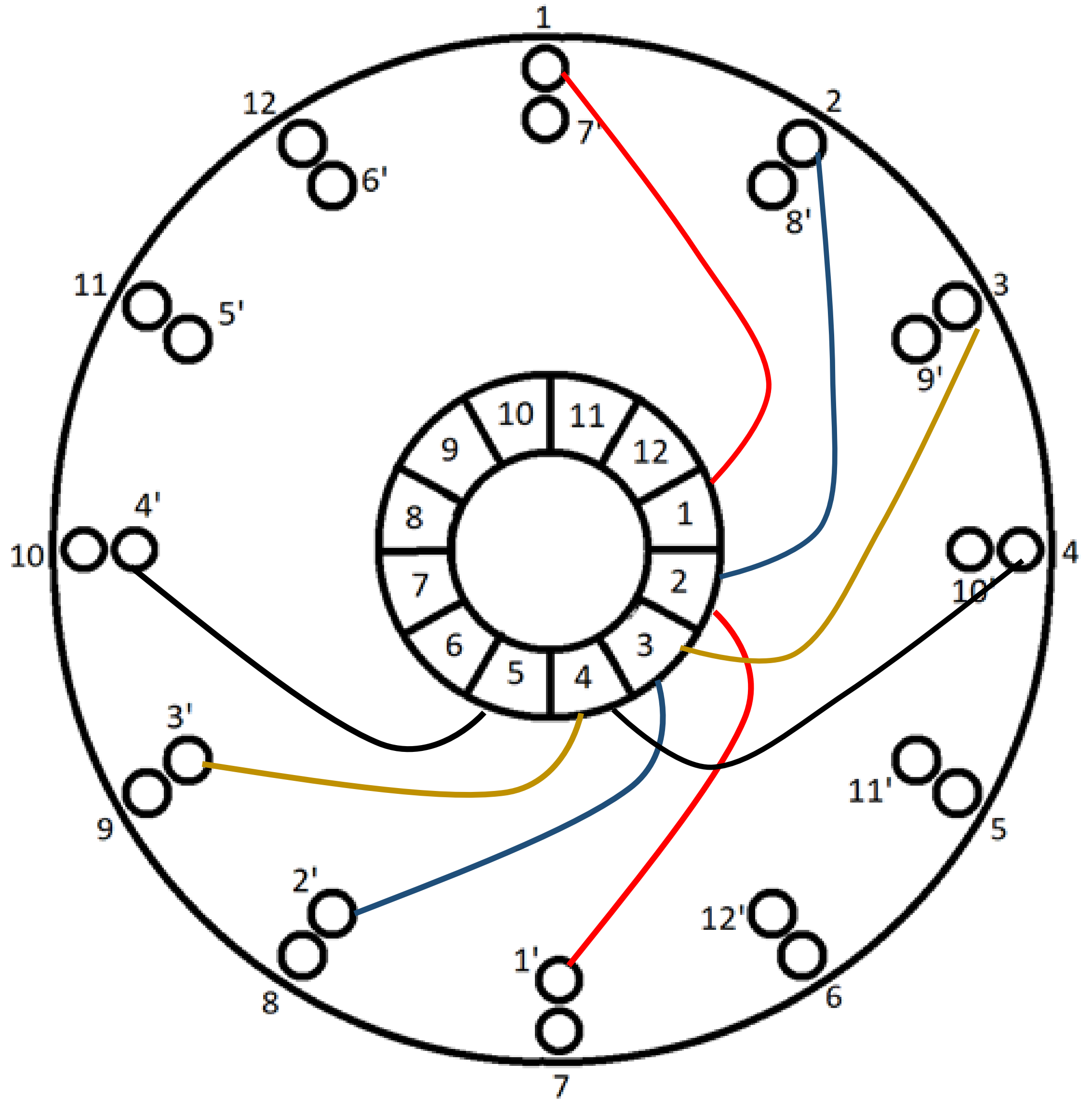
Simple lap winding

Commutator Pitch = 1

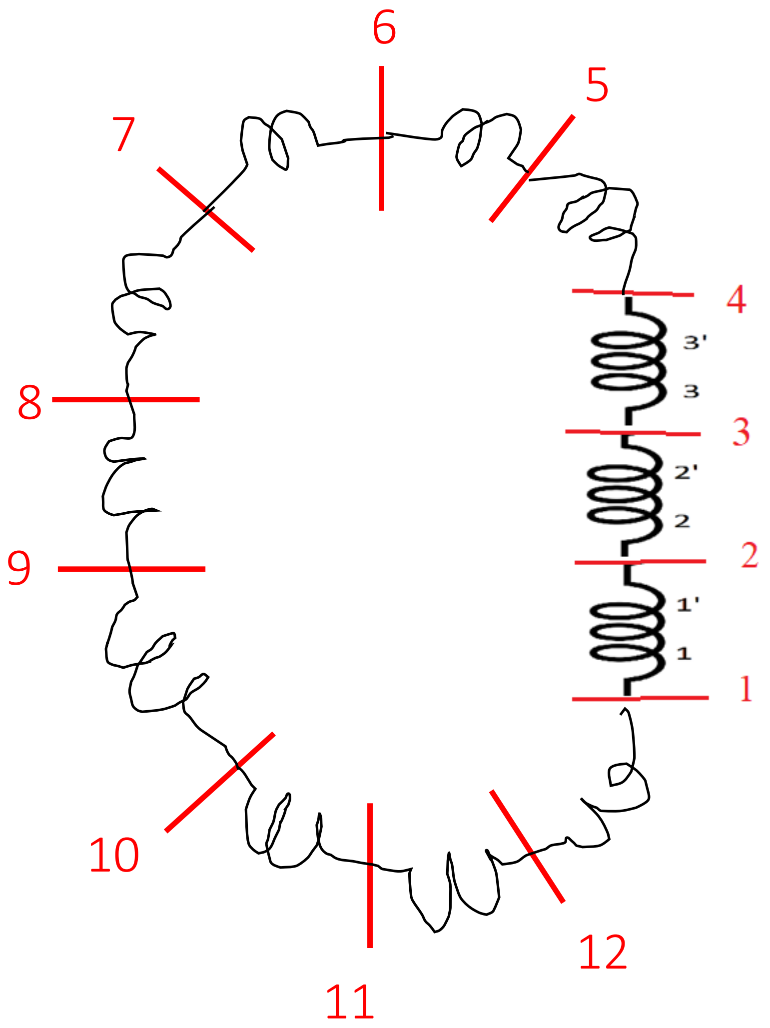
$$y_c = 1$$

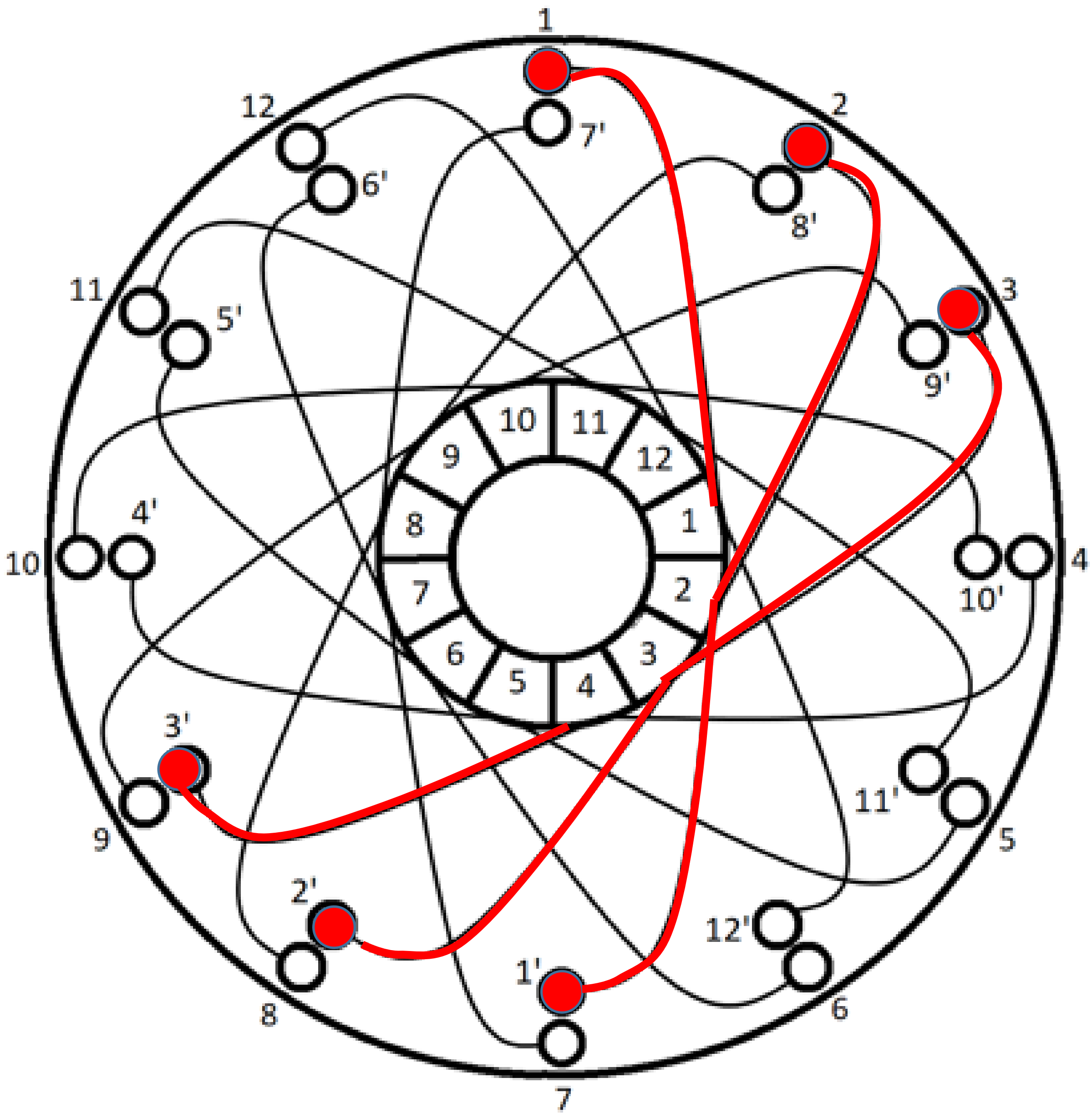


Simple lap winding

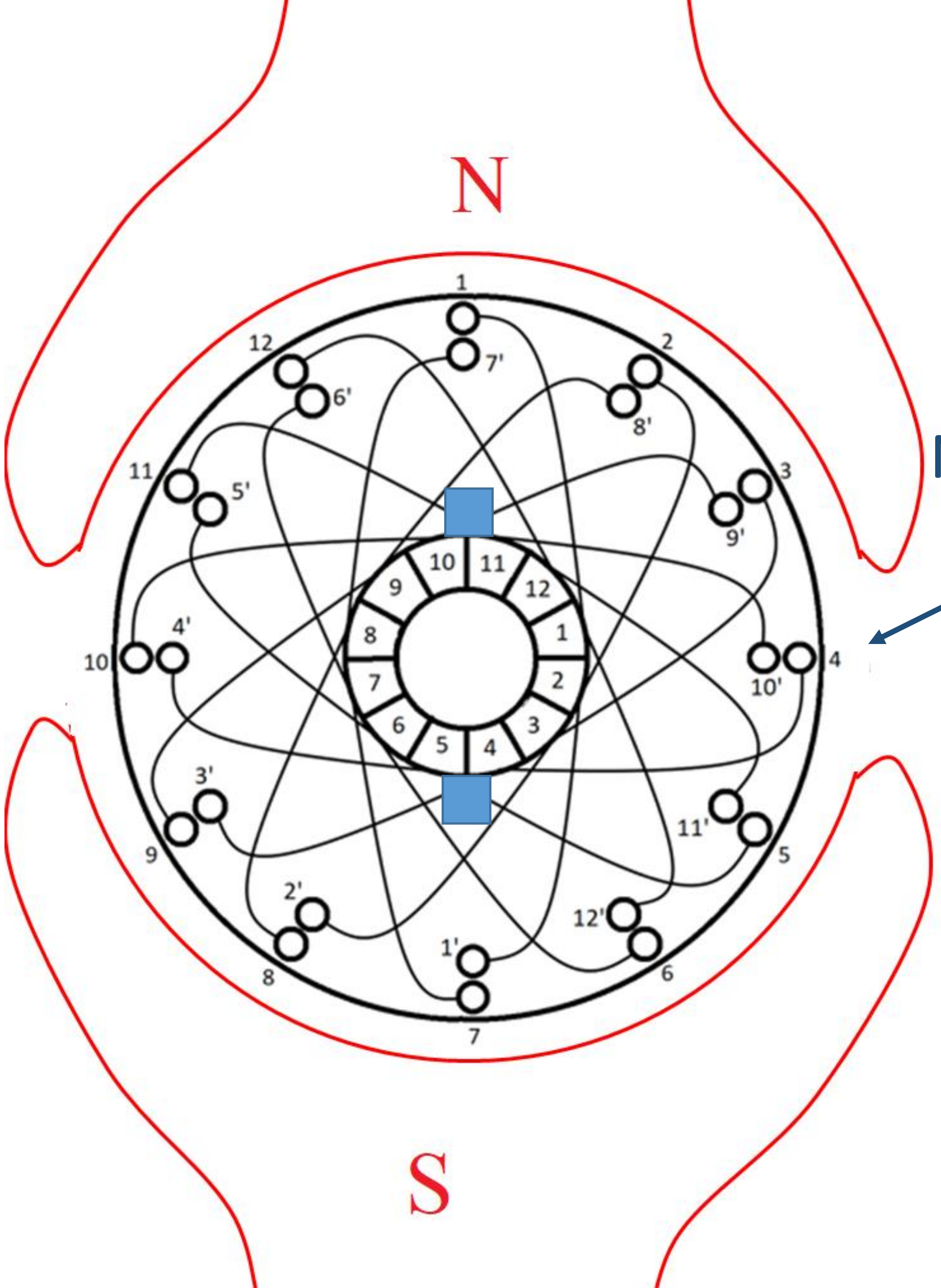


Simple lap winding





Simple lap winding



Natural axis

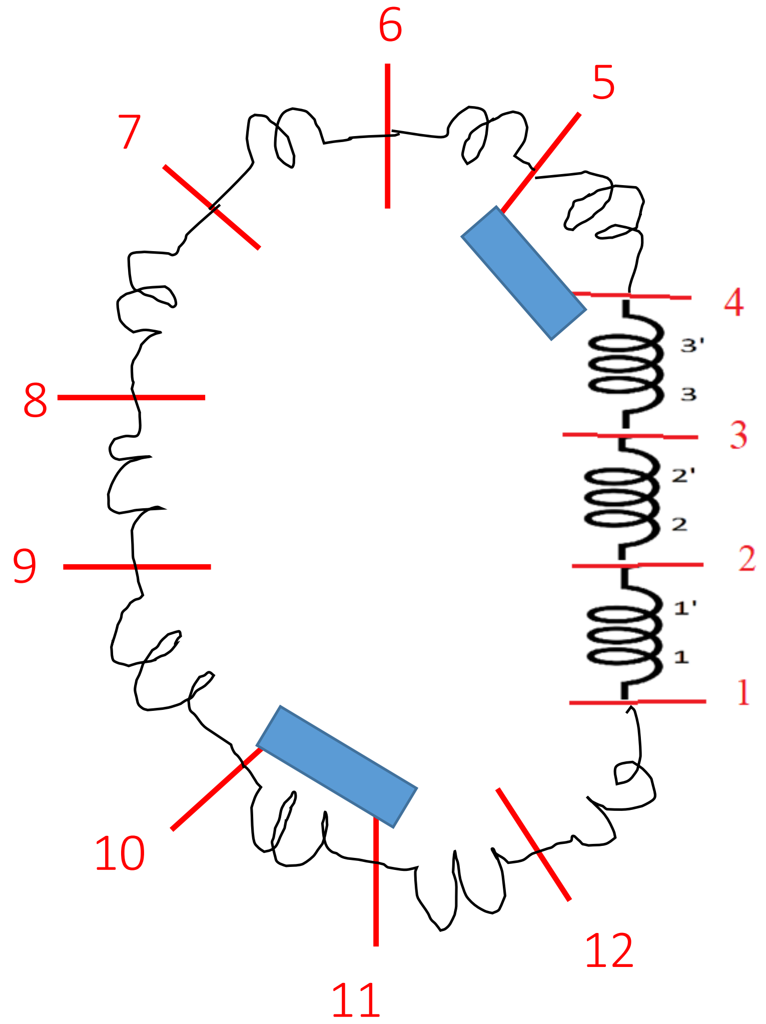
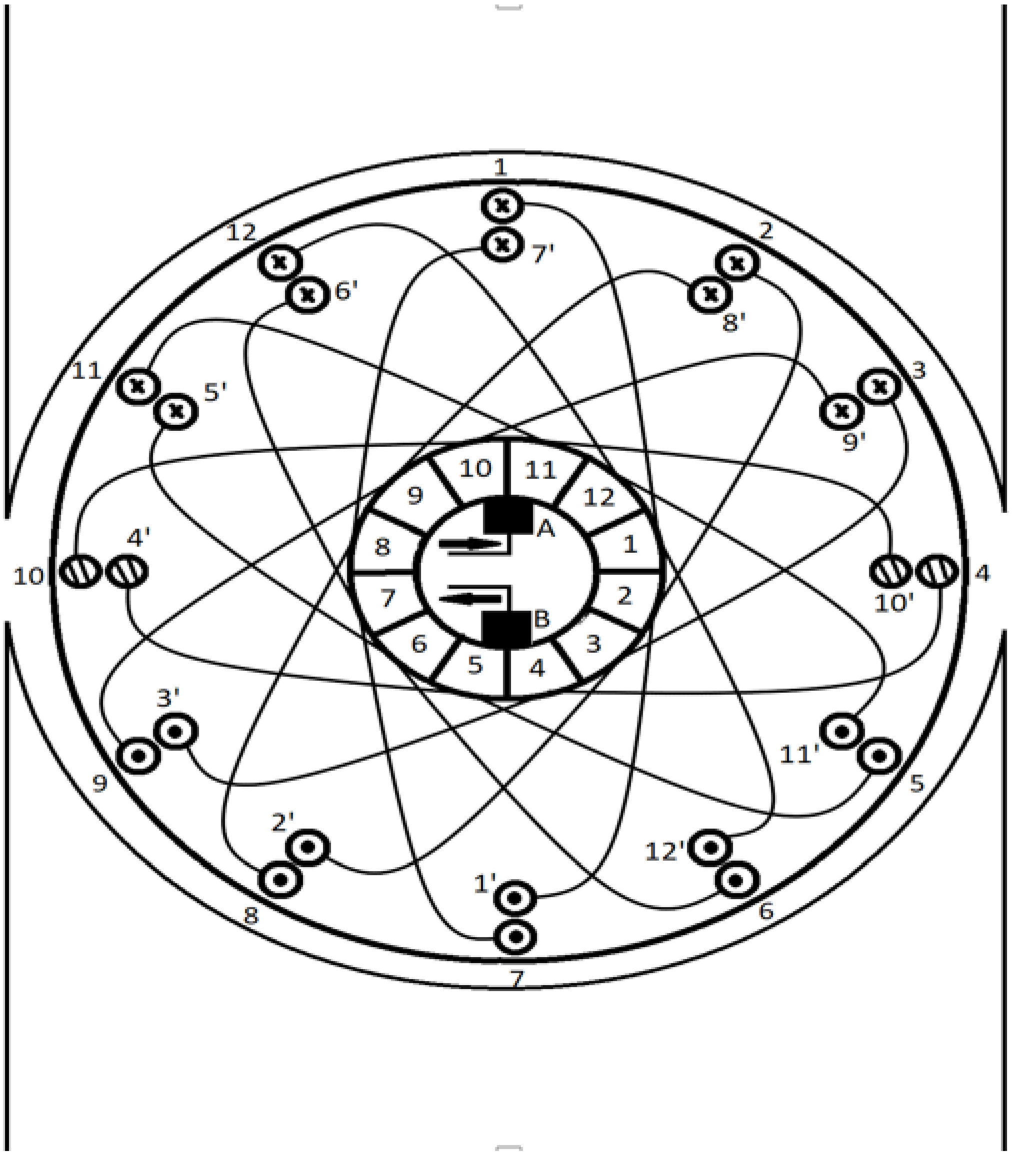
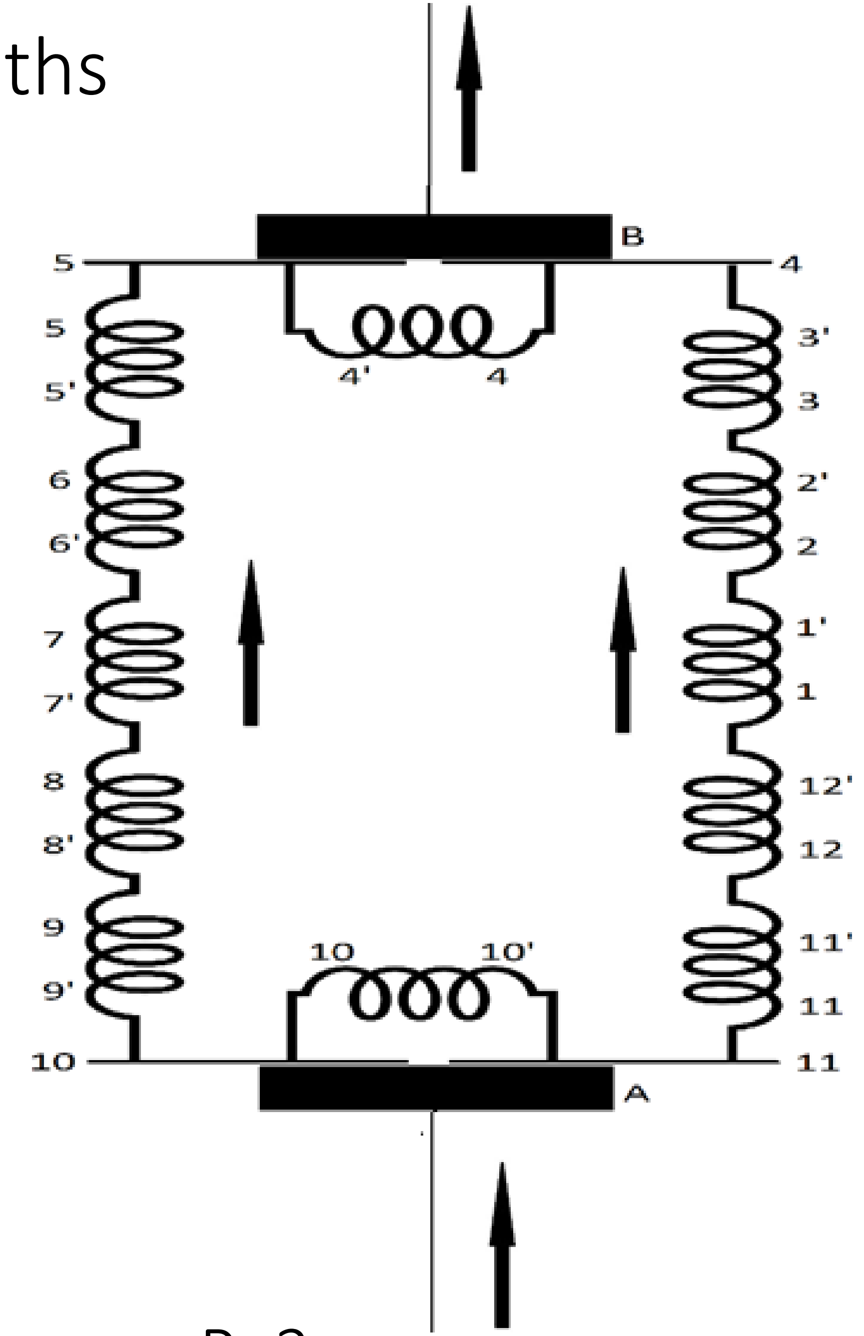


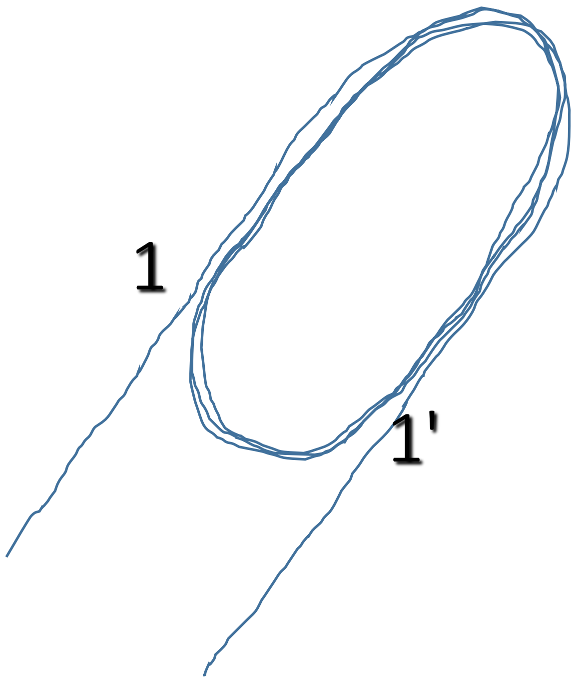
Diagram of Parallel Current Paths

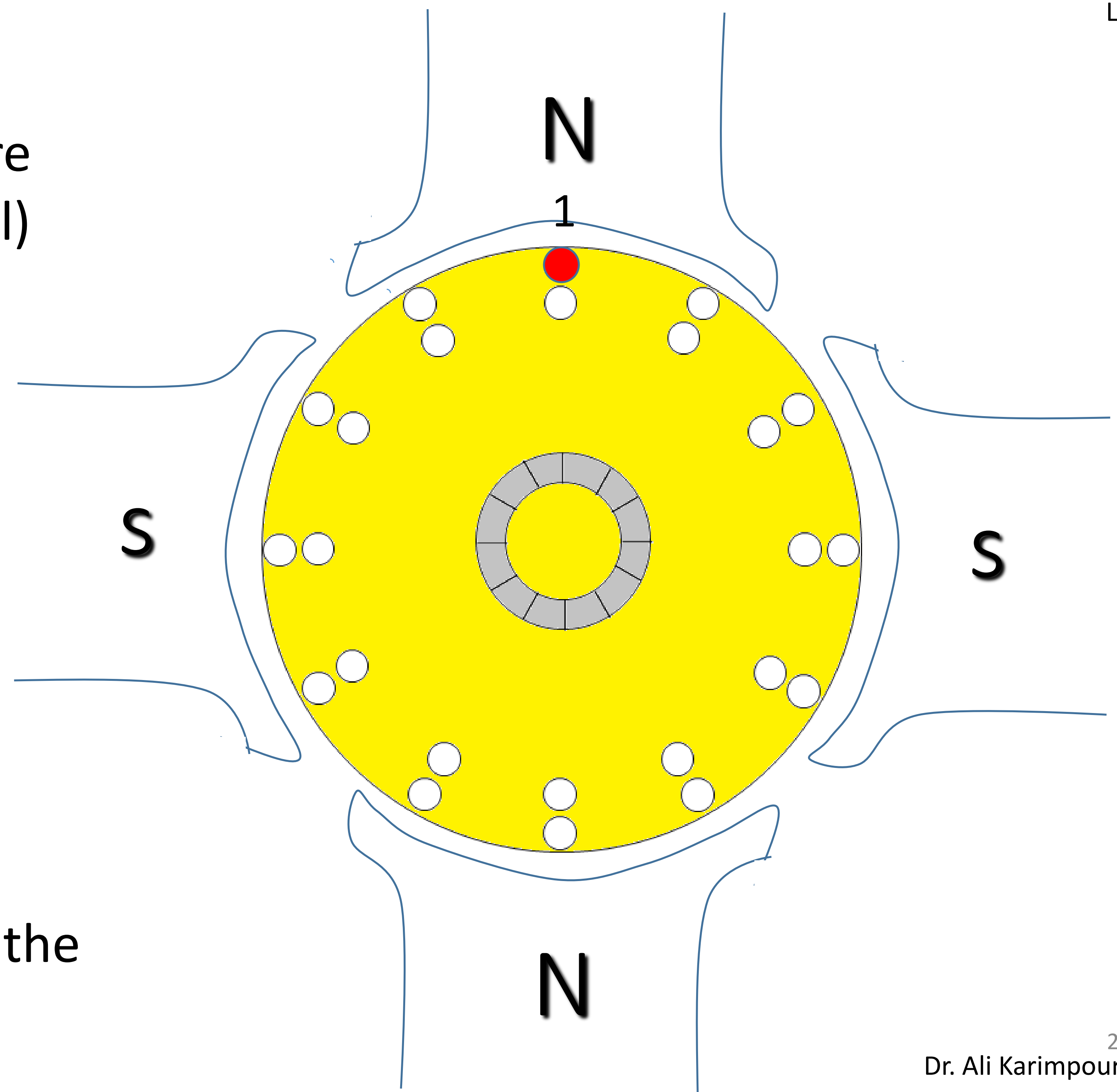




Number of Parallel Paths = m=aP=2

Part of the Armature Winding (Coil)

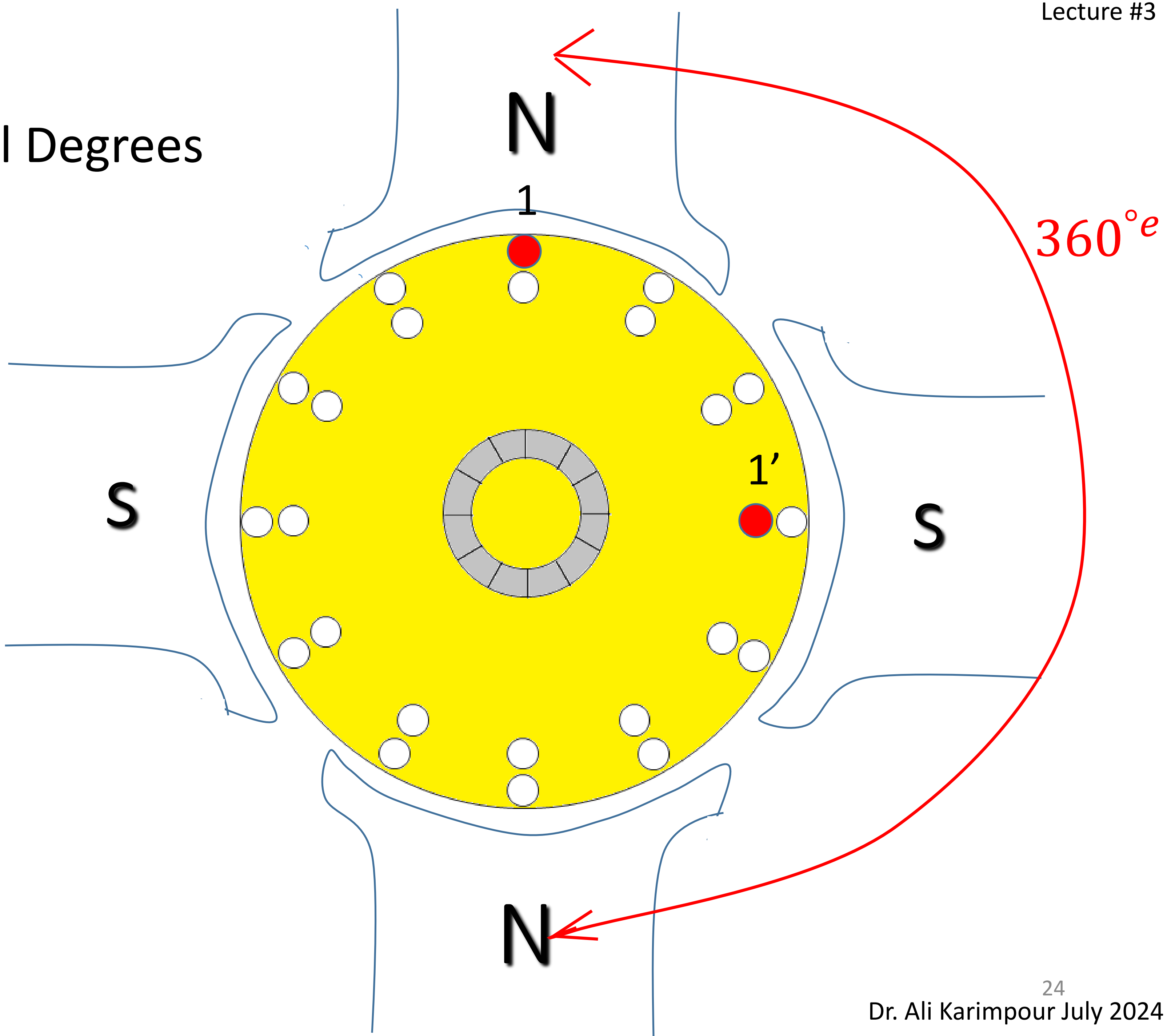


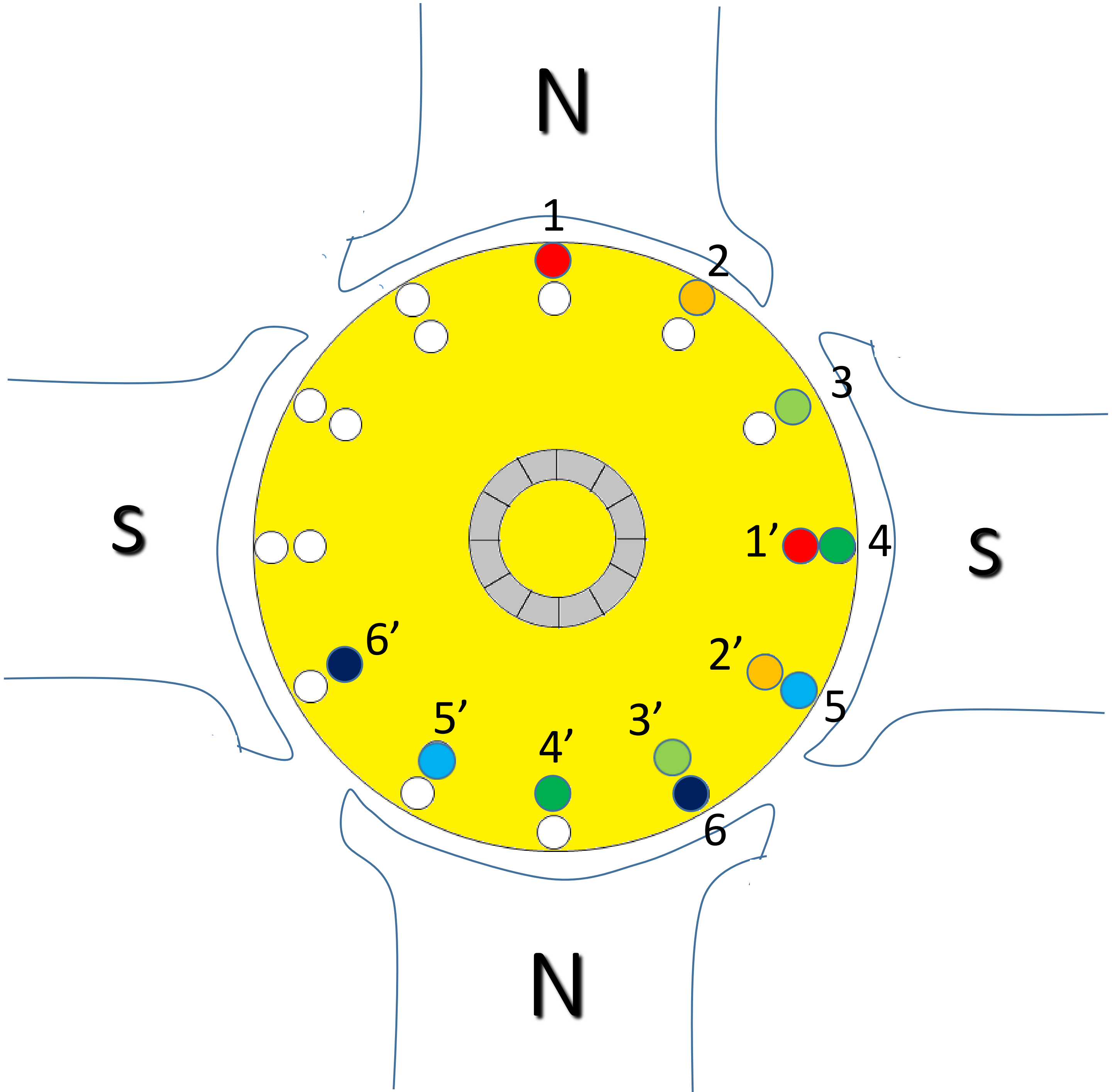


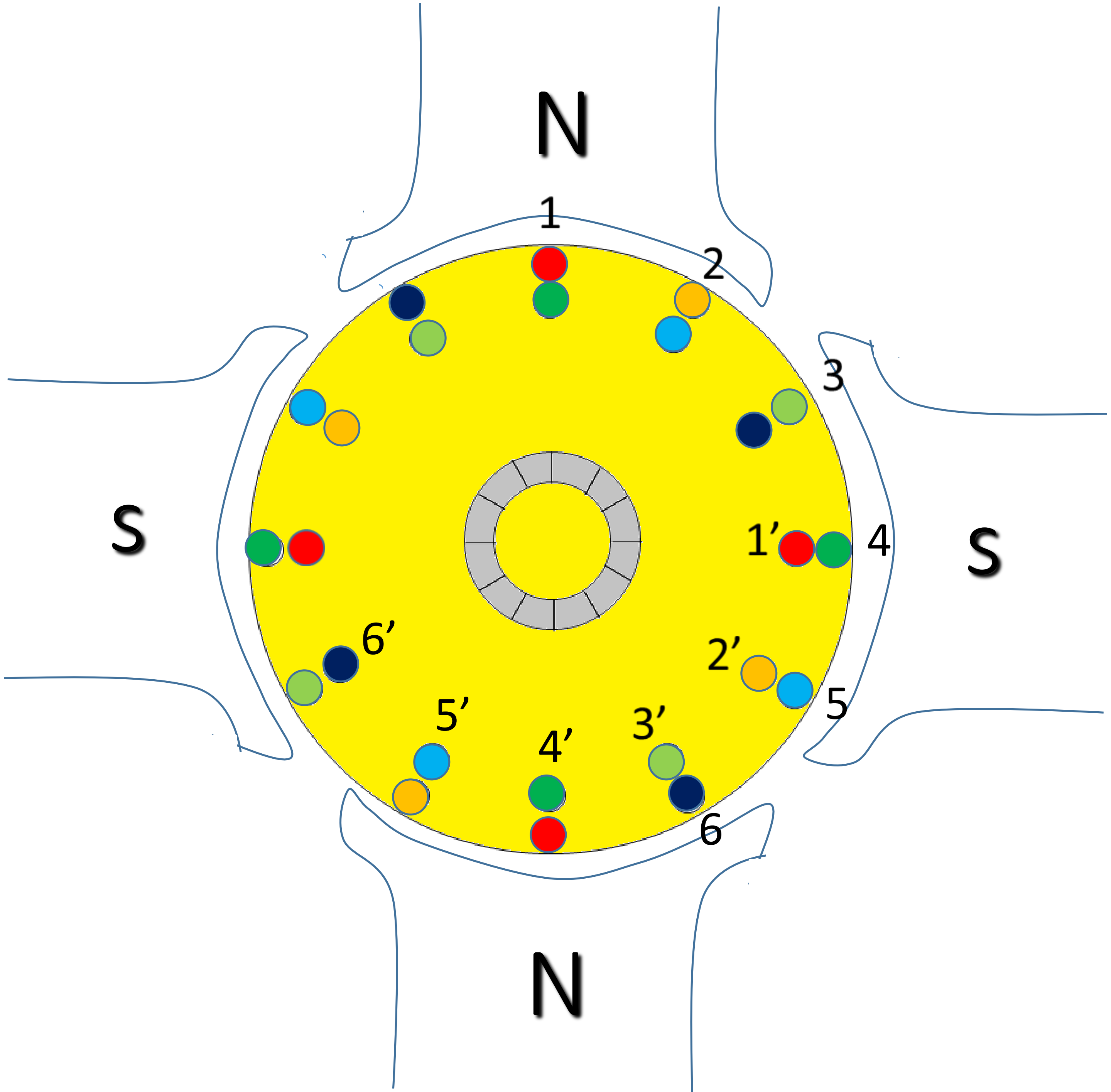
Where is the other side of the coil located?

Winding Pitch = 180 Electrical Degrees

Slot Pitch = 3



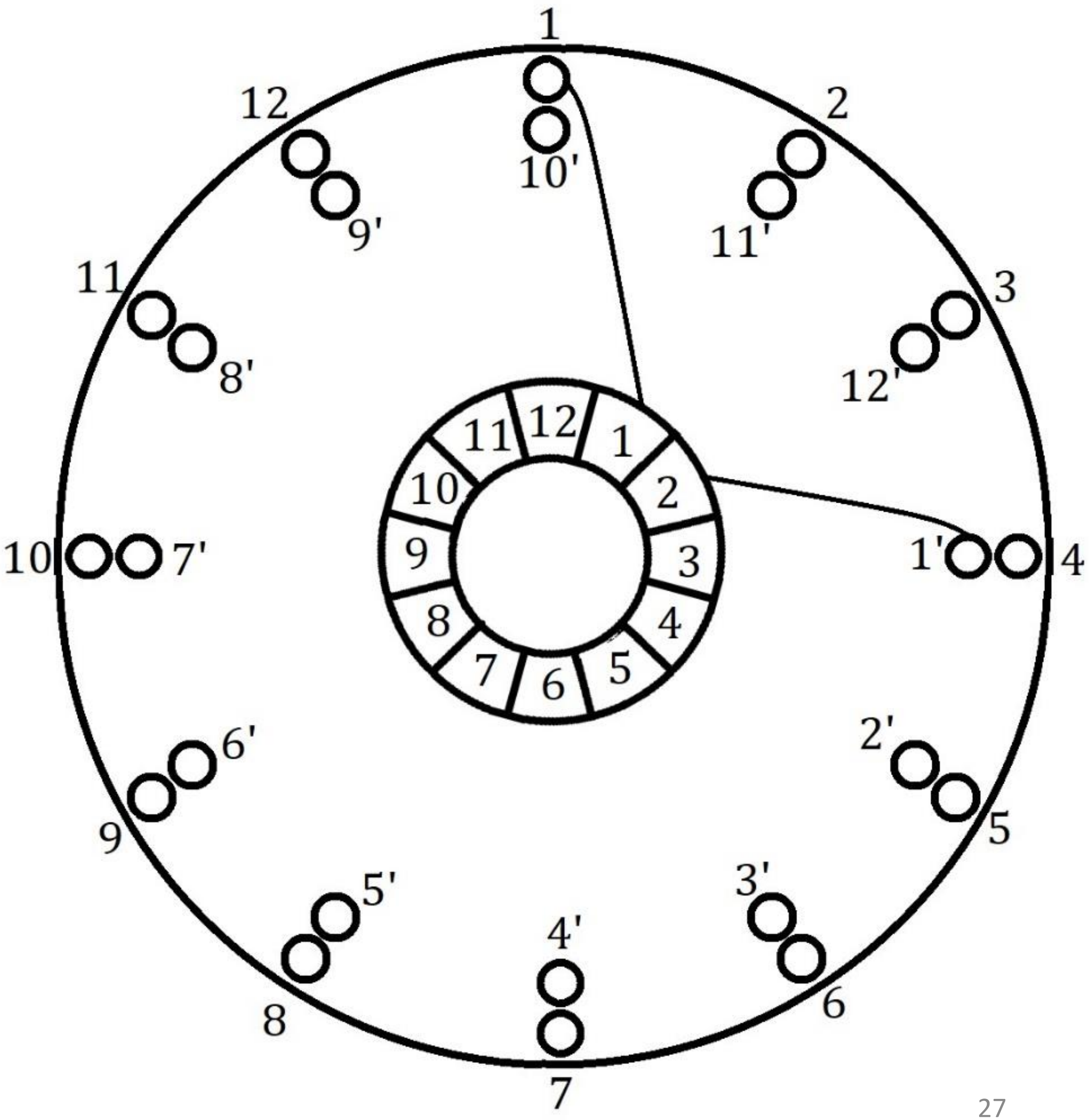

N
1
2
3
S
1'
4
S
6'
2'
5
5'
4'
3'
6
N


N
1
2
3
S
S
1’
4
6’
2’
5
5’
4’
3’
6
N

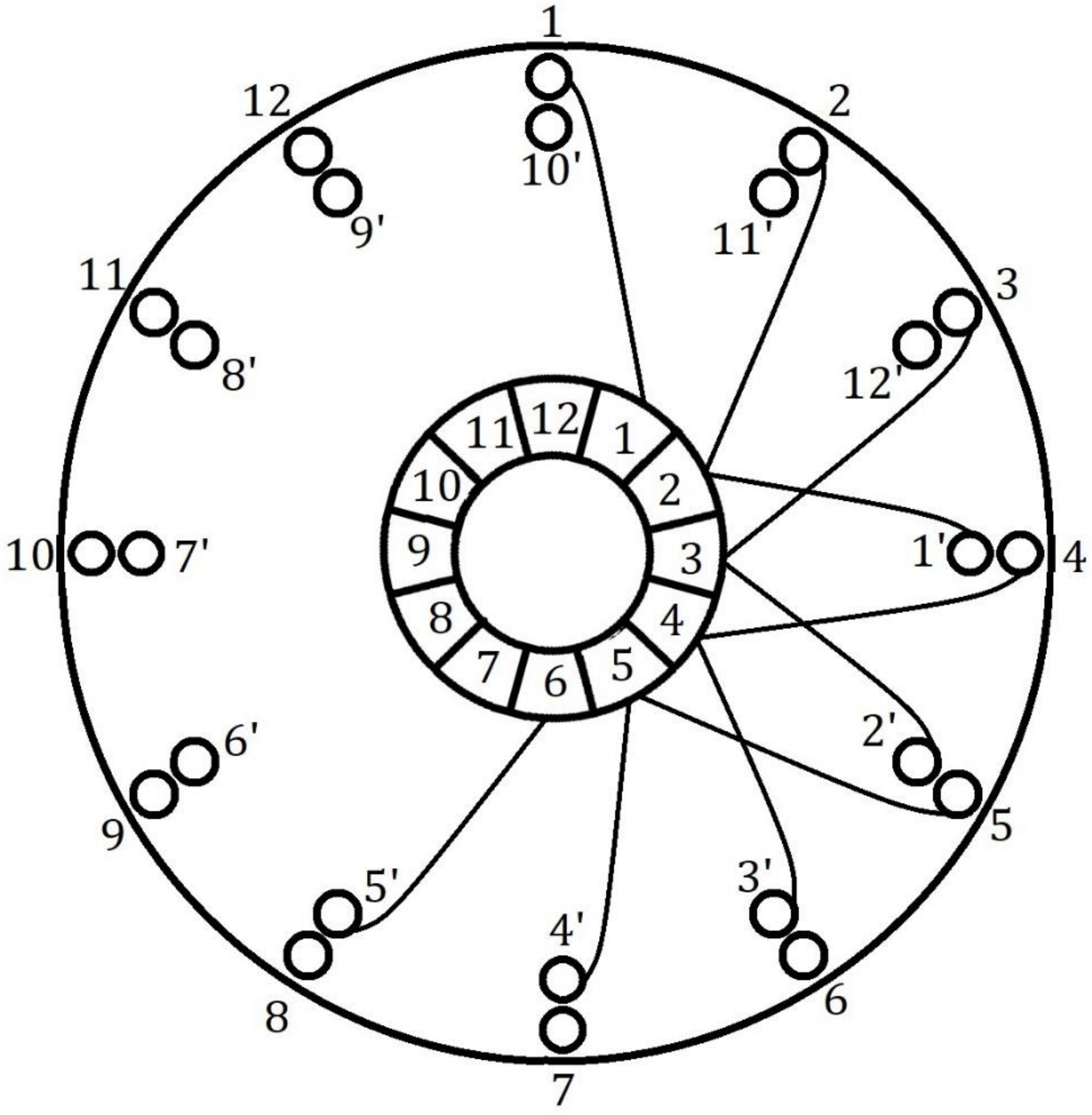
Simple lap winding

Commutator Pitch = 1

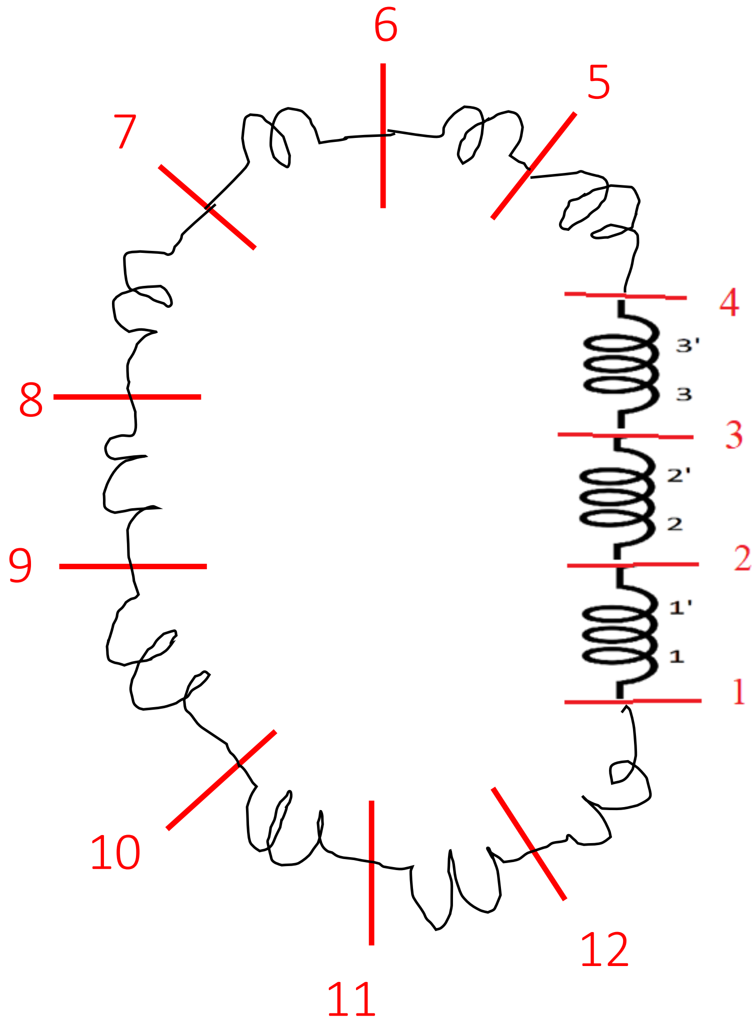
$$y_c = 1$$

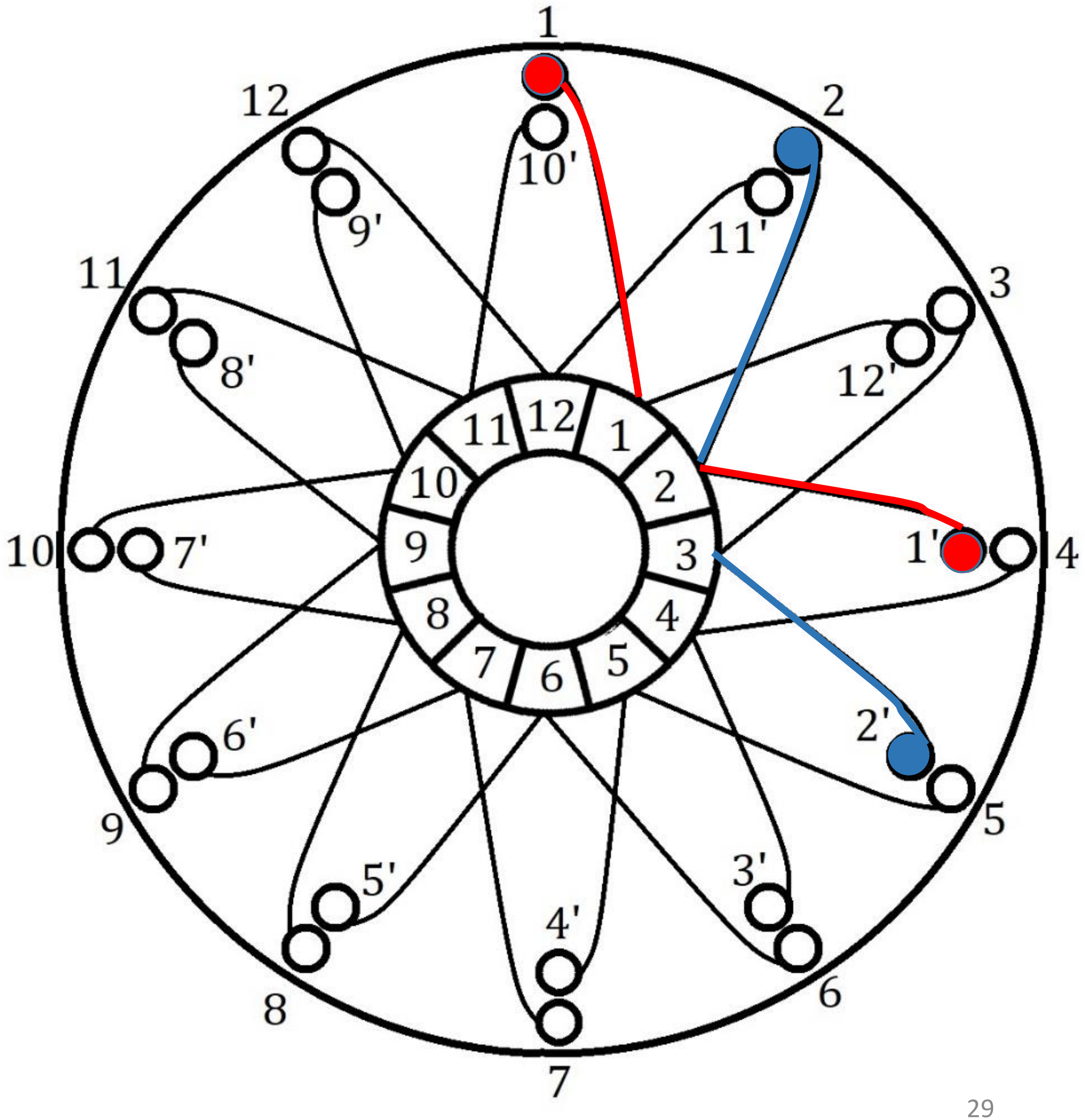


Simple lap winding

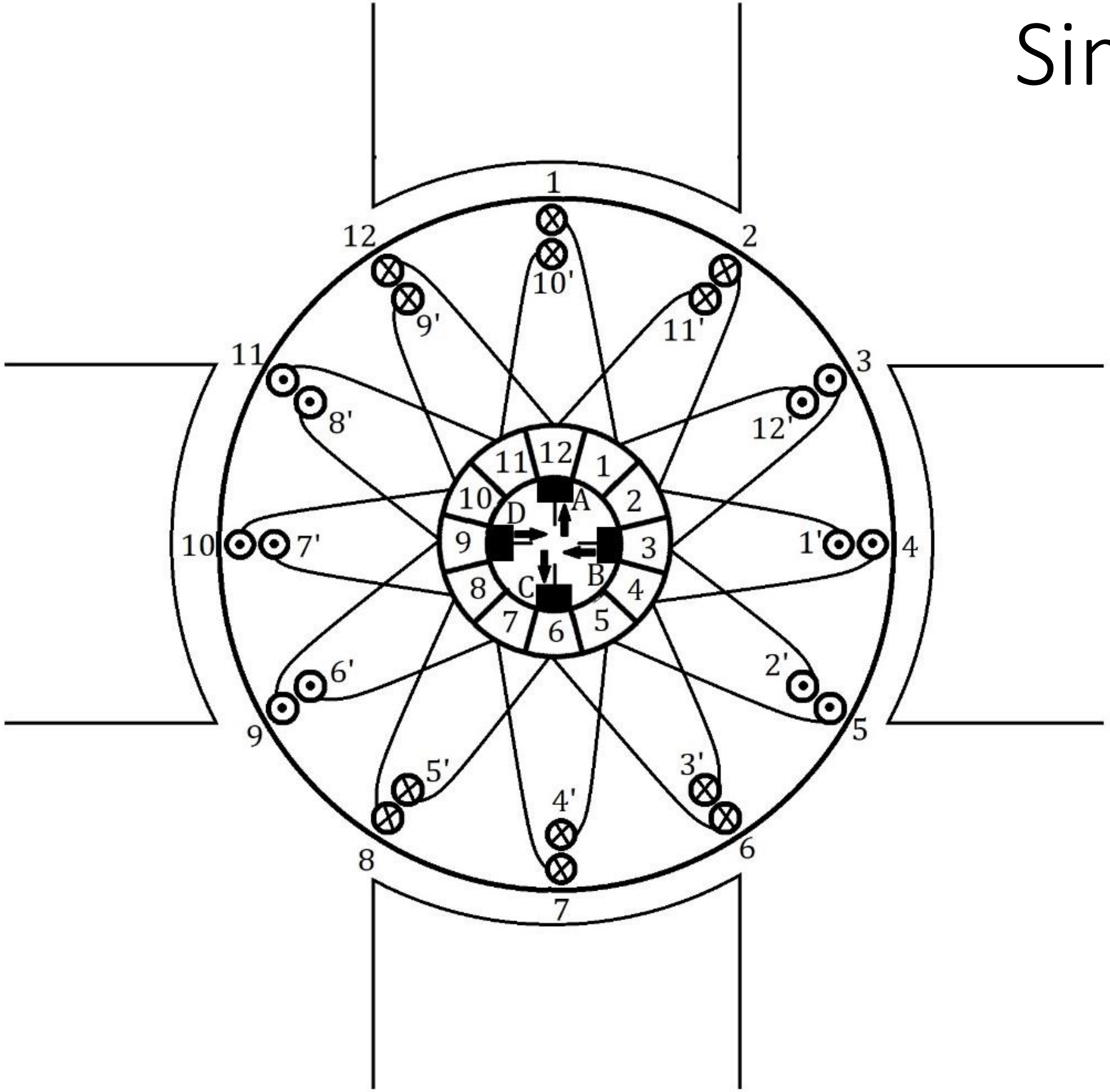


Simple lap winding





Simple lap winding



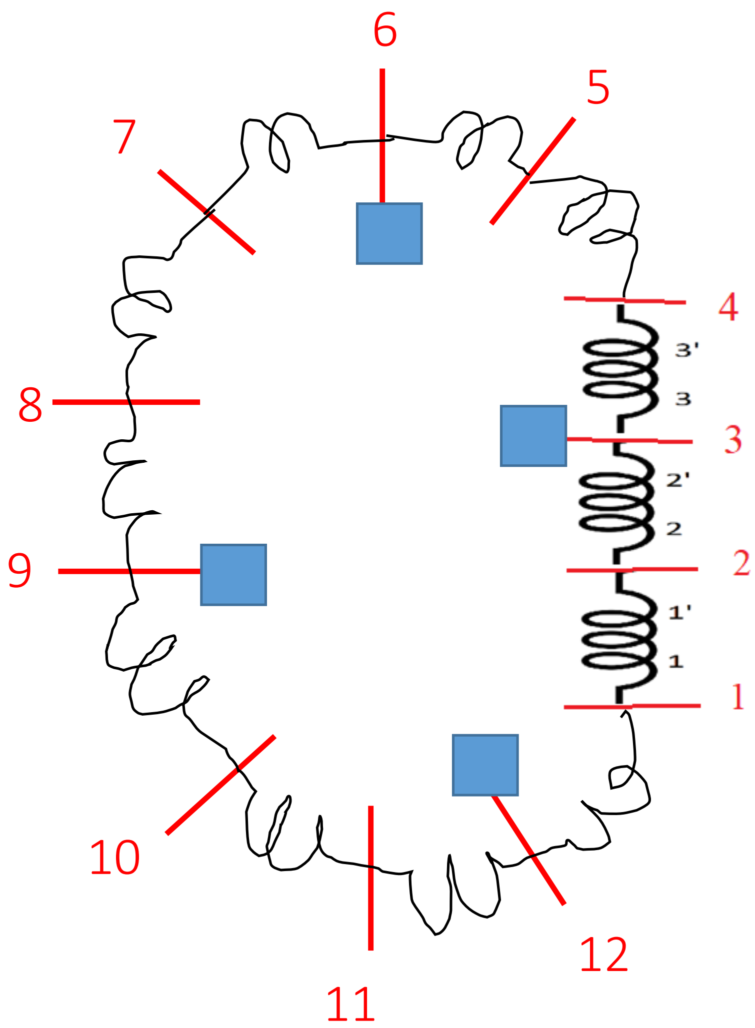
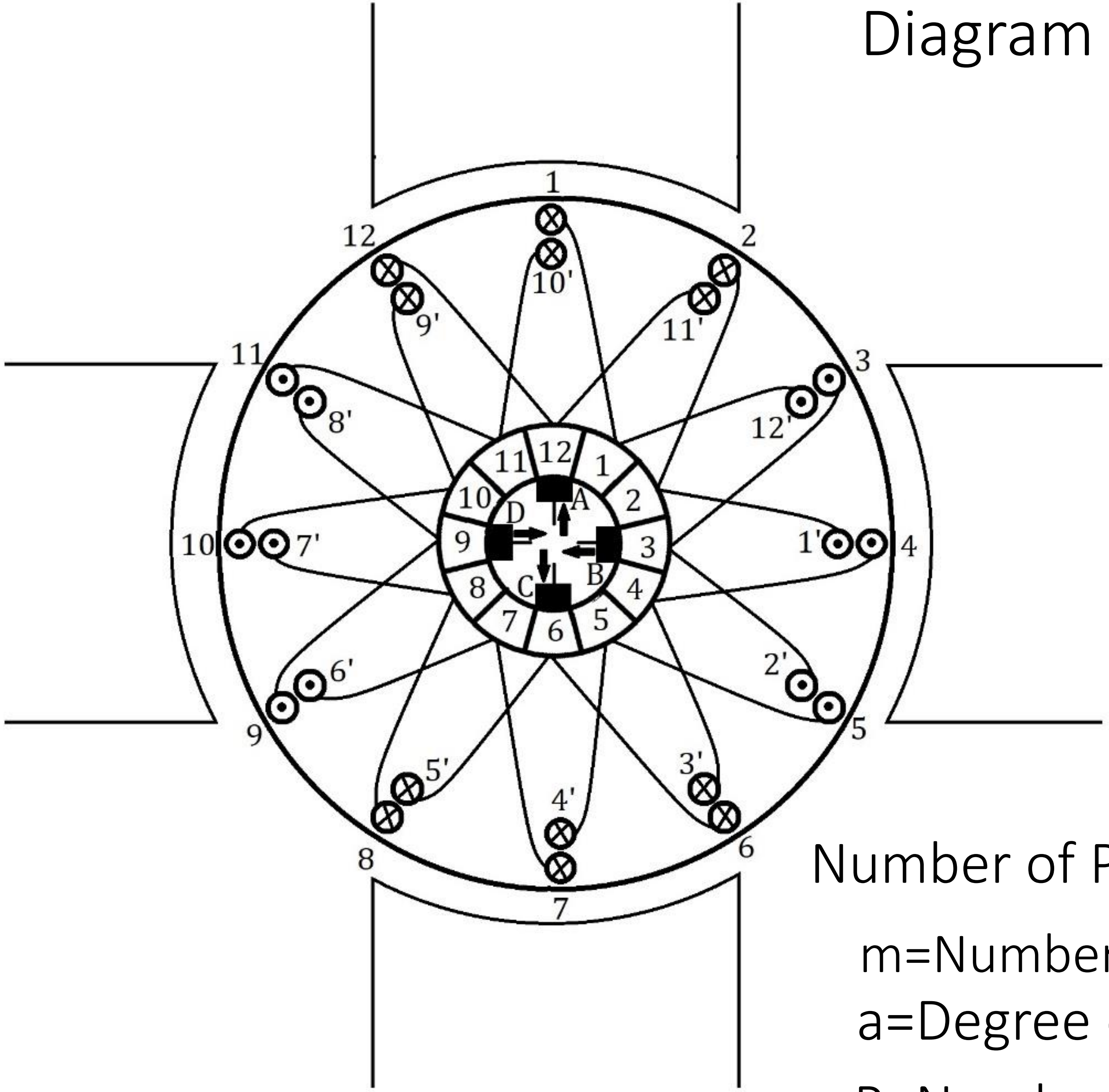
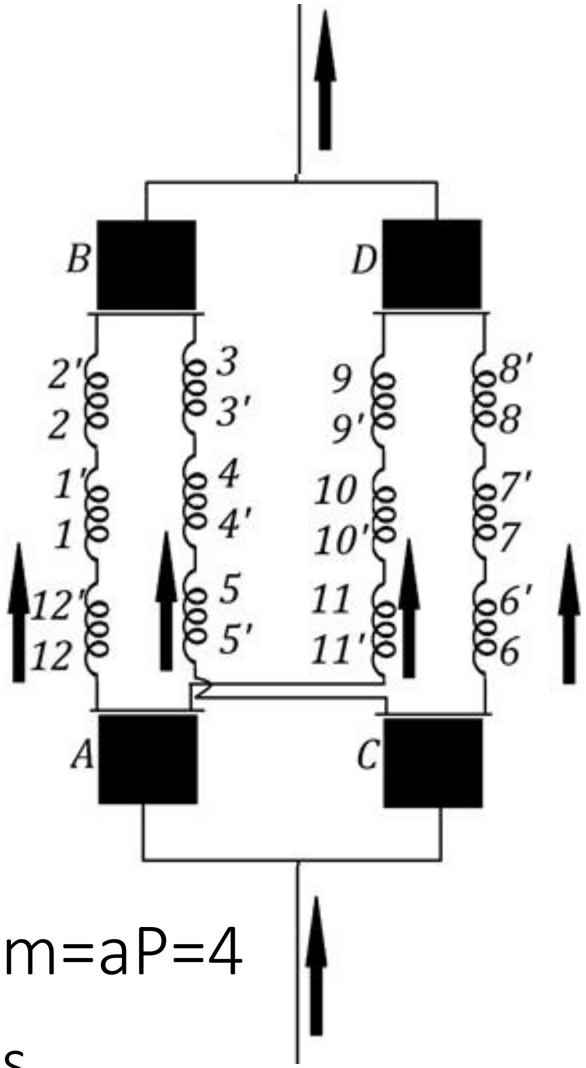


Diagram of Parallel Current Paths





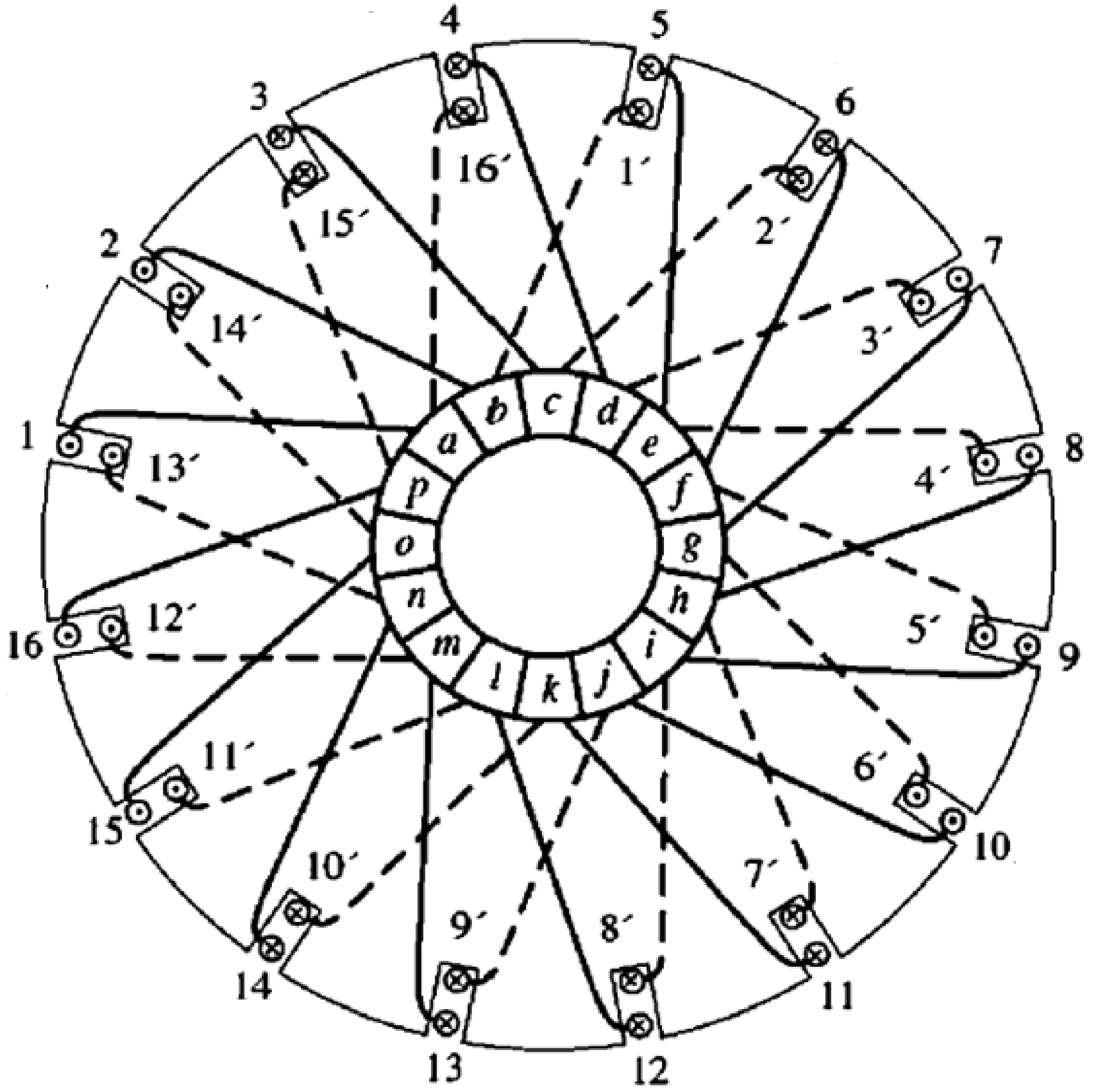
Number of Parallel Paths = m=aP=4

m=Number of Parallel Paths

a=Degree of Combination

P=Number of Poles

More exercise:



P=? Why?

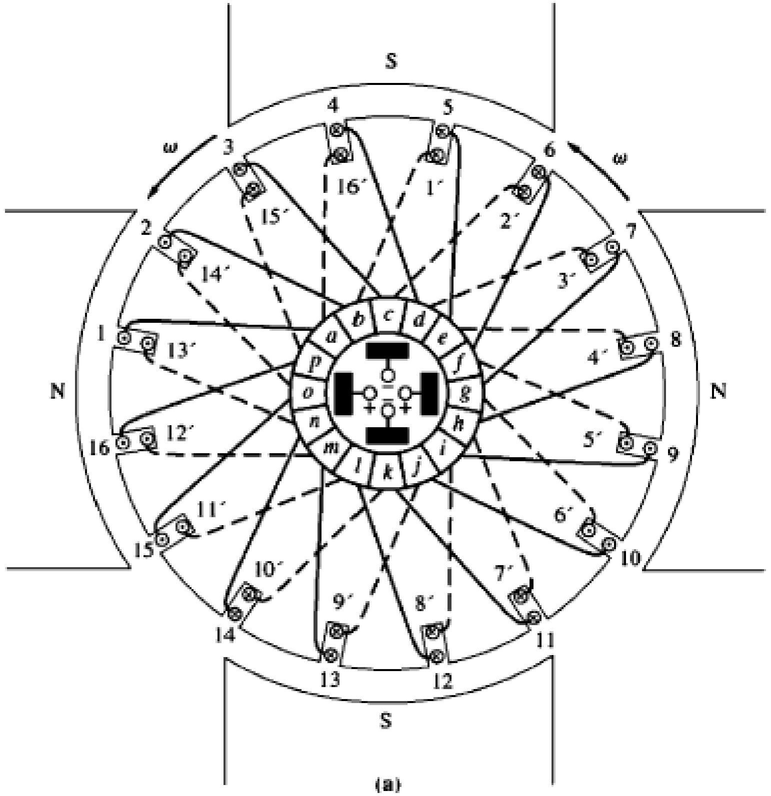
Winding type=? Why?

Simple or combined? Why?

m=? Why?

More exercise:

DC MACHINERY FUNDAMENTALS 495



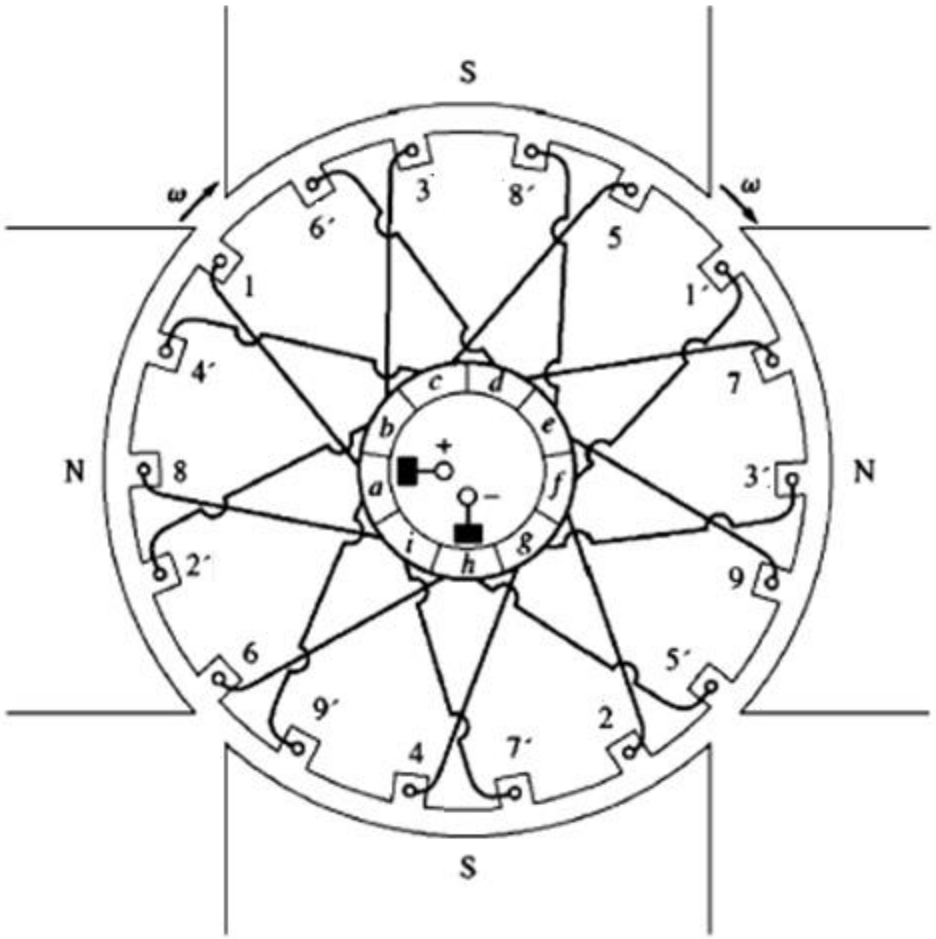
(a)

FIGURE 8–15
(a) A four-pole lap-wound dc motor. (b) The rotor winding diagram of this machine. Notice that each winding ends on the commutator segment just after the one it begins at. This is a progressive lap winding.

What book is this picture adapted from?

What is the problem of this figure?

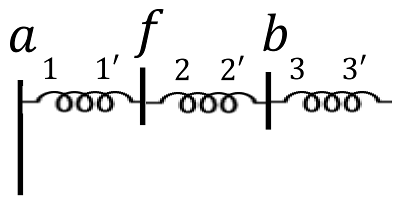
More exercise: Wave winding



$$y_c = \frac{2(C \pm a)}{P}$$

$$y_c = \frac{2(9+1)}{4} = 5$$

$$m = 2a$$



Complete the diagram and determine the parallel paths.

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….

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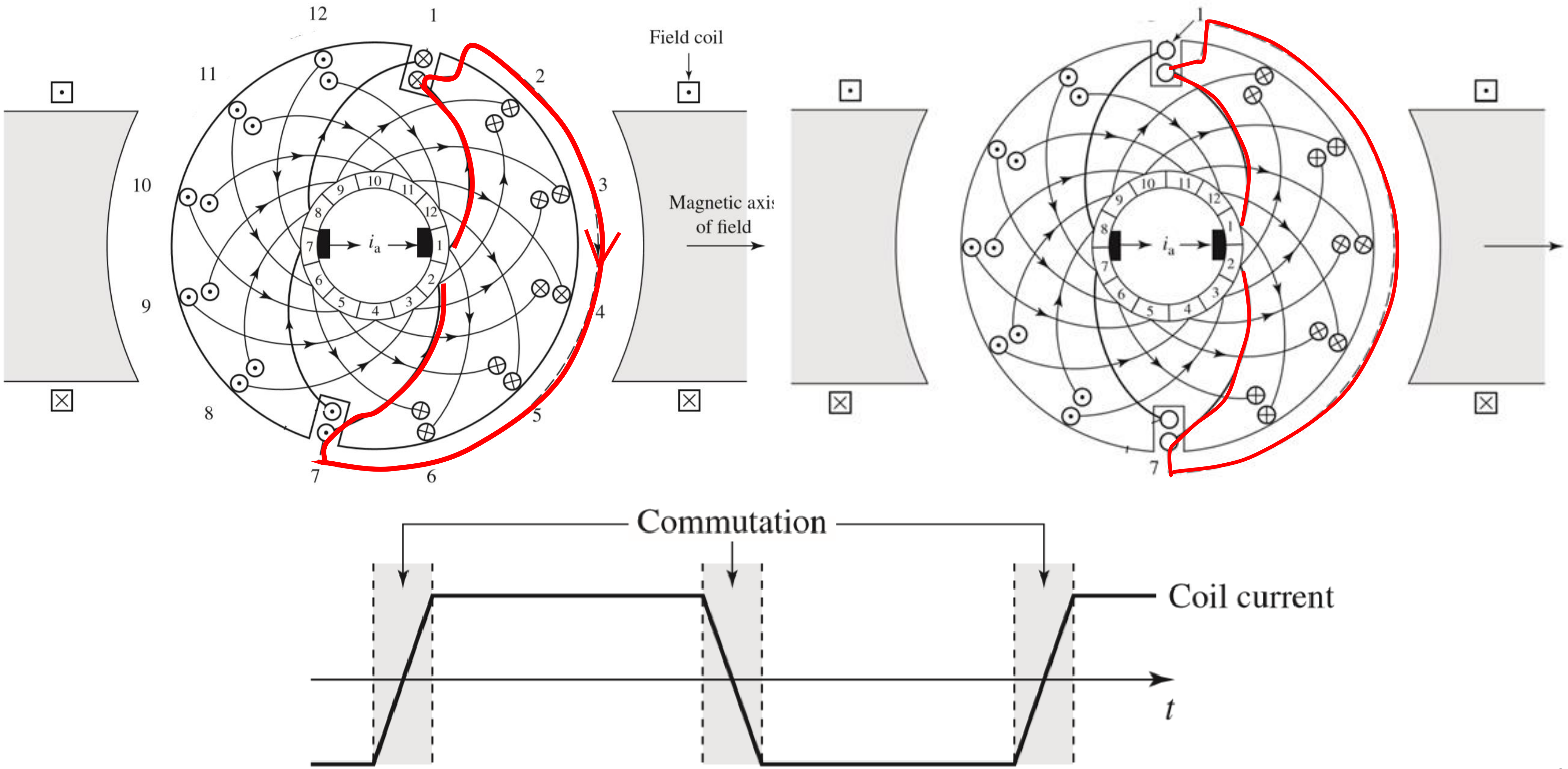
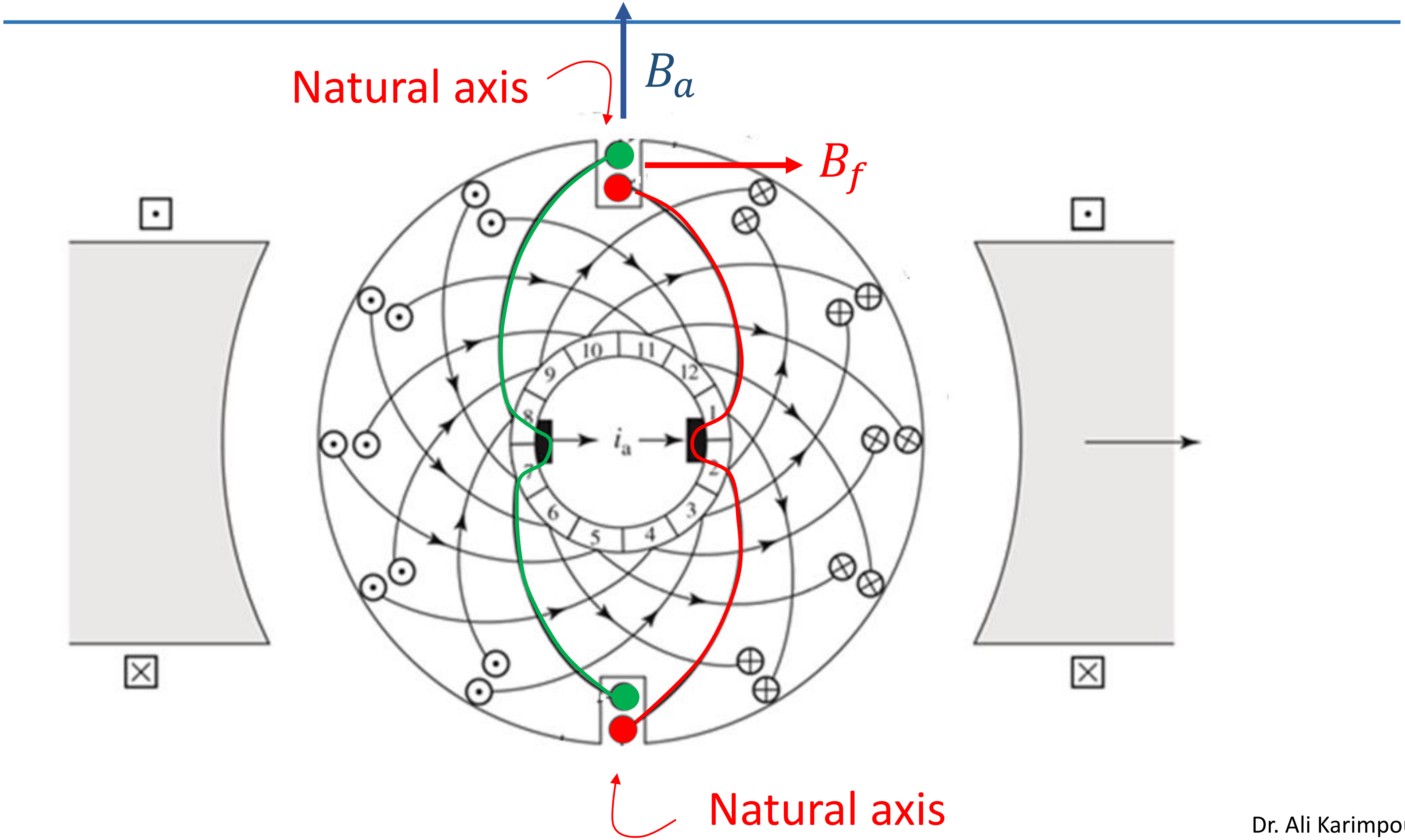
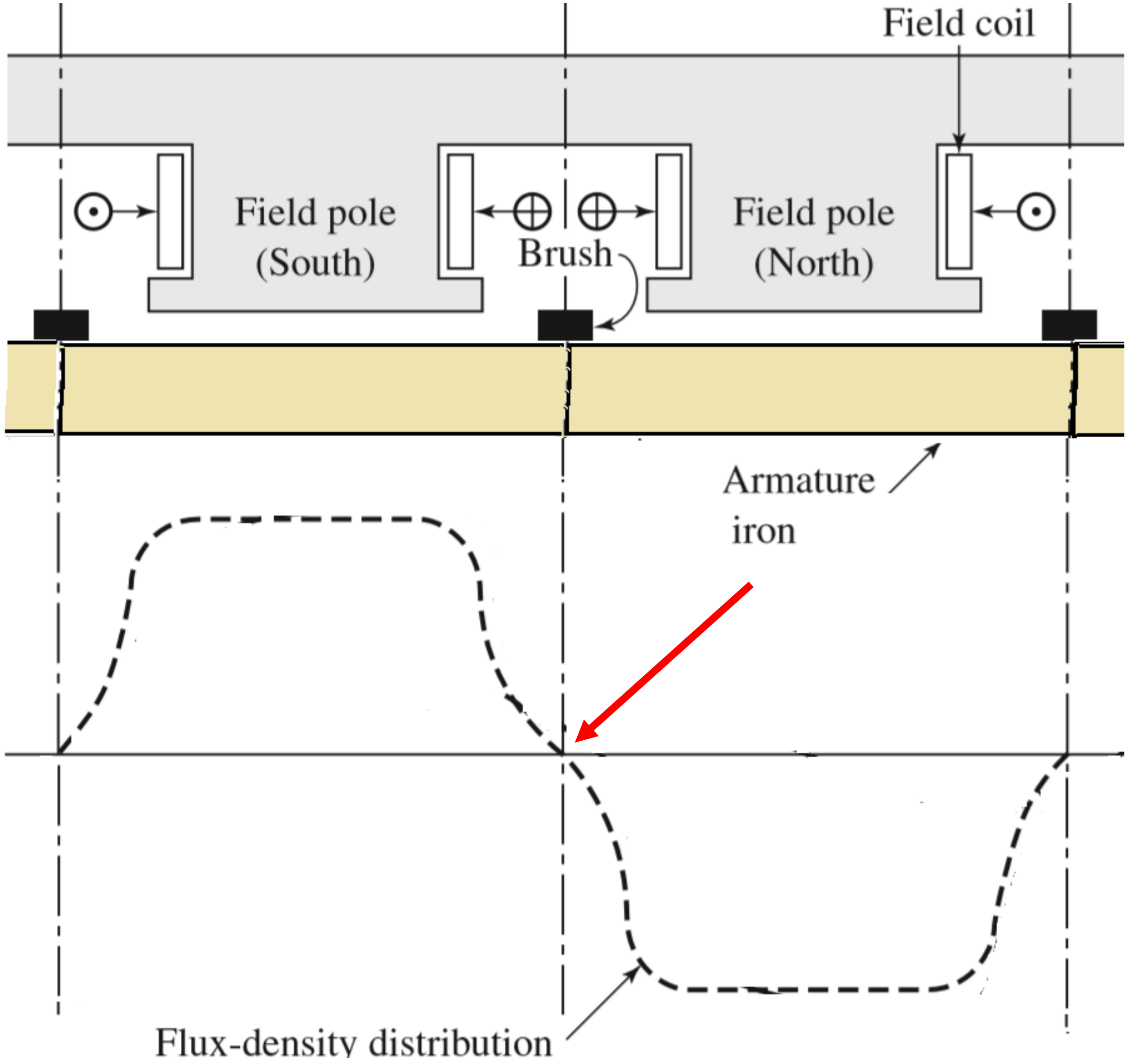
Commutation

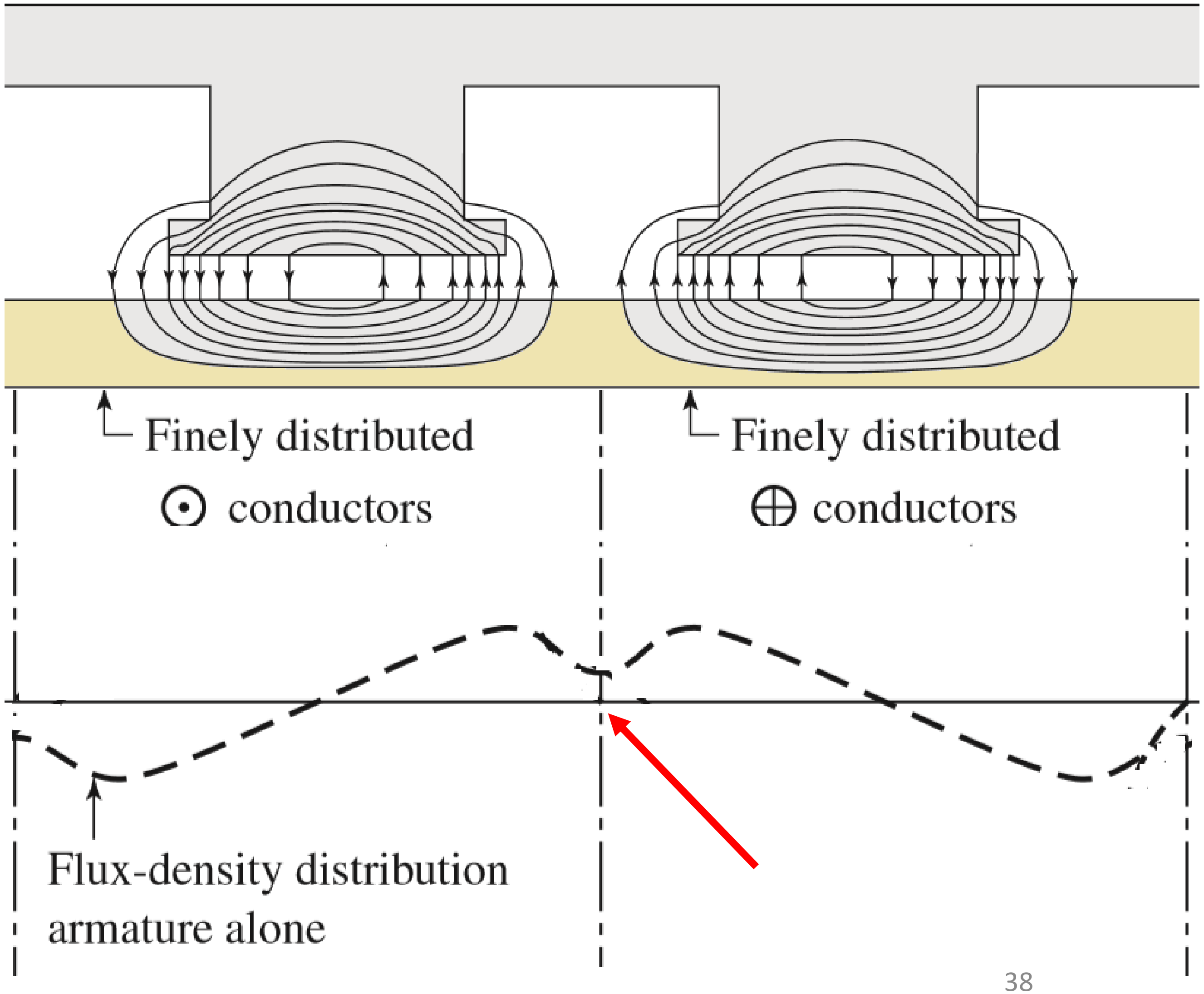


Natural axis-Armature reaction



Natural axis-Armature reaction





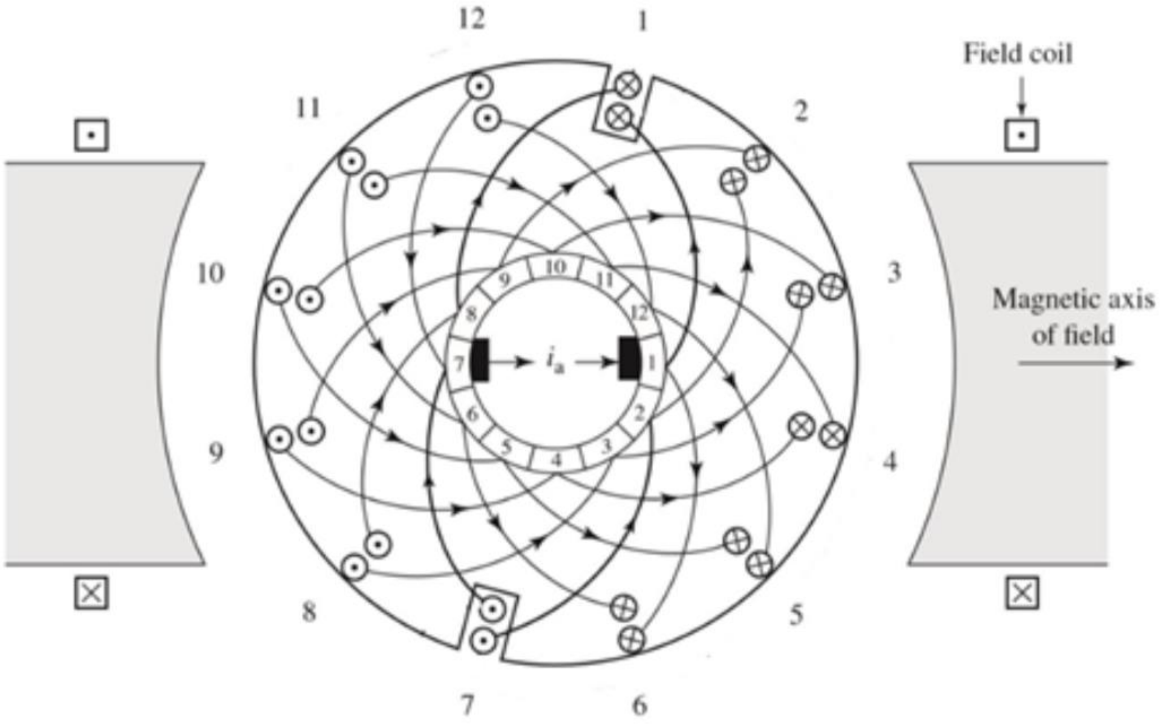
Exercise 1: Final 2022

Exercise 1: The figure shows a DC motor.

a) In which direction does the motor rotate and why?

b) Is the induced voltage on the wire near number 3 greater or the wire near number 4? Why?

c) In the loaded condition, is the neutral axis closer to number 12 or number 1?



Natural axis-Armature reaction

Problems?

1-???

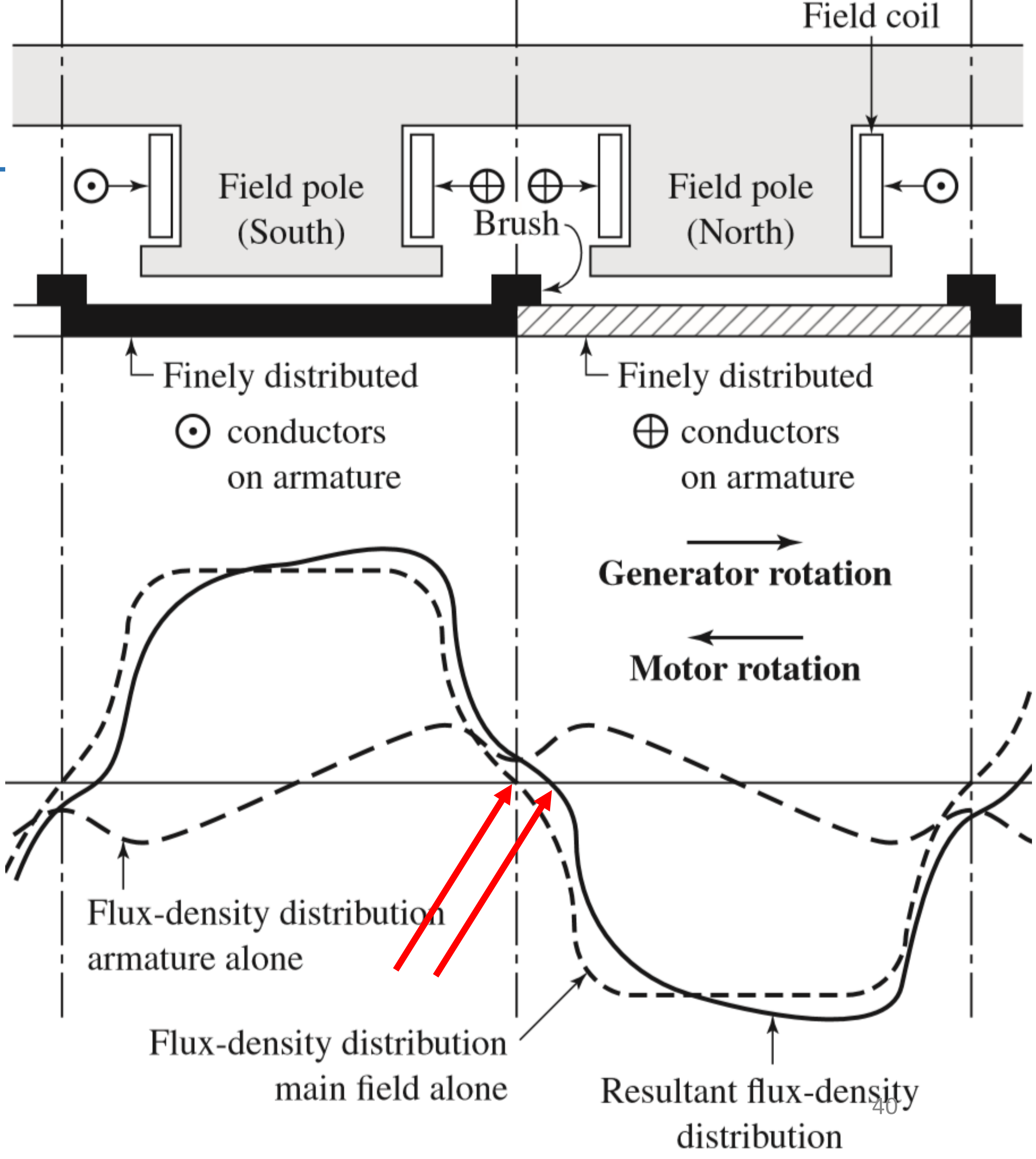
2-???

How to solve the Problems?

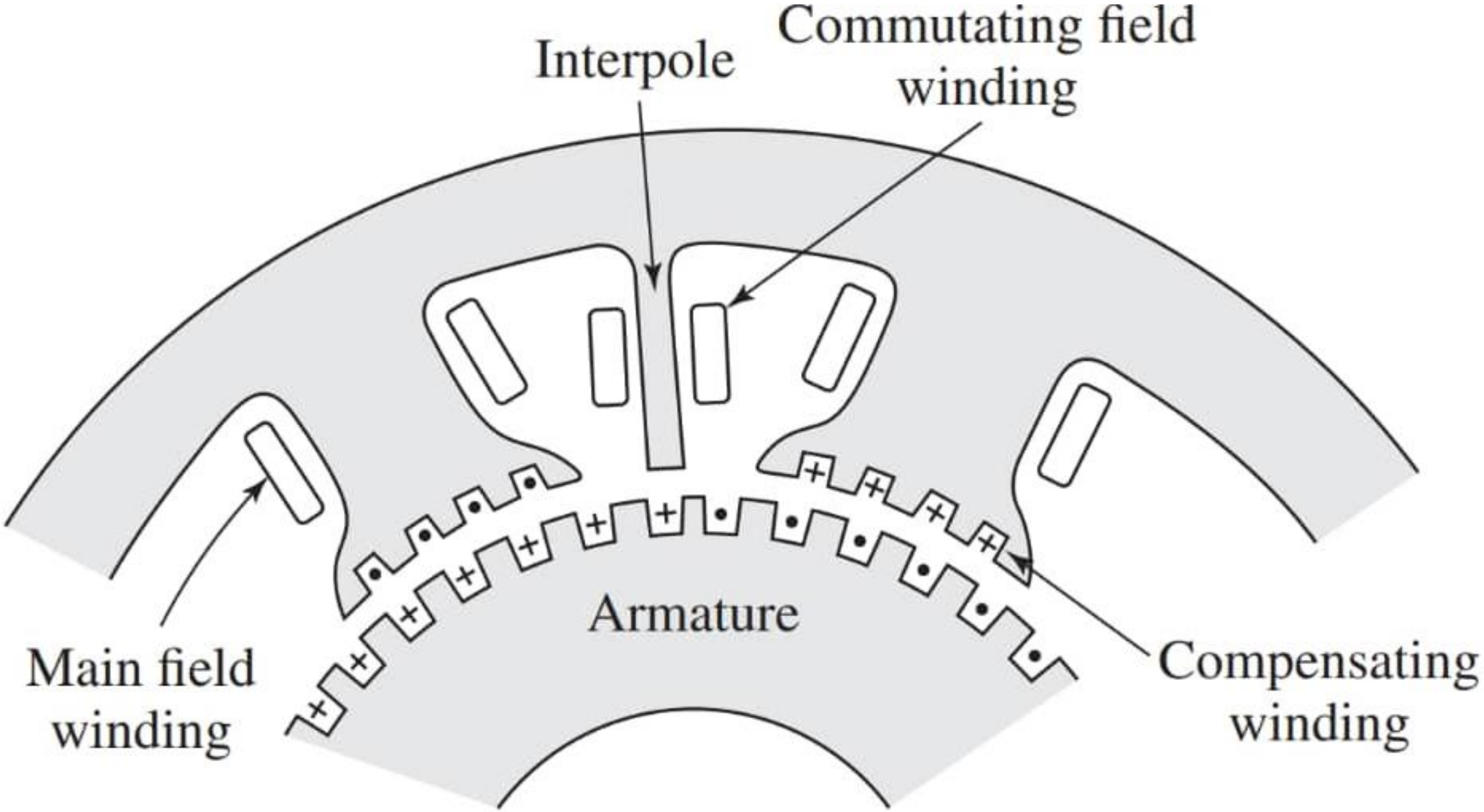
1-???

2-???

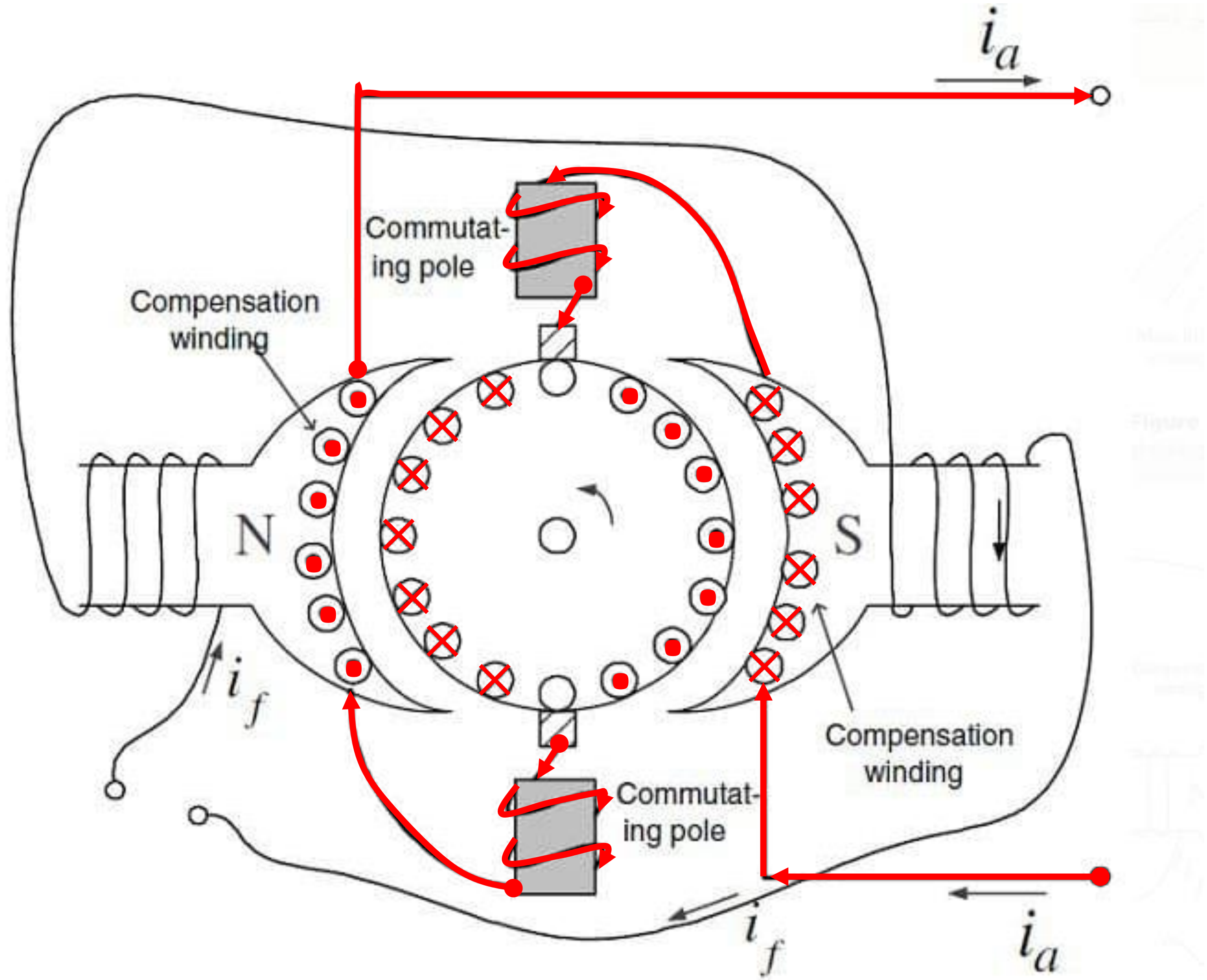
3-???



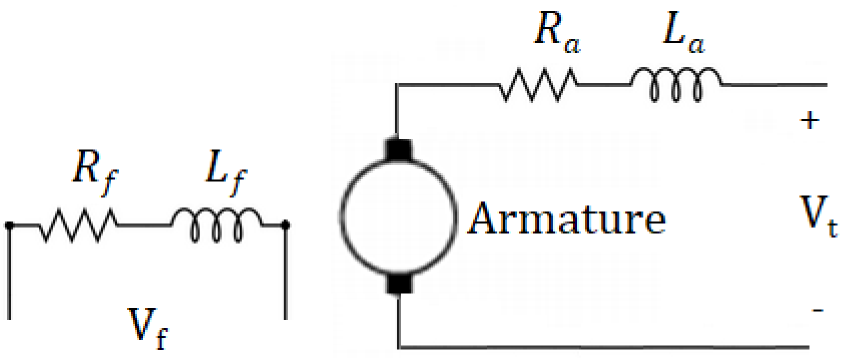
Inter poles and compensation winding



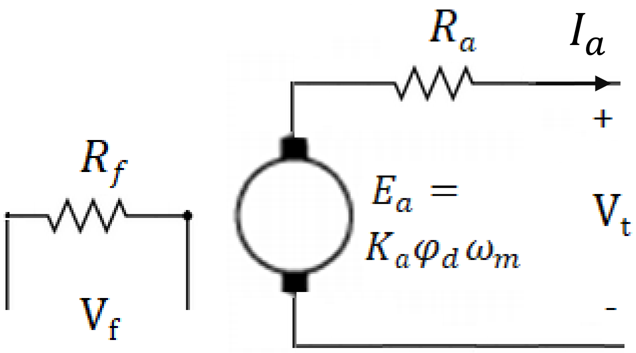
Inter poles and compensation winding



Equivalent circuit in DC Machine

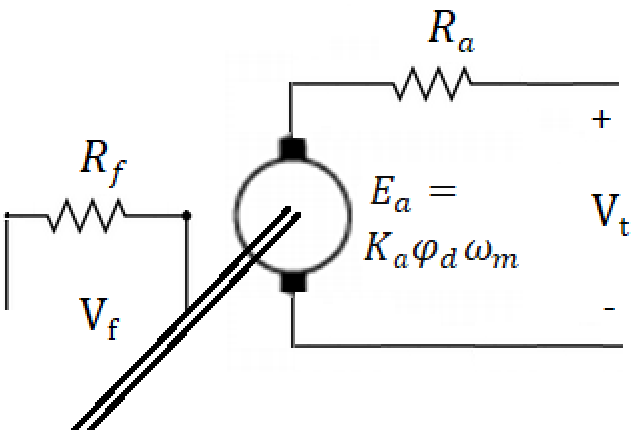


Equivalent circuit of DC generator

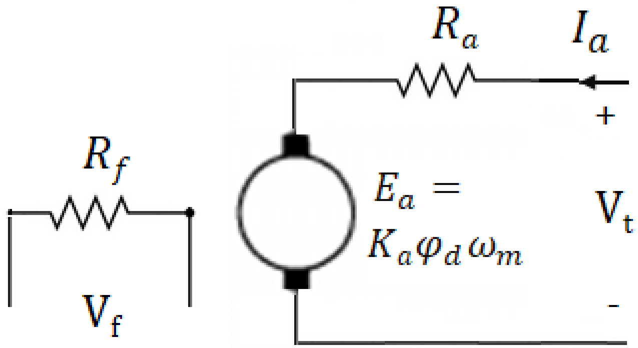


$$V_f = R_f \, I_f$$

$$E_a = V_t + R_a \, I_a$$



Equivalent circuit of DC motor



$$V_f = R_f \, I_f$$

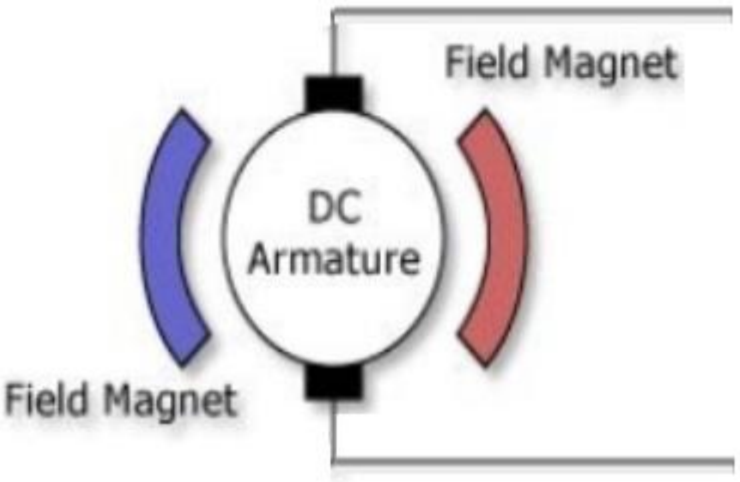
$$V_t = E_a + R_a \, I_a$$

Different Types of Field Excitations

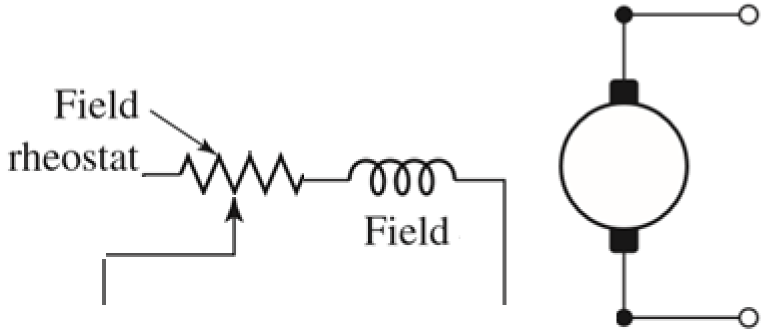
Equivalent circuit in DC Machine

How can we energize the field winding?

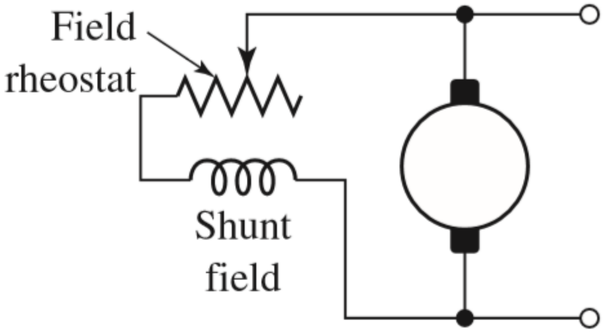
1-PM DC machines



2- Separate excitation DC machines



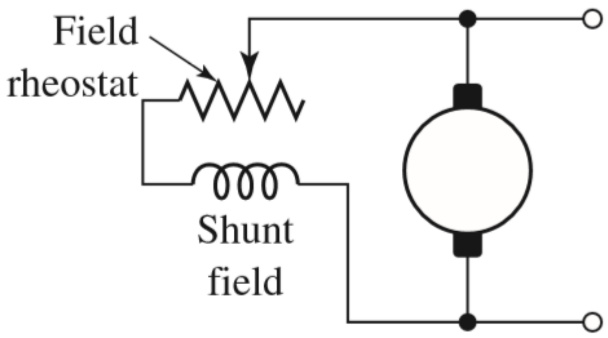
3- Self excitation DC machines



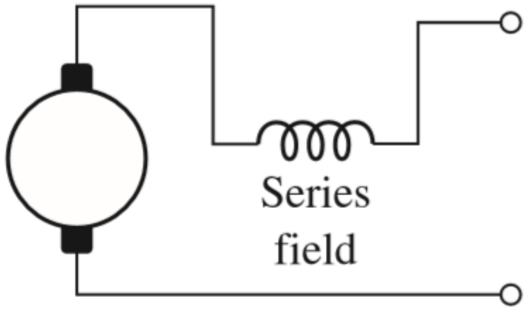
Equivalent circuit in DC Machine

Different types of self excitation DC machines

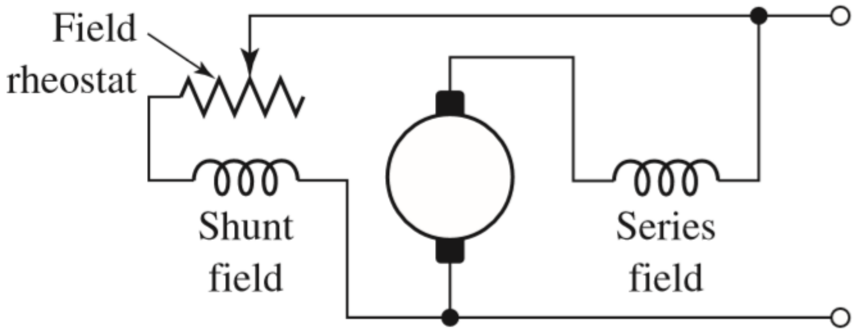
1- Shunt excitation



2- Series excitation



3- Compound excitation



Different types of compound excitation (Short-Long-Cumulative-Differential)

How to distinguish shunt winding from series winding?

Electrical Machine II Syllabus

1. Introduction

….

2. Introduction to Rotating Machines

….

….

3. DC Machines
   - Commutator Action
   - Analytical Fundamentals
   - Electric-Circuit Aspects
   - Effect of Armature MMF (Armature reaction, Commutation and Interpoles and Compensating Windings)
   - Steady-State DC Machine Performance
   - Permanent-Magnet DC Machines
   - Series Universal Motors
   - DC Motor Starting
4. Induction Machines

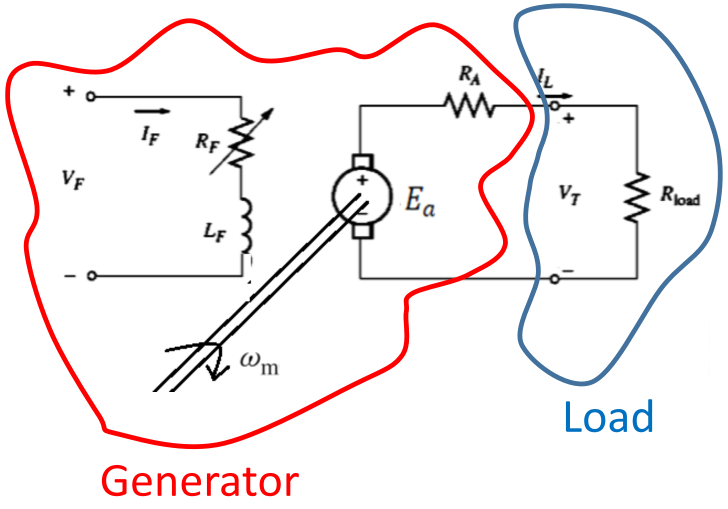
….

….

Important Characteristics in DC machines

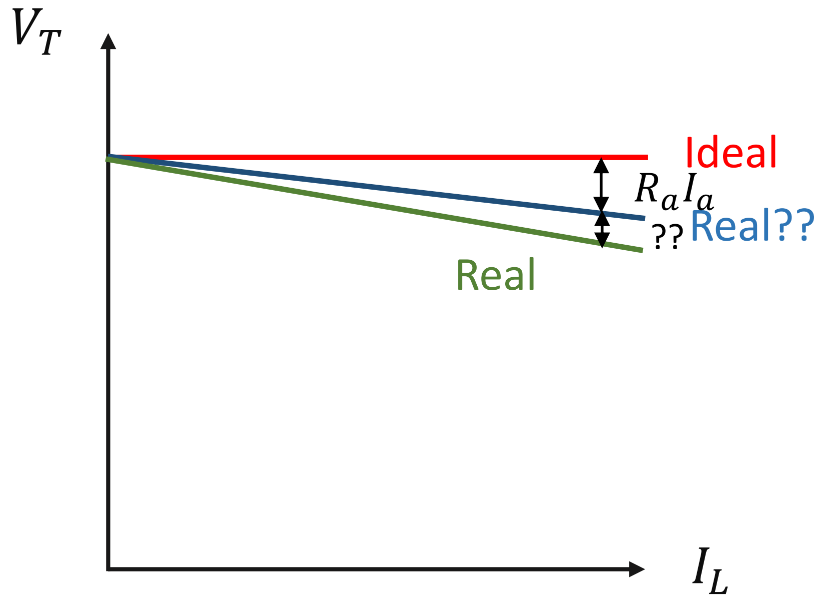
Important characteristics in DC generators

DC generators



What is the output voltage V_T versus I_L?

Let ω_m fixed.



Steady-state volt-ampere characteristics

Voltage regulation ??

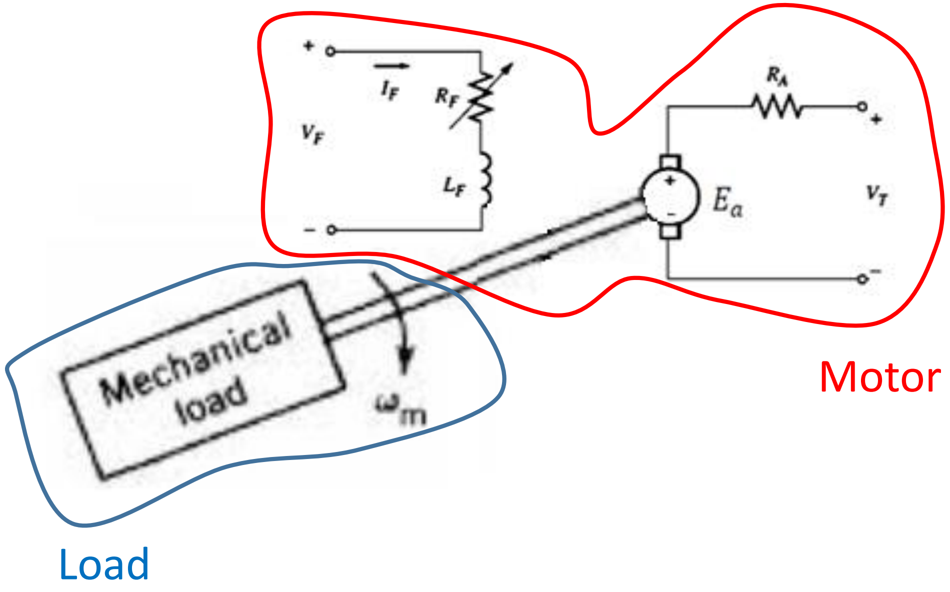
$$VR = \% \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100$$

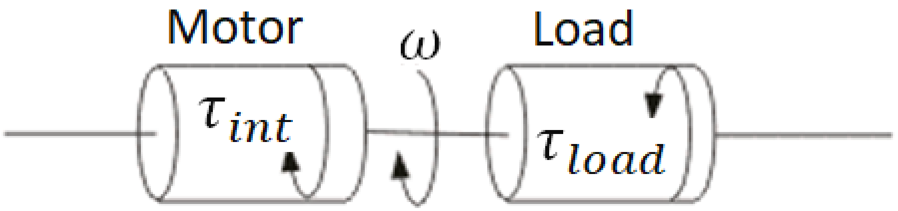
Important characteristic in DC motors

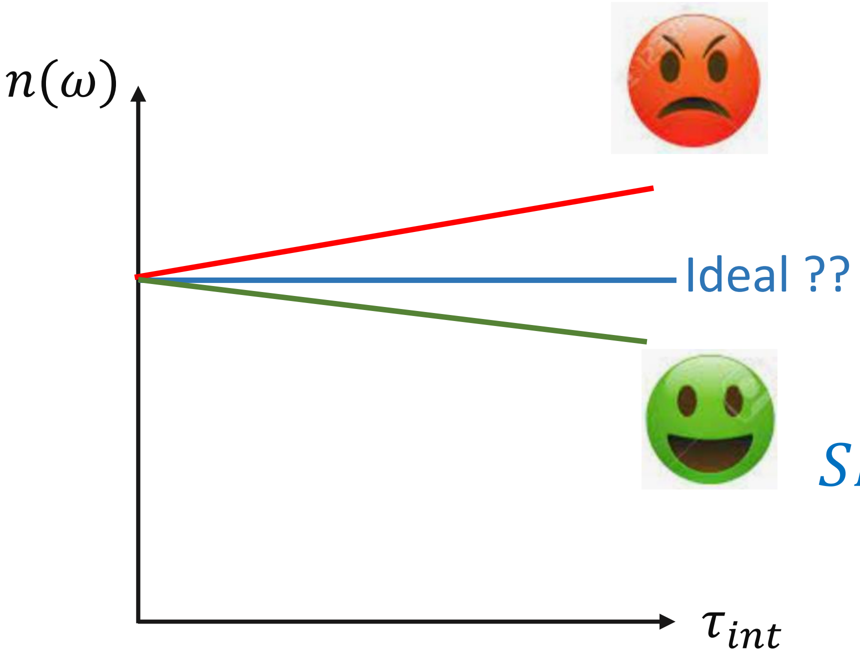
DC Motors

What is the output speed n versus internal torque τ_{int}?

Let v_t fixed.





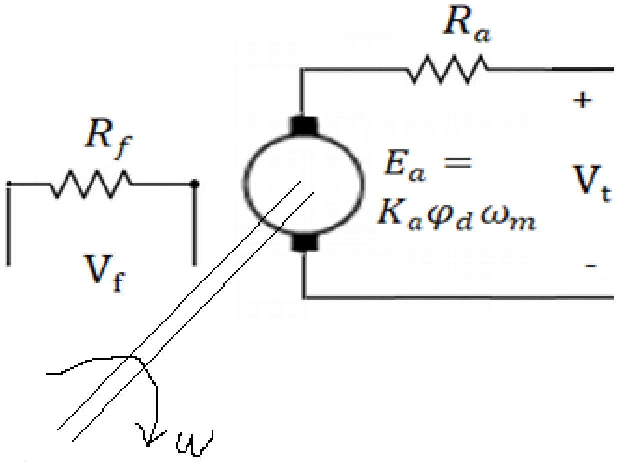


Speed regulation ??

$$SR = \% \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100$$

Steady-state speed-torque characteristics

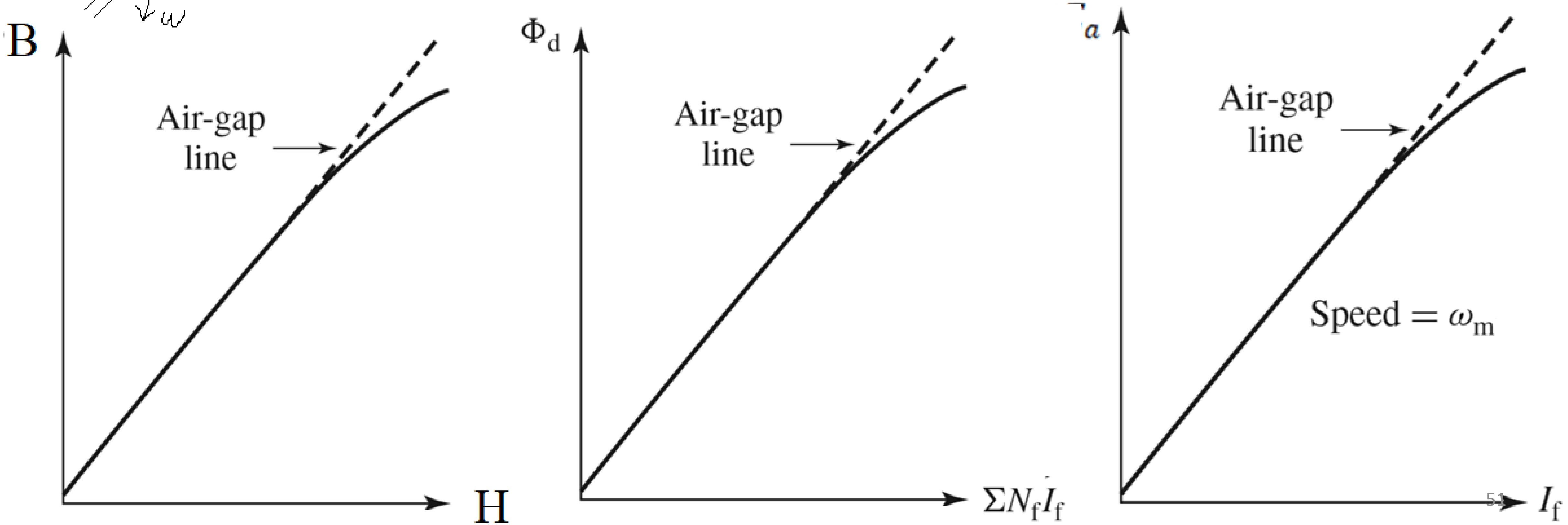
Magnetization curves in DC Machine



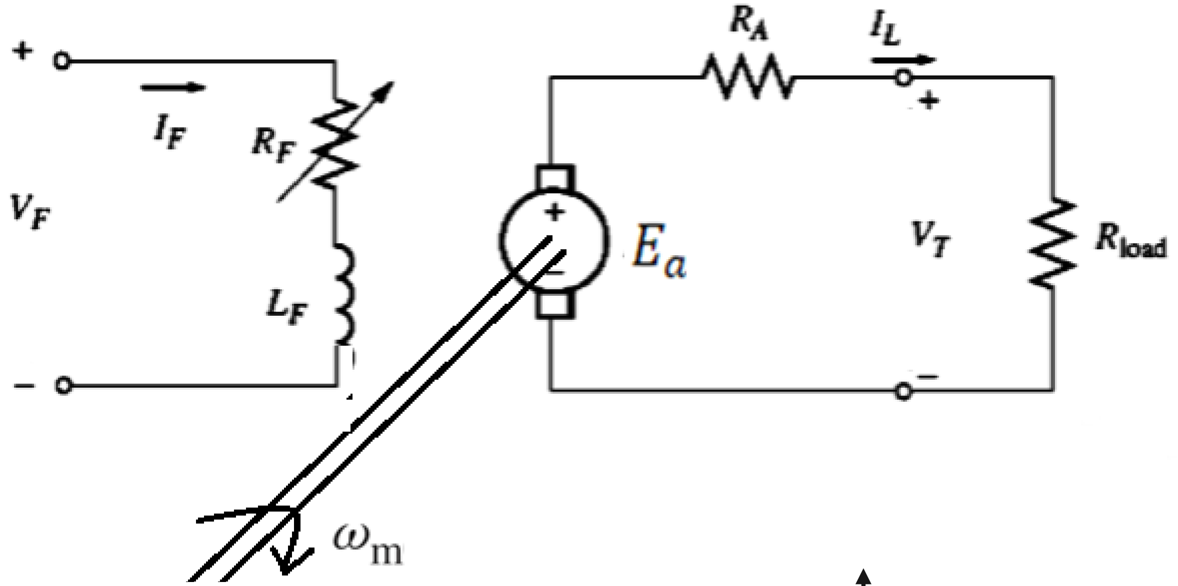
What happens if we change V_f from 0 to rated value?

Clearly I_f change from zero to rated value.

Typical form of magnetization curves of a dc machine.

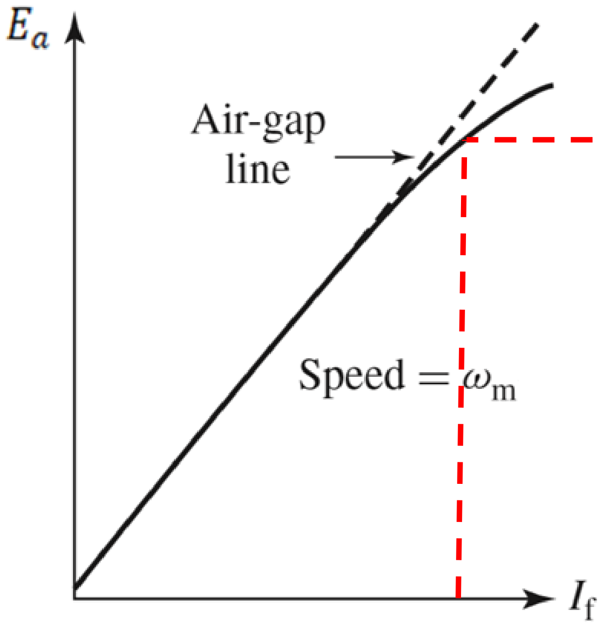


Steady-state volt-ampere characteristics in DC generators

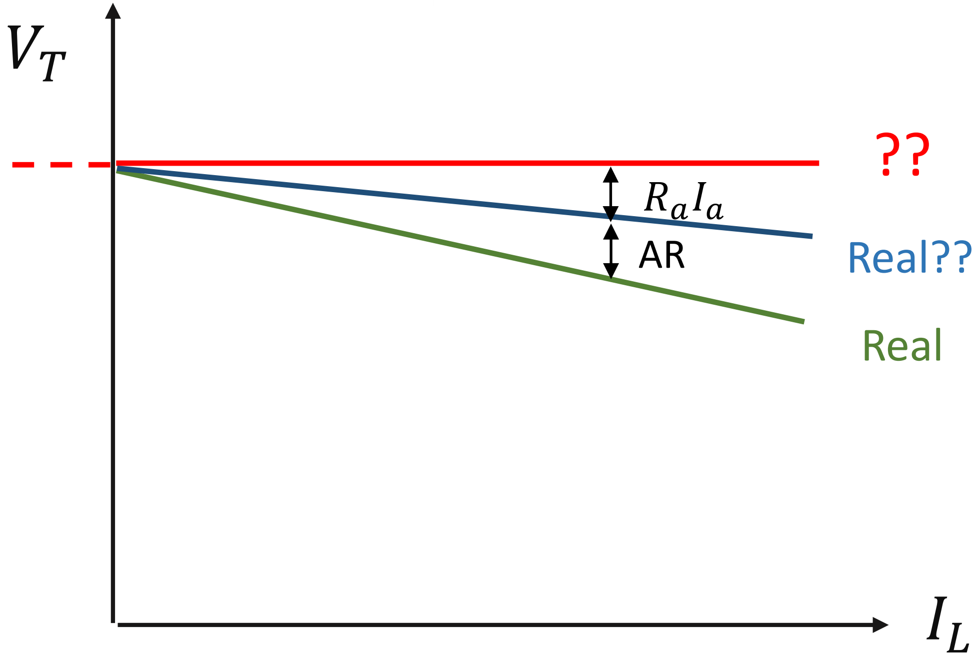


What is the output voltage V_T versus I_L?

Let I_F and ω_m be fixed.



magnetization curves



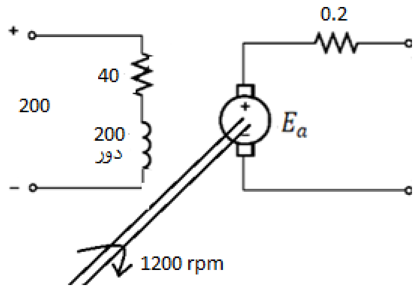
Volt-ampere characteristics for shunt DC generators?

Steady-state volt-ampere characteristics in DC generators

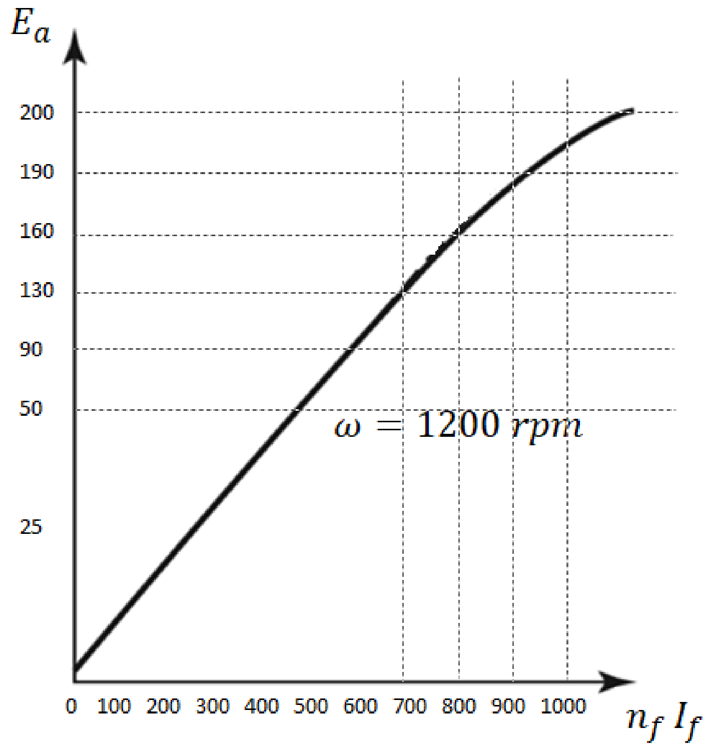
Exercise 2: Consider a 10 kW, 250 V separated excitation DC generator. The no-load voltage the generator is 260 volts and its armature resistance is 0.25 ohm. Ignore the armature reaction and derive voltage regulation at full load.

DC generators characteristics

Example 1: Consider the magnetic characteristic of a separately excited DC generator. Assume the field winding has 200 turns, the field winding resistance is 40 ohms, and the armature resistance is 0.2 ohms. If 200 volts are applied to the field winding and the generator is rotating at 1200 RPM, a) calculate the terminal voltage under no-load conditions.



$$V_T = 195\ v$$



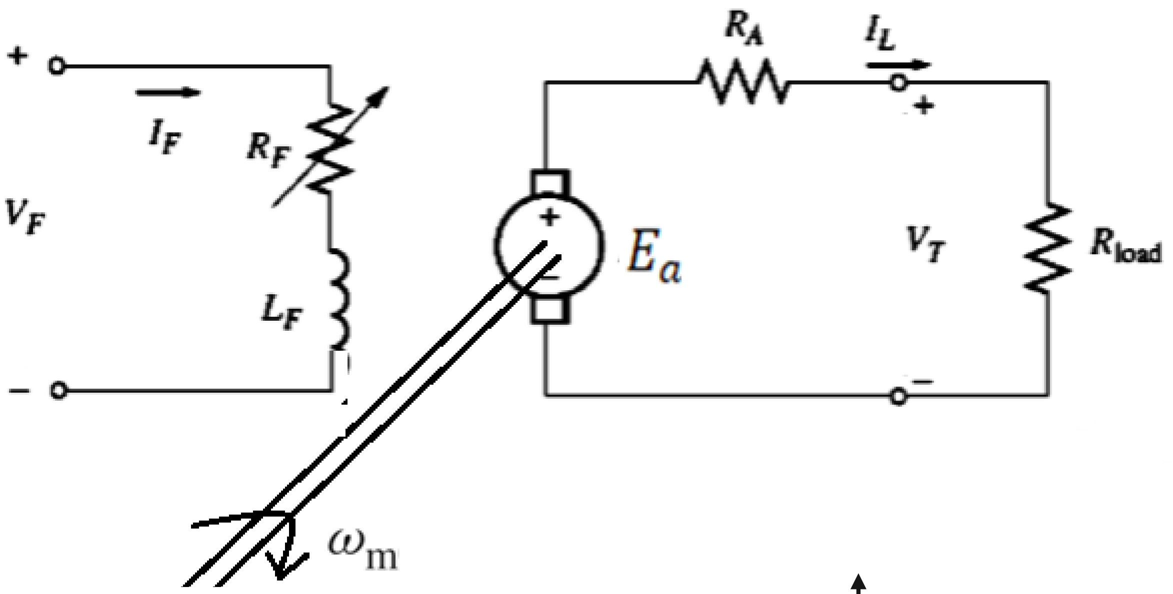
b) If we neglect the armature reaction and the generator speed remains at 1200 RPM, determine the output voltage for a load current of 50 amperes.

$$V_T = 195 - 0.2 \times 50 = 185\ v$$

c) If the field voltage is constant and the speed is 1200 RPM, and the output voltage is 180 volts under a load current of 50 amperes, what is the armature reaction in At?

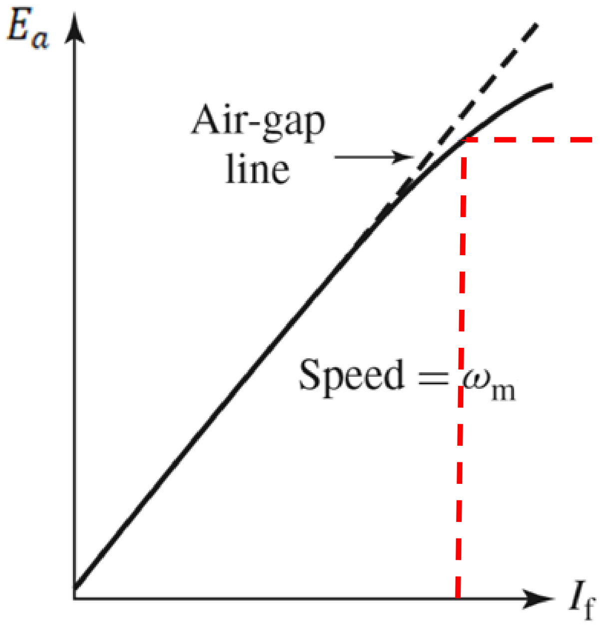
$$E_a = 180 + 0.2 \times 50 = 190\ v \qquad Effective\ At = 920 \qquad AR = 1000 - 920 = 80\ At$$

Steady-state volt-ampere characteristics in DC generators

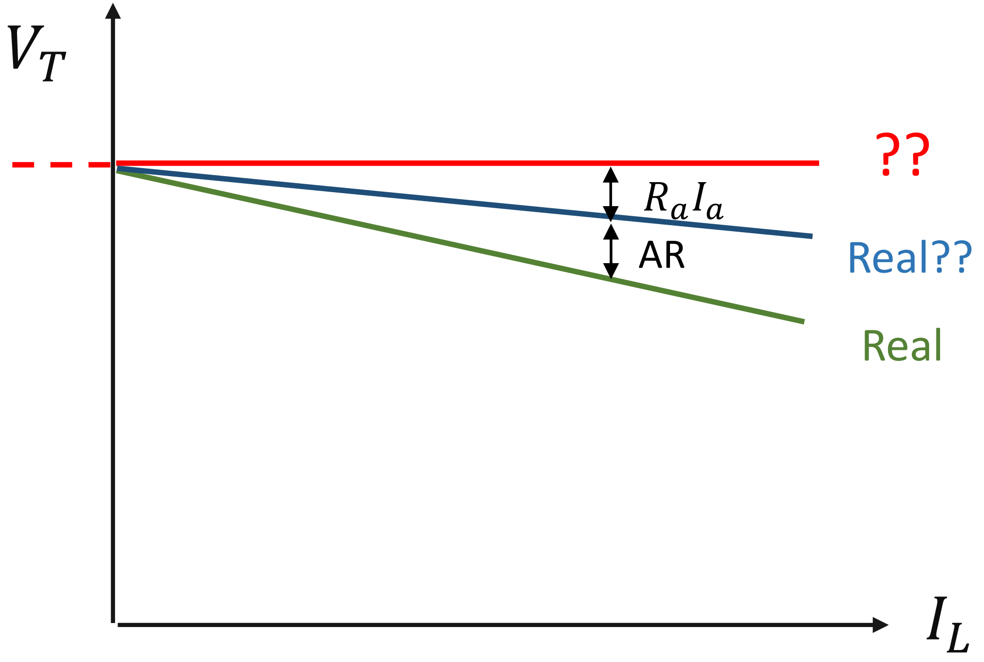


What is the output voltage V_T versus I_L?

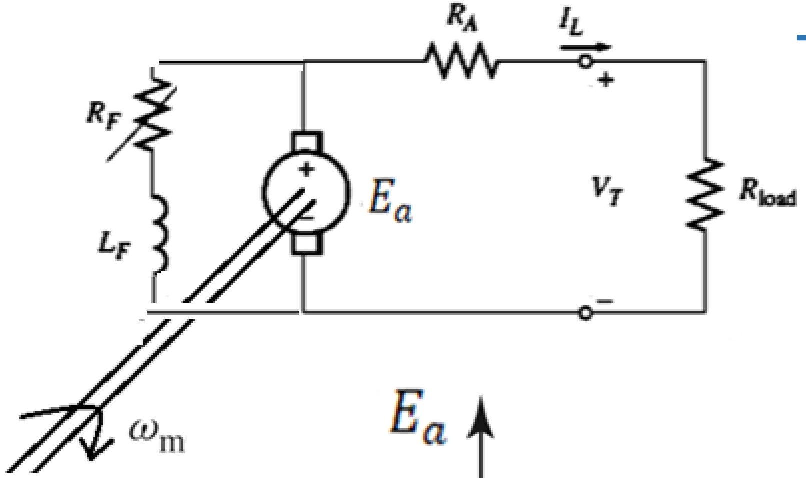
Let ω_m be fixed.



magnetization curves

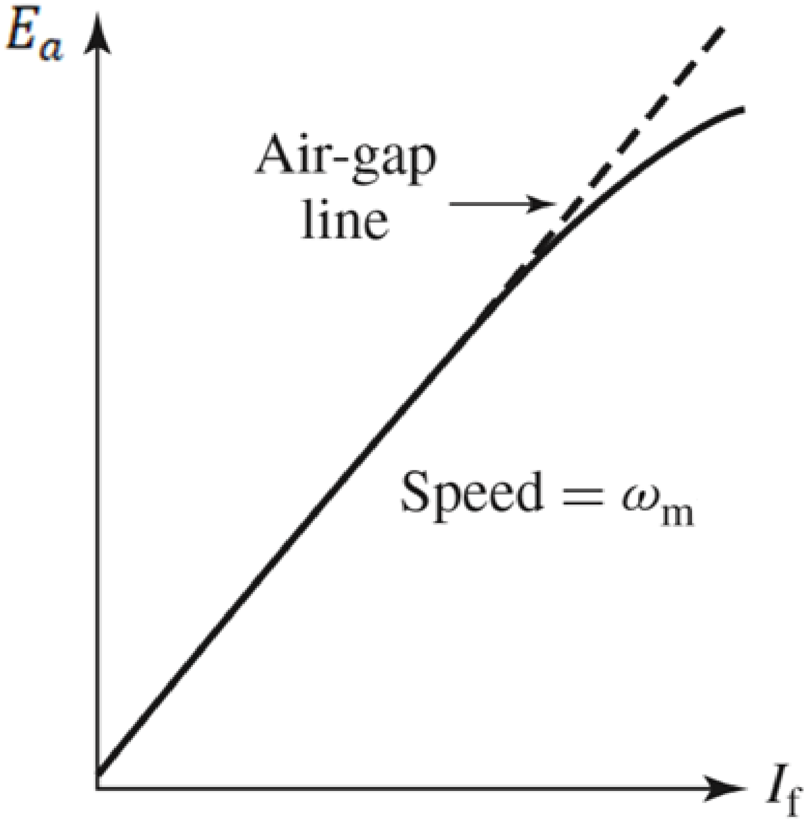


Steady-state volt-ampere characteristics in DC generators

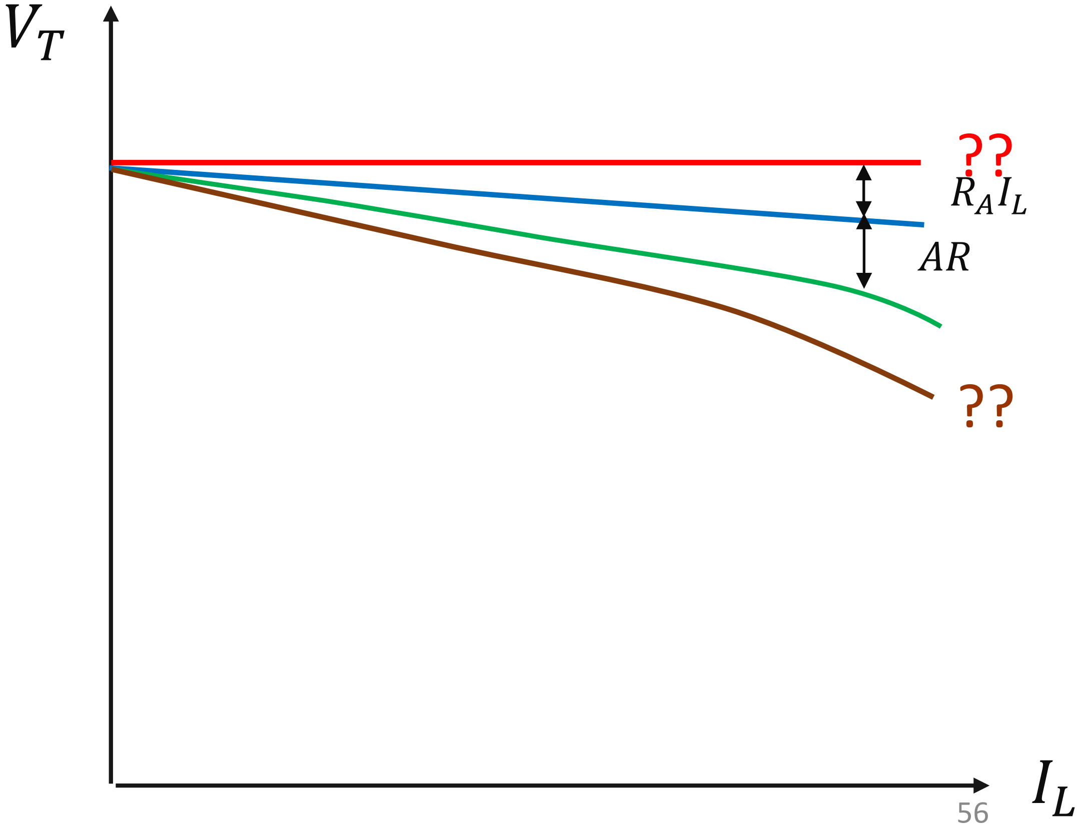


What is wrong in this figure?

$$V_T = E_a - R_A I_L$$



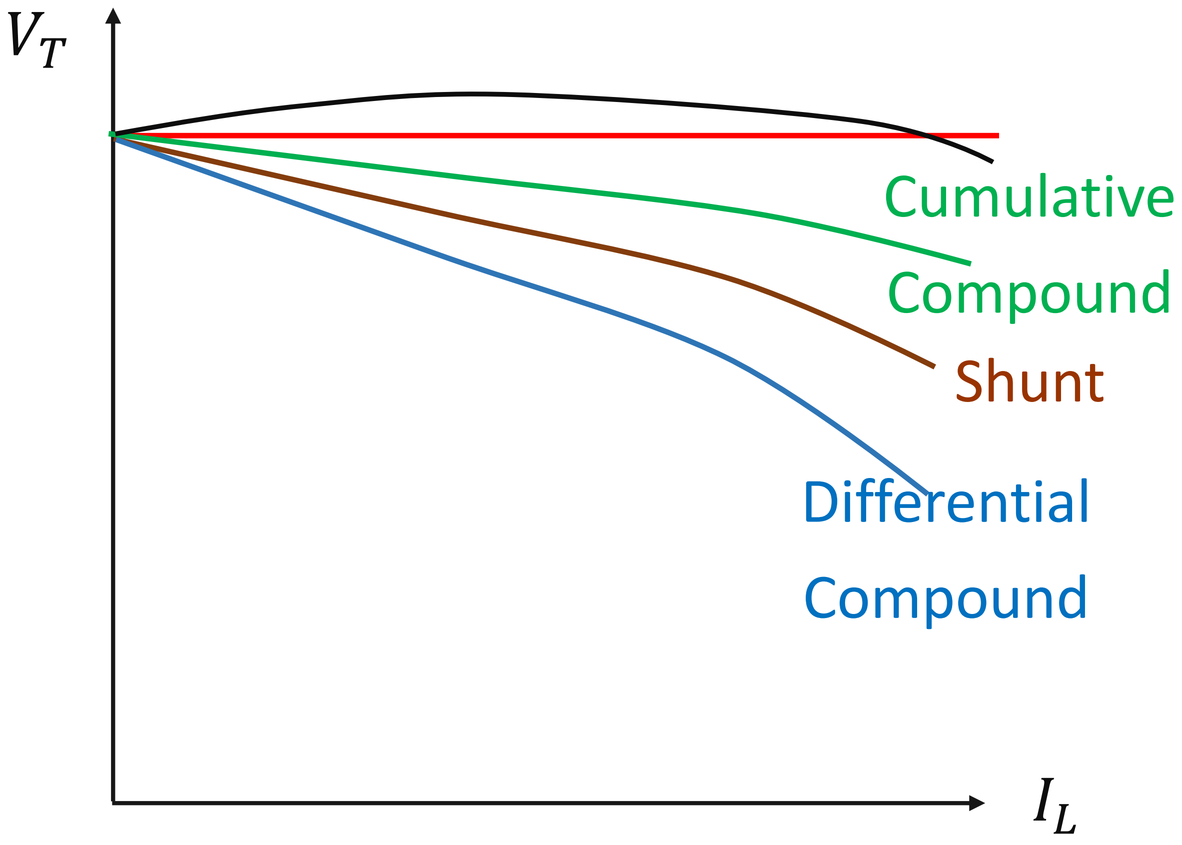
magnetization curves



DC generators characteristics

What is the output voltage V_T versus I_L?

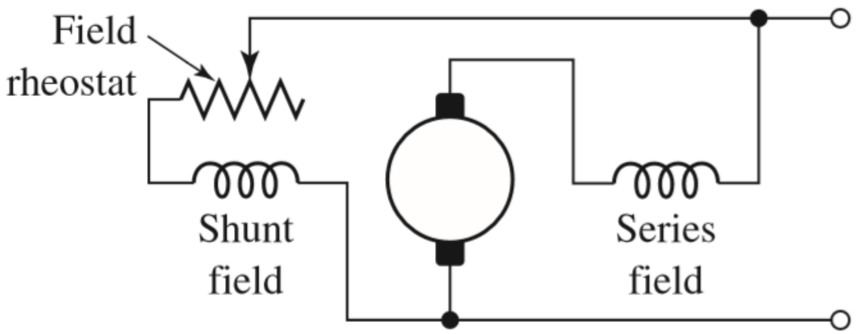
Let ω_m is fixed.



Voltage regulation ??

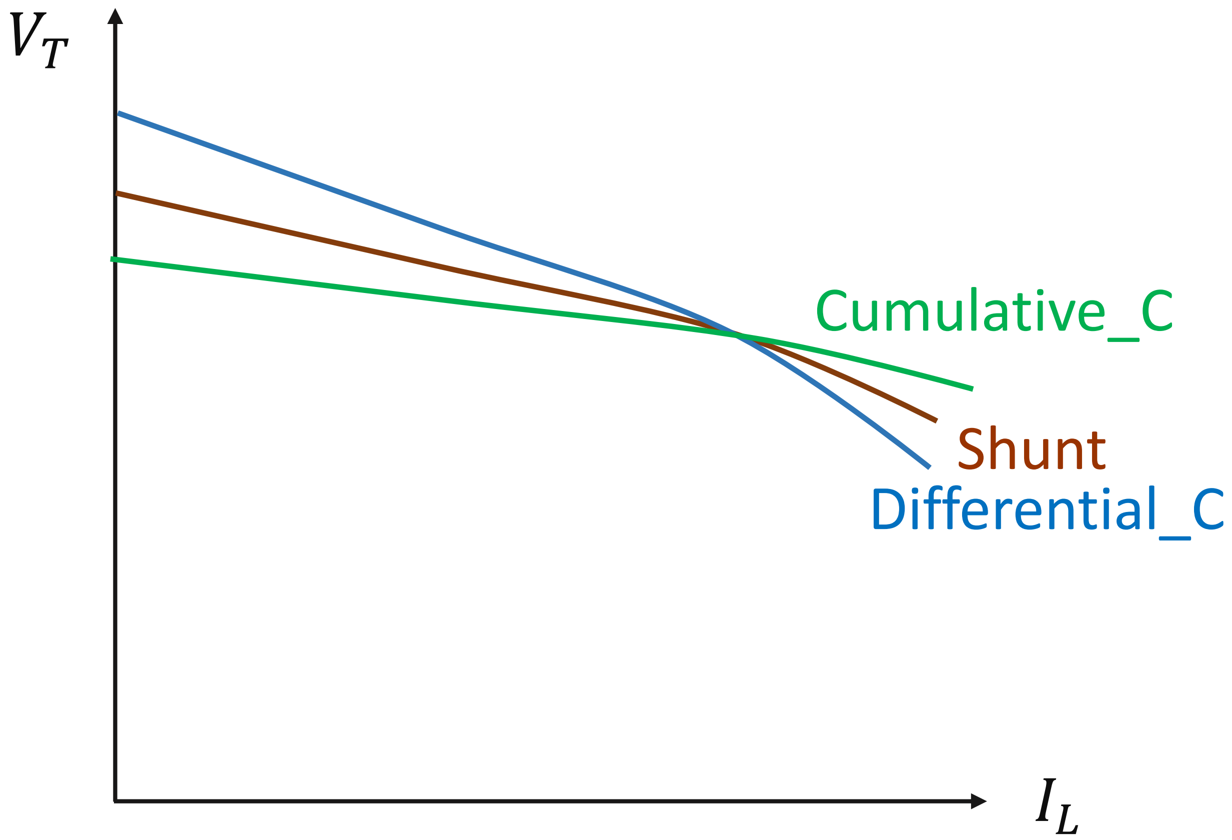
$$VR = \% \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100$$

DC generators characteristics

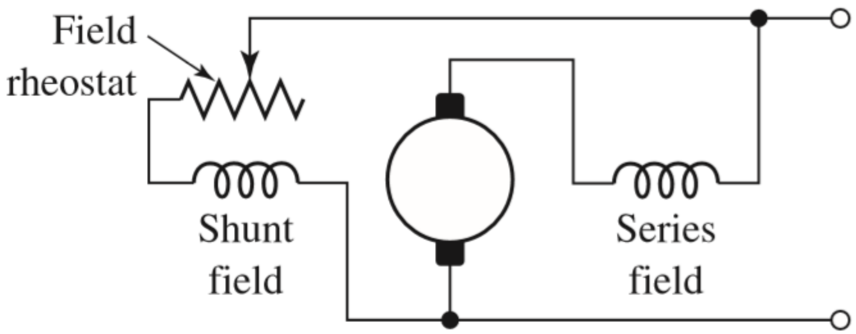


What is the output voltage V_T versus I_L?

Let ω_m is fixed.

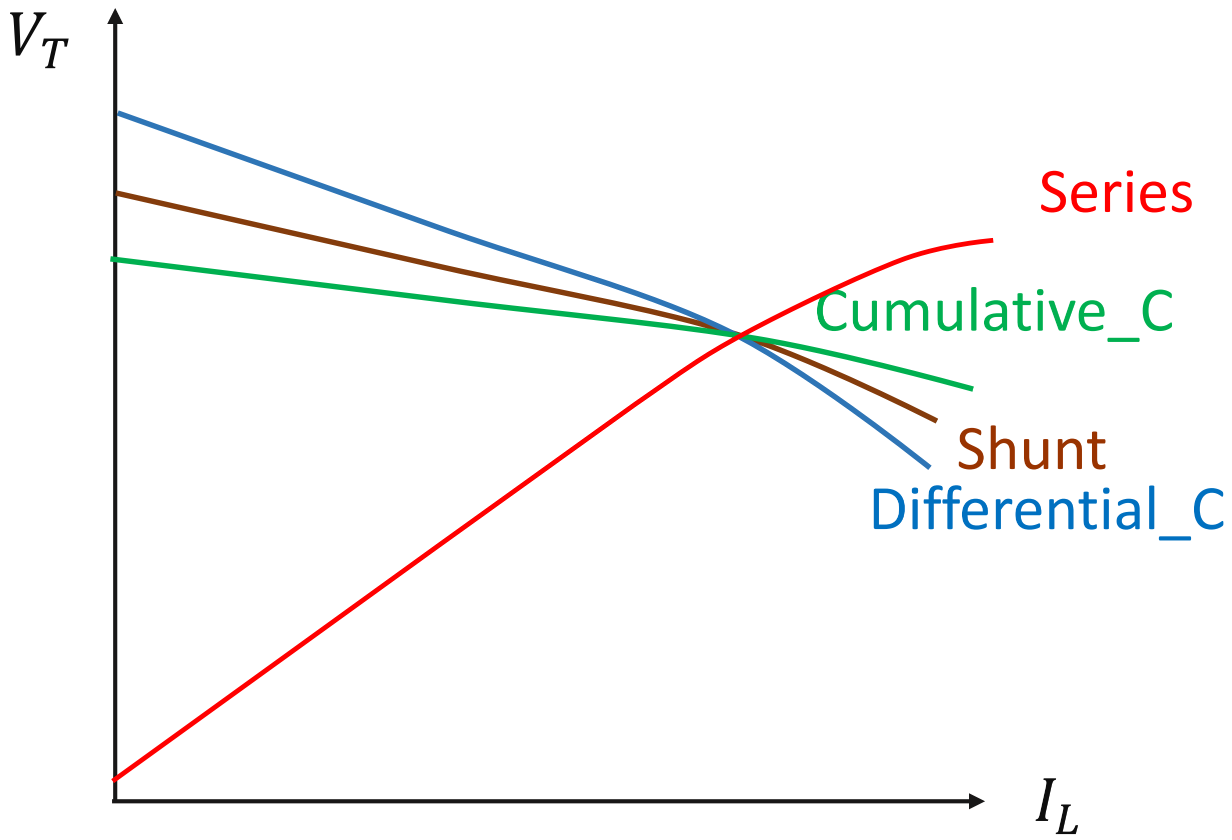


DC generators characteristics



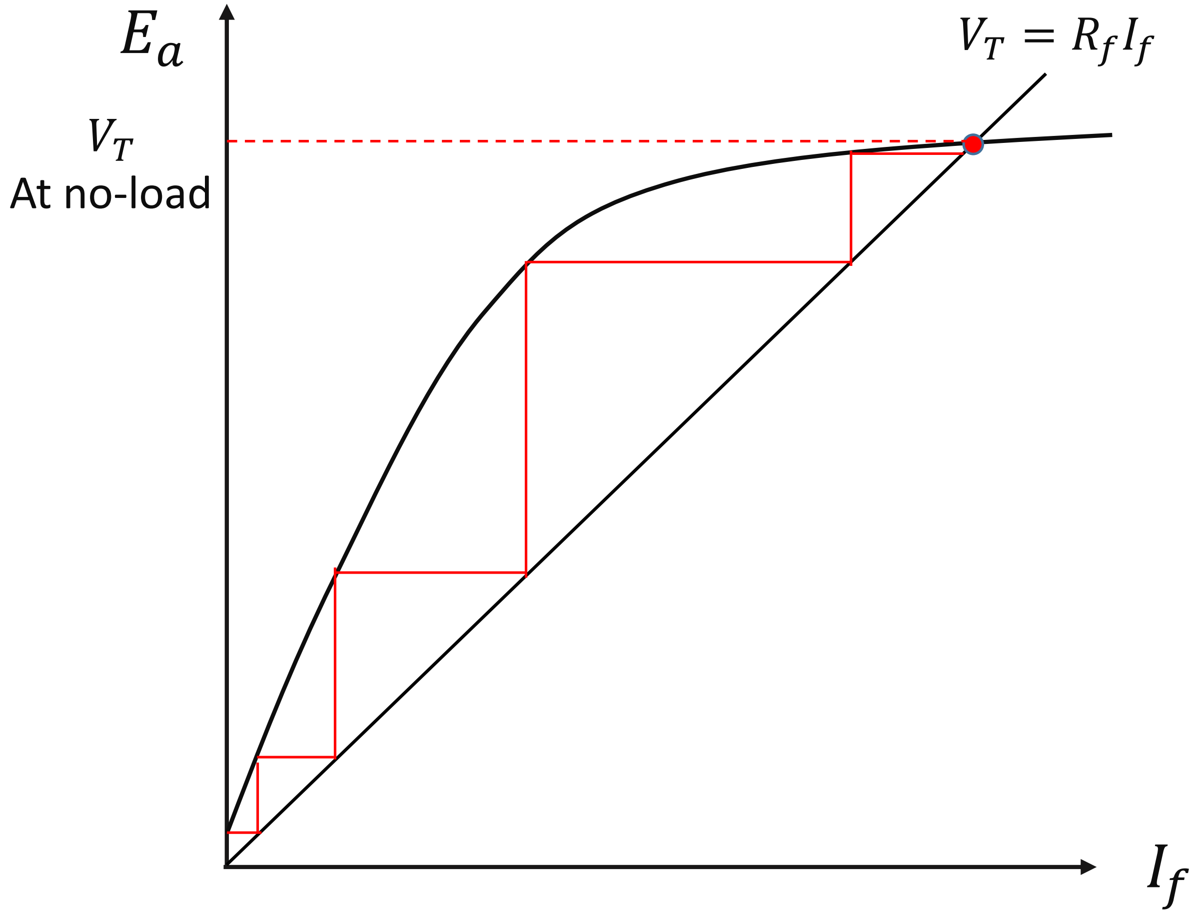
What is the output voltage V_T versus I_L?

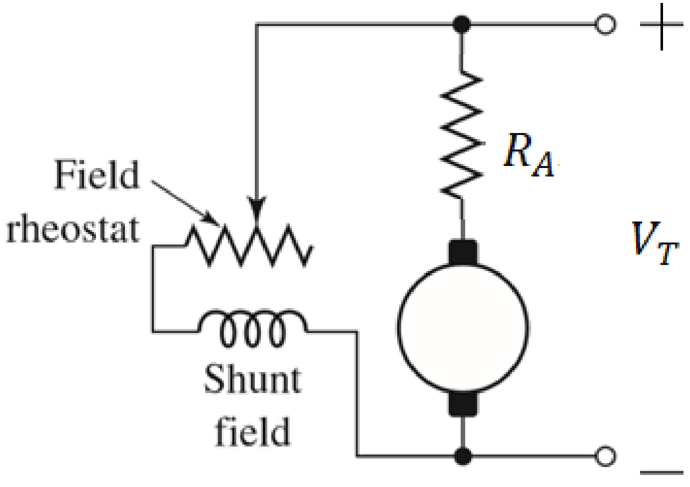
Let and ω_m is fixed.



Output voltage of a shunt generator at no load condition

What is the output voltage V_T?





Output voltage of a shunt generator at no load condition

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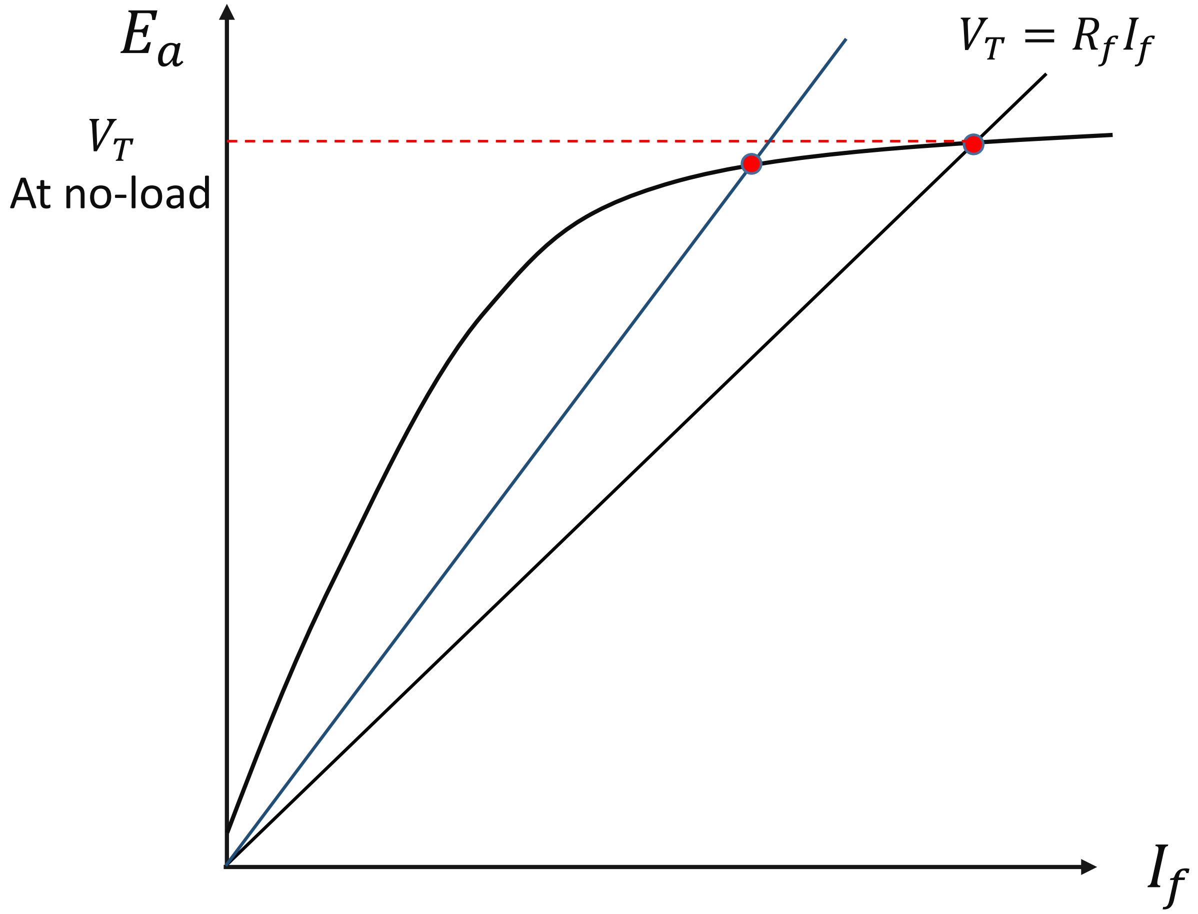
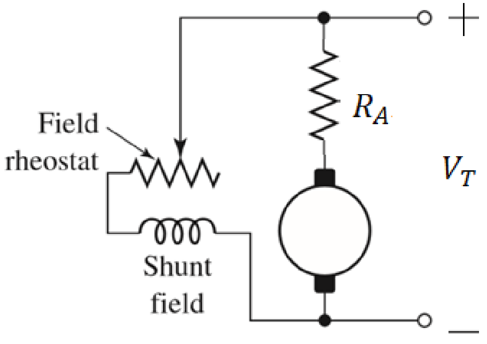


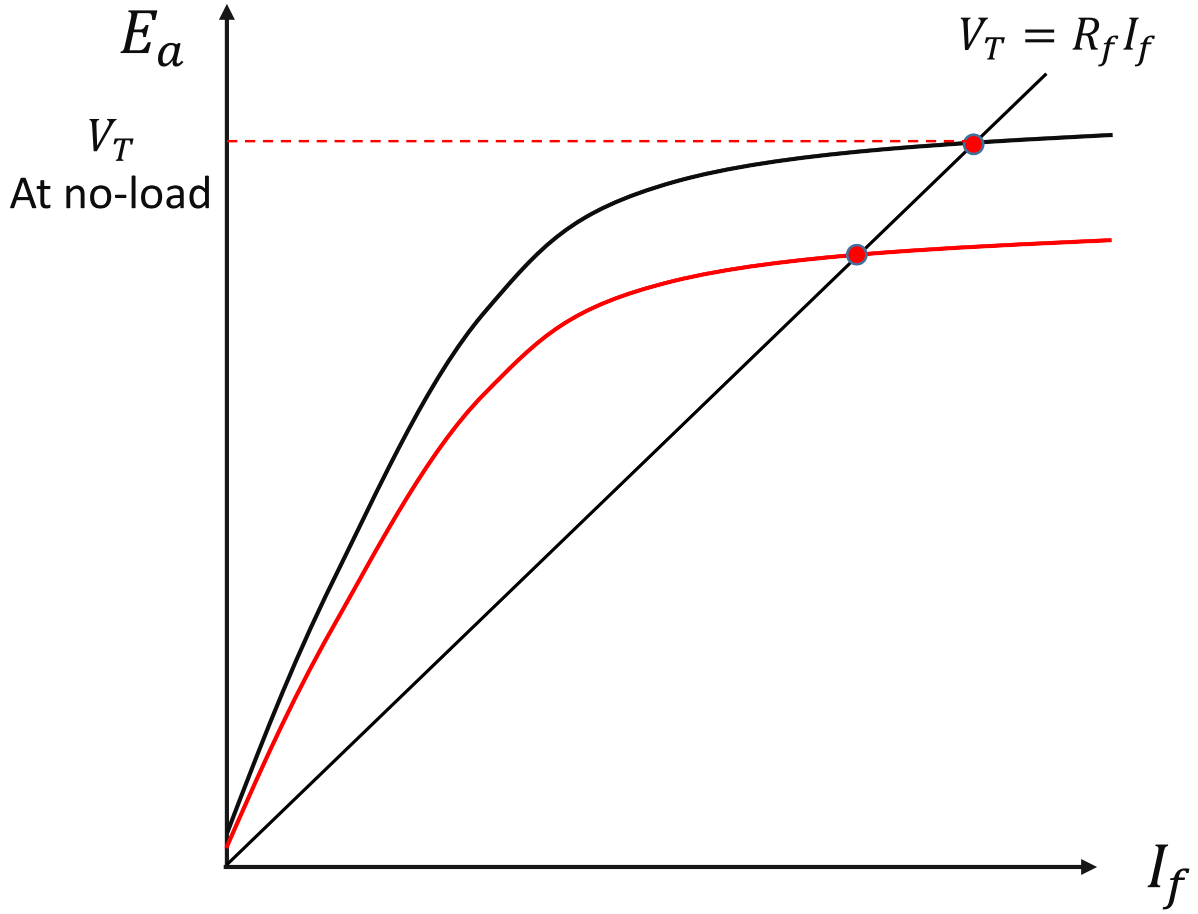


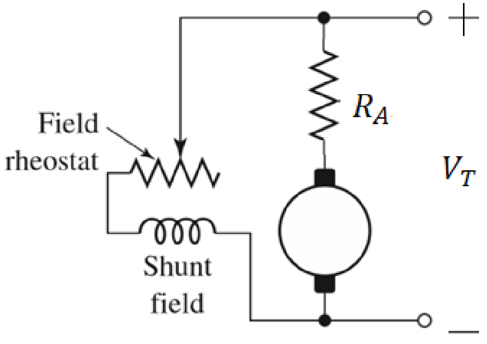
How to change no-load voltage?

- Changing the field resistance.

Output voltage of a shunt generator at no load condition

What is the output voltage V_T?



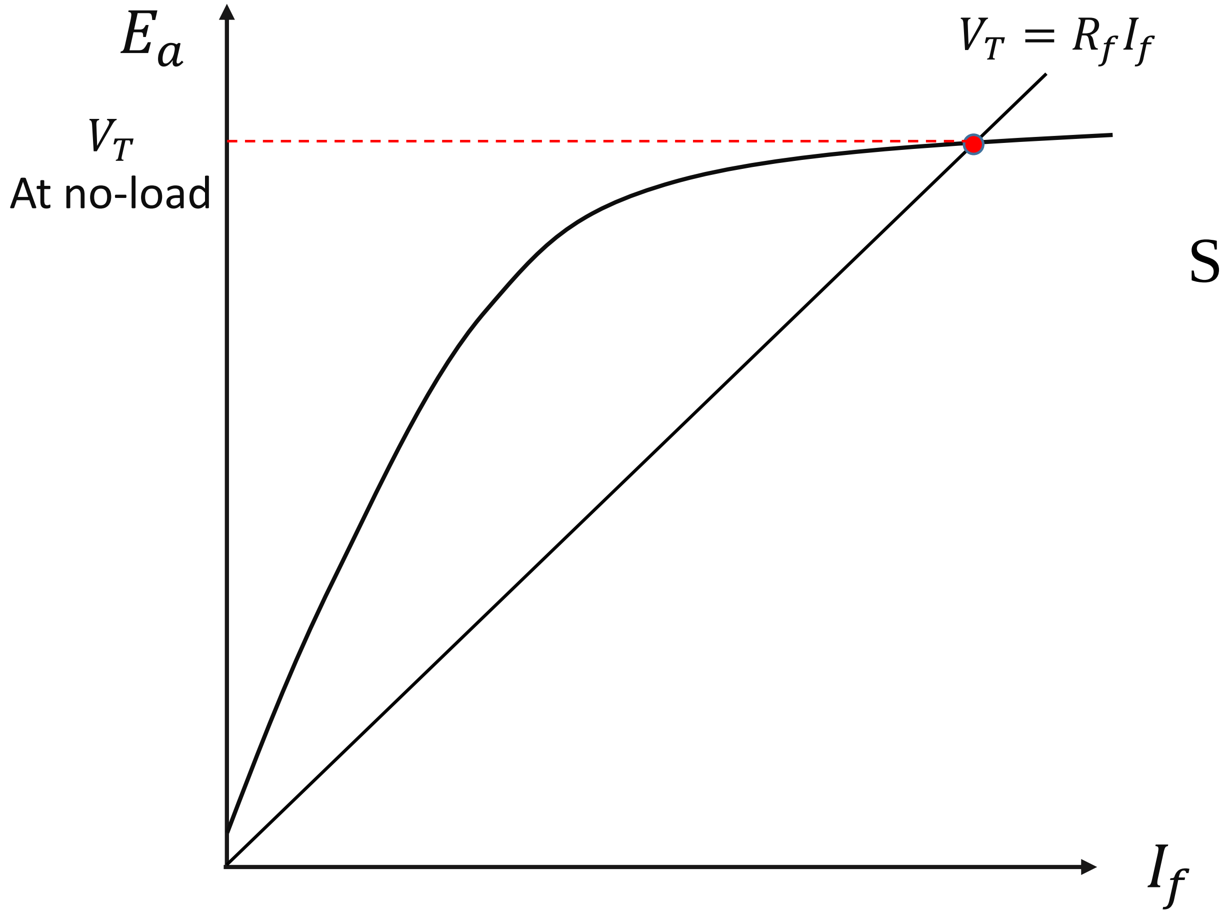


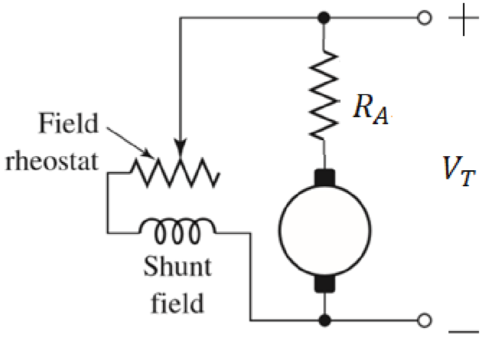
How to change no-load voltage?

- Changing the field resistance.
- Changing the speed

Output voltage of a shunt generator at no load condition

What is the output voltage V_T?



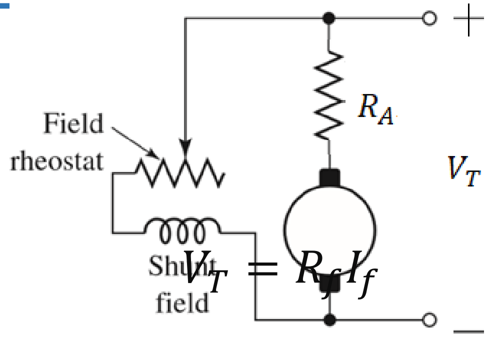


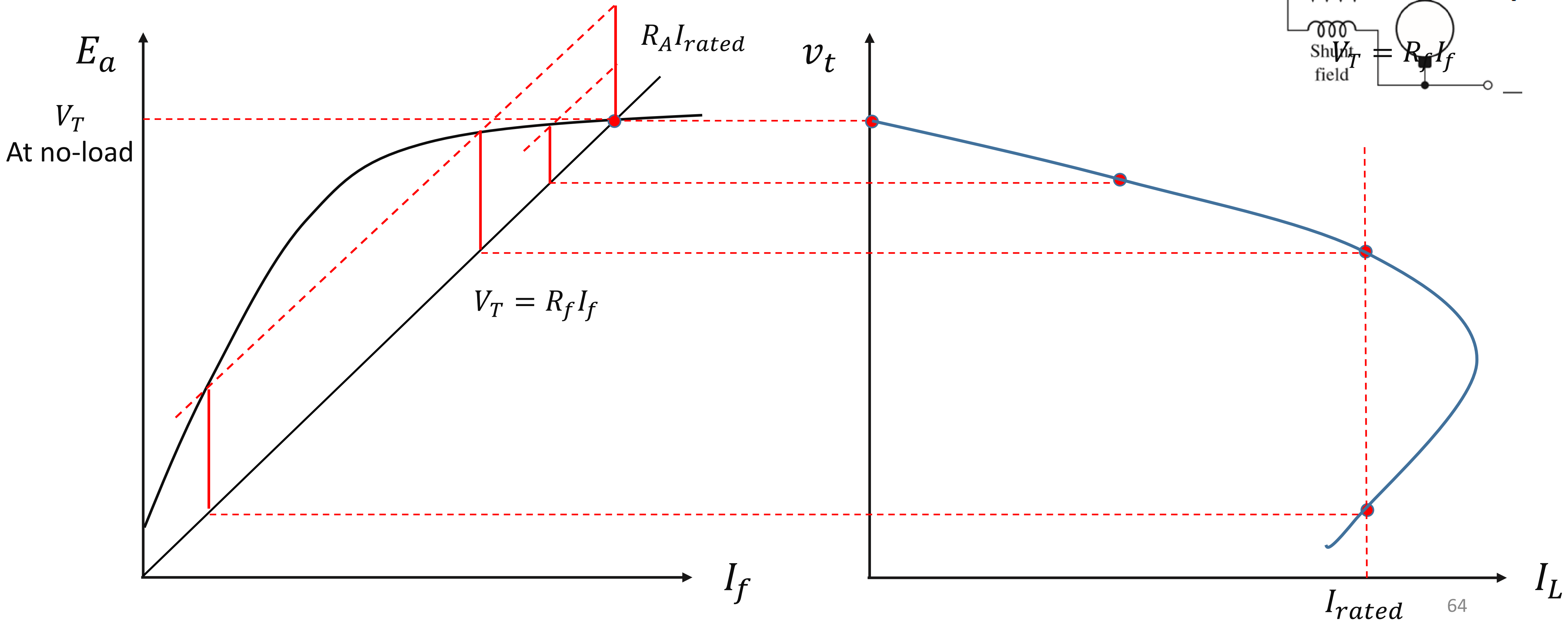
Several reasons for the voltage to fail to build up.

- No residual magnetic flux.
- Direction of rotation is reversed.
- Field resistance is bigger than critical resistance.

Volt-ampere characteristic of a shunt generator (Ignoring AR)

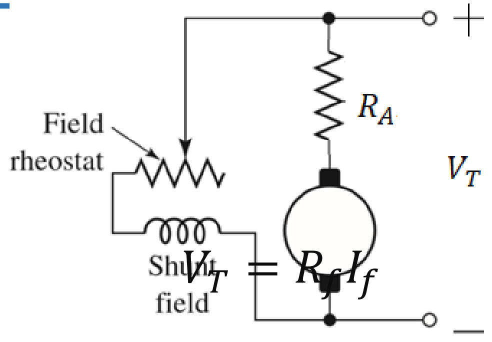
What is the output voltage V_T?

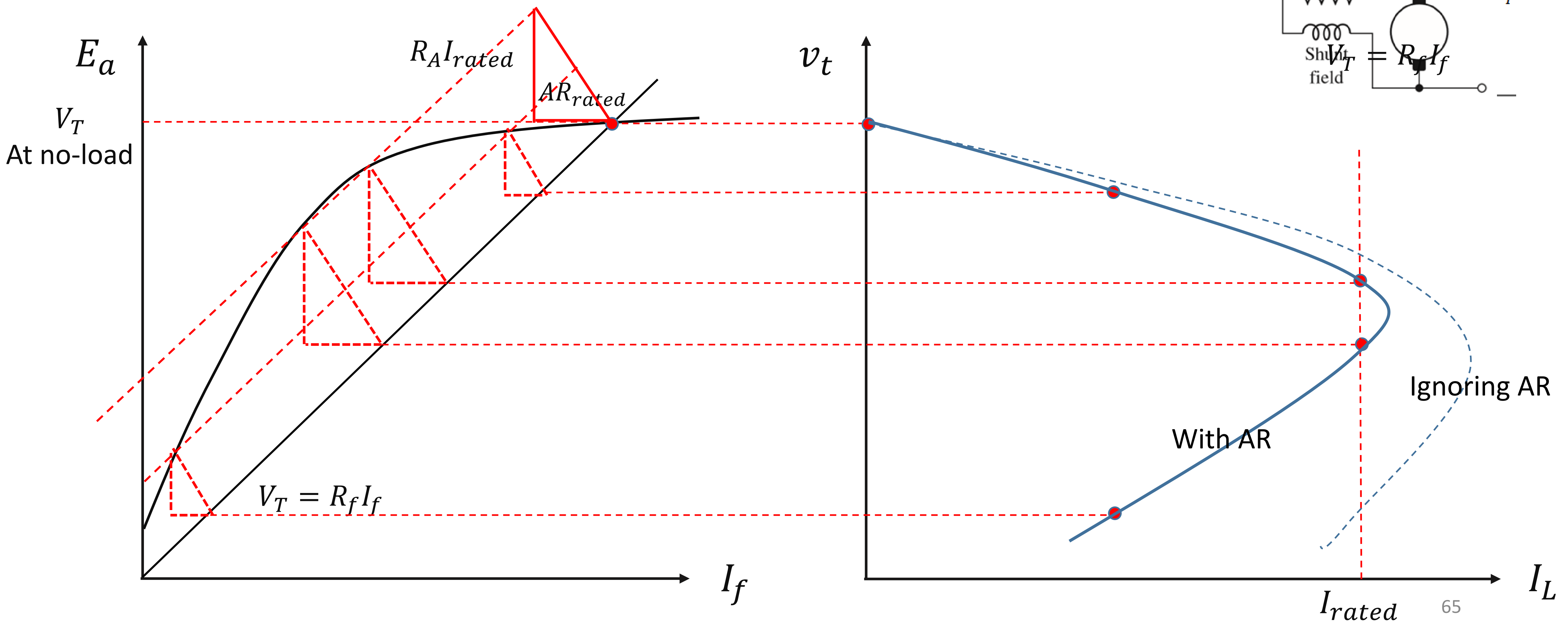




Volt-ampere characteristic of a shunt generator (With AR)

What is the output voltage V_T?





Dr. Ali Karimpour July 2024

Volt-ampere characteristic of a shunt generator (With AR)

Exercise 3 (Final Exam December 2022):

The magnetic characteristic of a 20 kW, 250 V generator at a speed of 1195 RPM is given as follows:

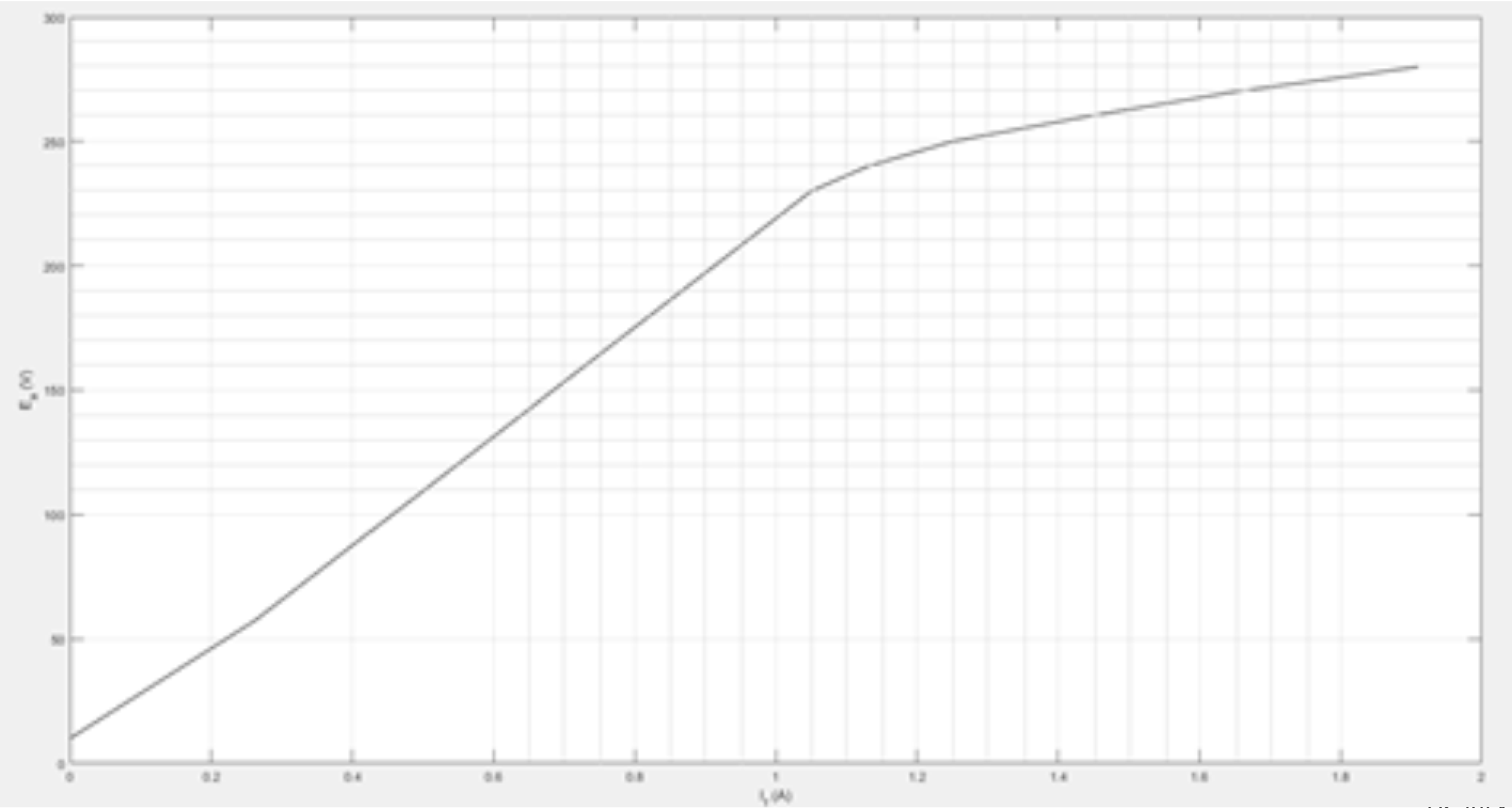
This generator is shunt-connected and produces 250 V at no load with a speed of 1195 RPM. The shunt winding has 650 turns, and the series winding has 10 turns. The armature and brush resistance is 0.15 ohms, and the series winding resistance is 0.05 ohms.

a) Determine the resistance of the shunt field winding.

b) This machine, when separately excited with a field current of 1.85 A and an armature current of 80 A at a speed of 1145 RPM, produces a voltage of 250 V. Find the armature reaction in ampere turns.

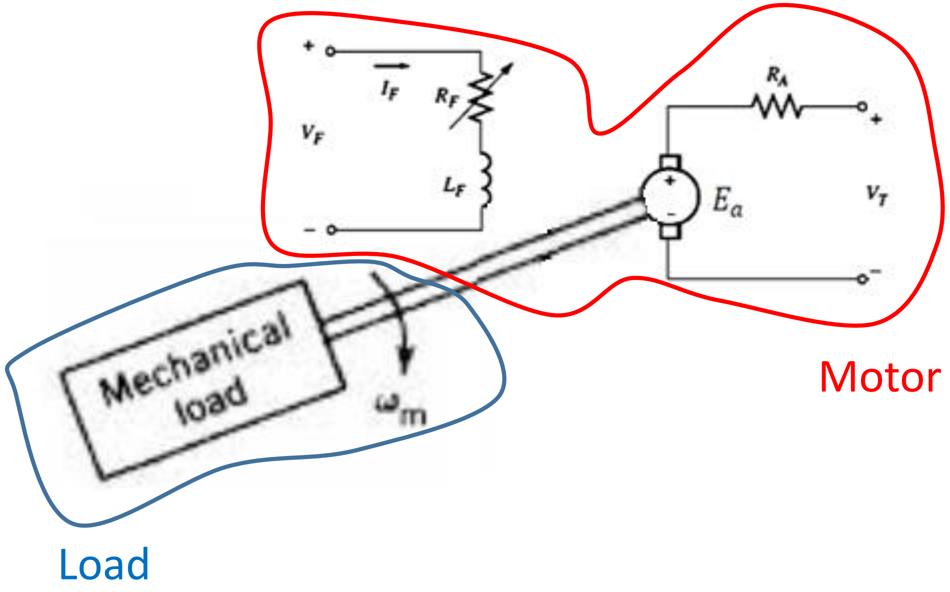
c) If we want to convert this generator to compound connection and have it produce 250 V at no load with a speed of 1195 RPM, and also produce 250 V at a load current of 80 A and a speed of 1195 RPM, what should be done? Note that you do not have access to the internal structure of the machine.

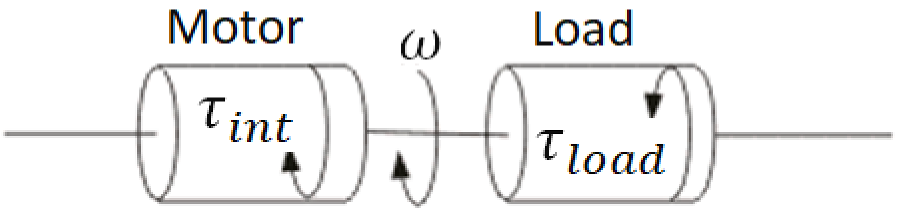
Volt-ampere characteristic of a shunt generator (With AR)



Important characteristic in DC motors

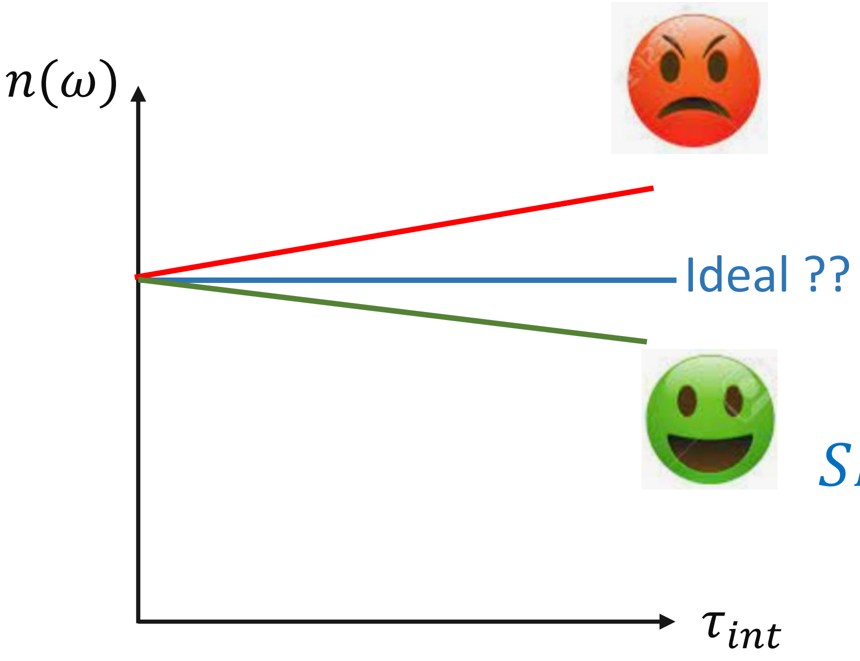
DC Motors





What is the output speed n versus internal torque τ_{int}?

Let v_t fixed.

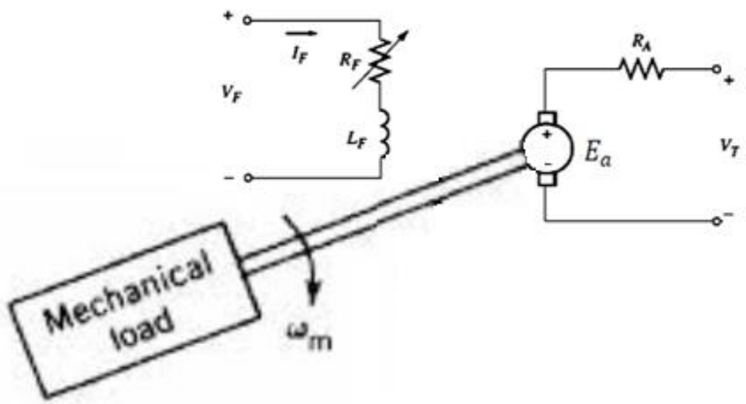


Speed regulation ??

$$SR = \%\frac{n_{nl} - n_{fl}}{n_{fl}} \times 100$$

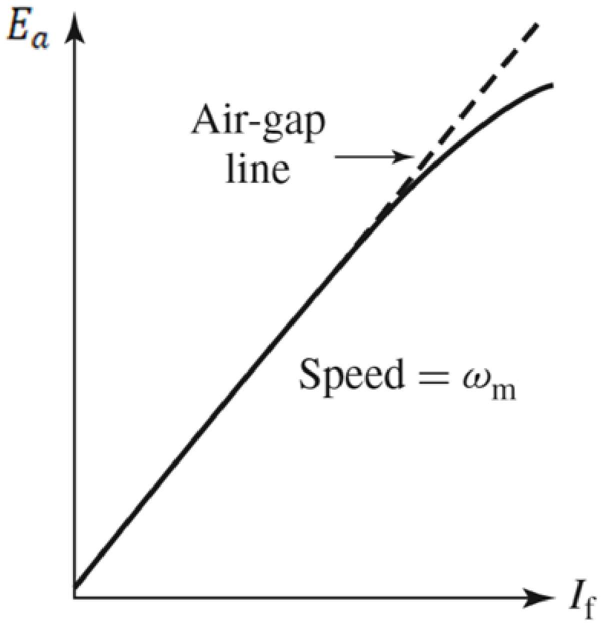
Steady-state speed-torque characteristics

DC motors characteristics

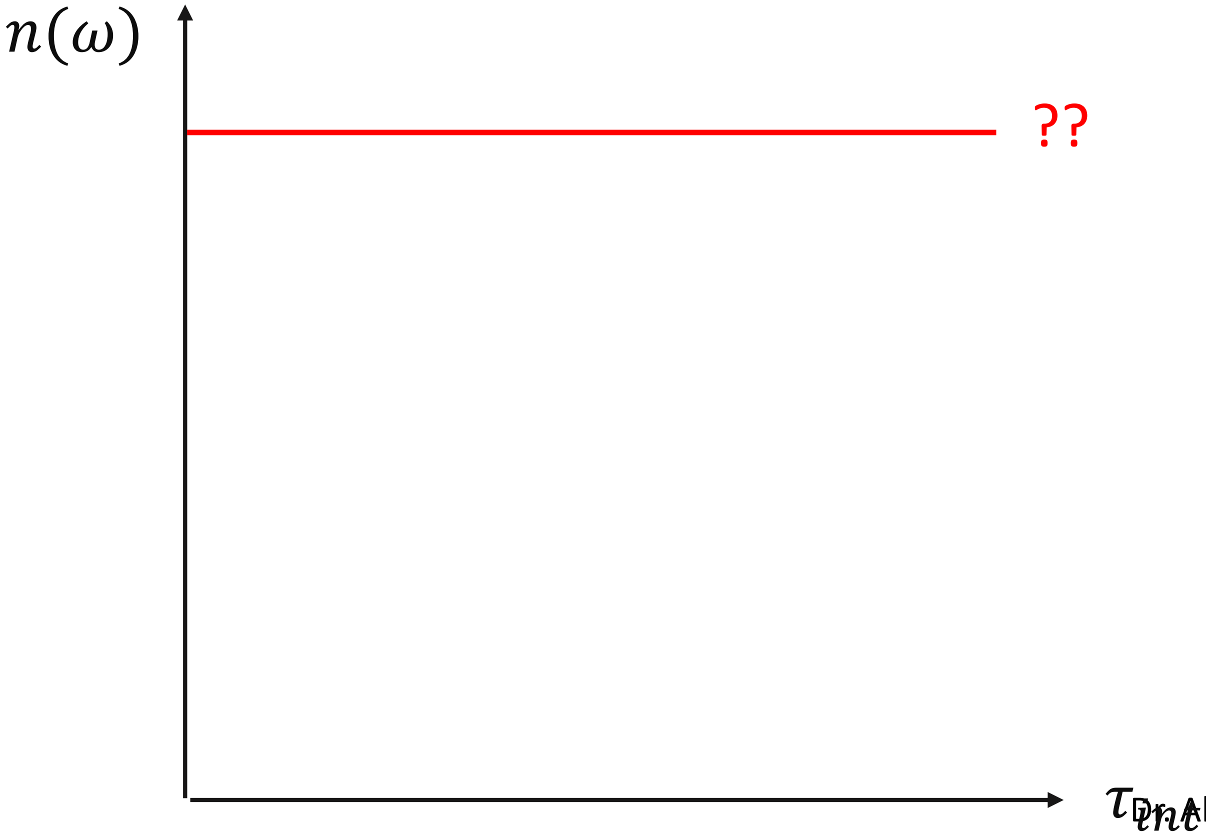


What is the output voltage $n(\omega)$ versus τ_{int}?

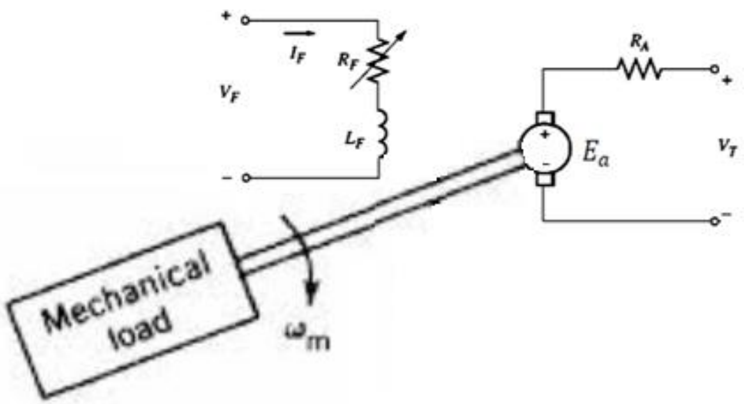
$$E_a = K_a \varphi_d \omega_m \qquad \omega_m = \frac{E_a}{K_a \varphi_d} = \frac{V_T - R_A I_a}{K_a \varphi_d} \qquad \tau_{int} = K_a \varphi_d I_a$$



magnetization curves



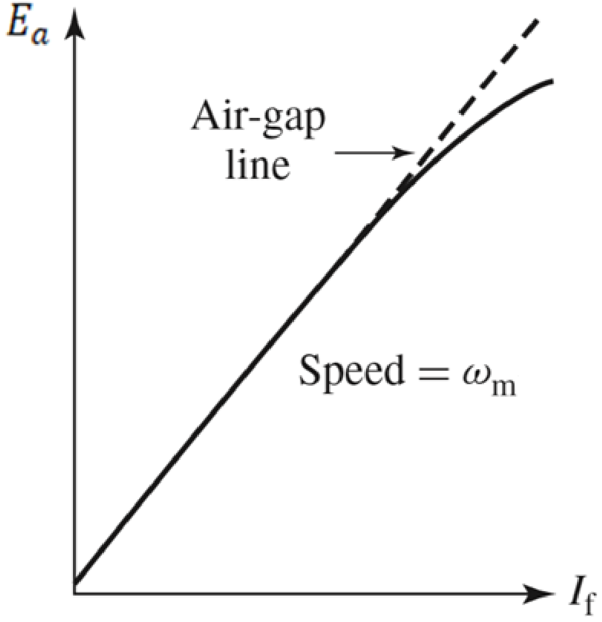
DC motors characteristics



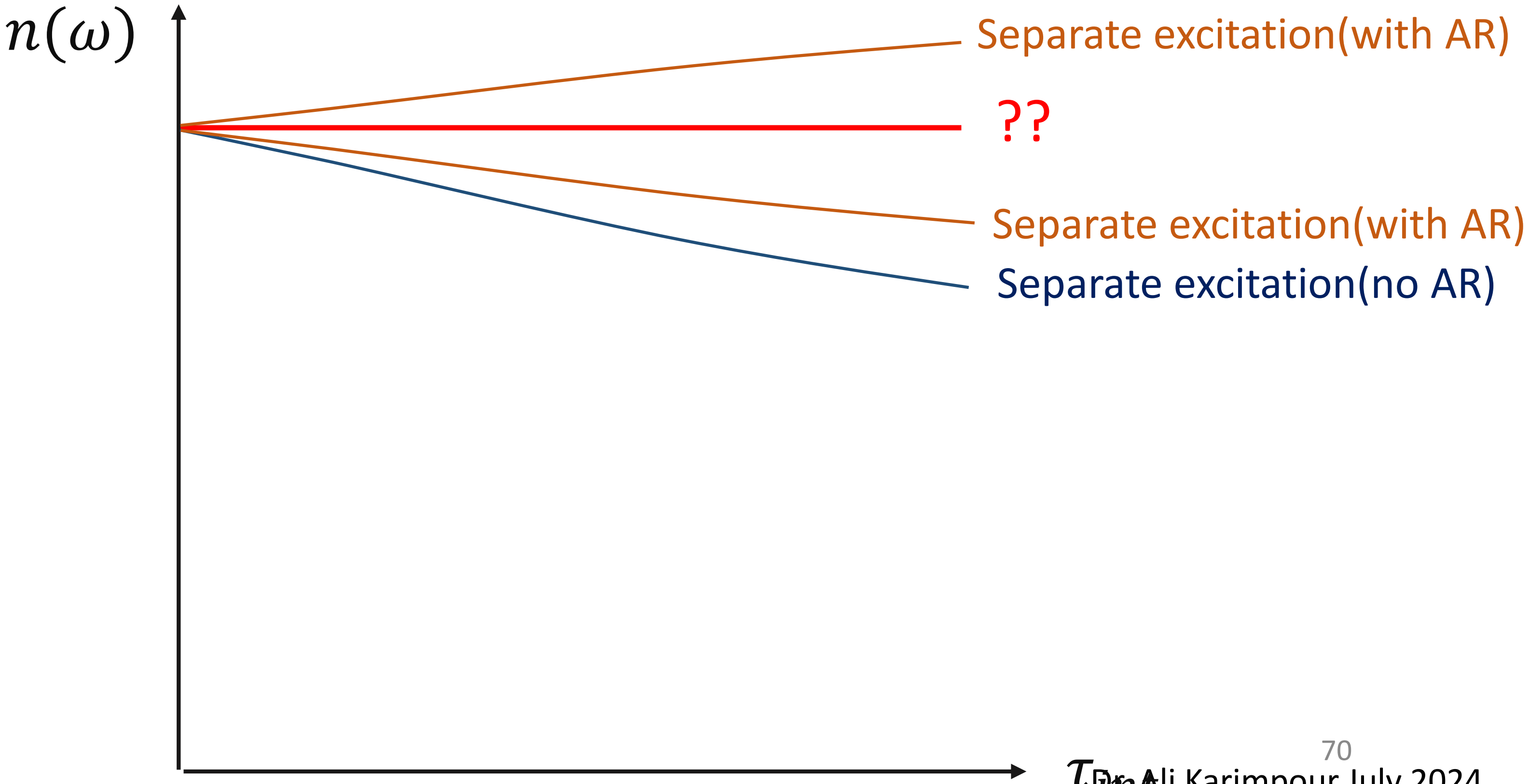
What is the output voltage $n(\omega)$ versus τ_{int}?

$$E_a = K_a \varphi_d \omega_m \qquad \omega_m = \frac{E_a}{K_a \varphi_d} = \frac{V_T - R_A I_a}{K_a \varphi_d} \qquad \tau_{int} = K_a \varphi_d I_a$$

Separate excitation



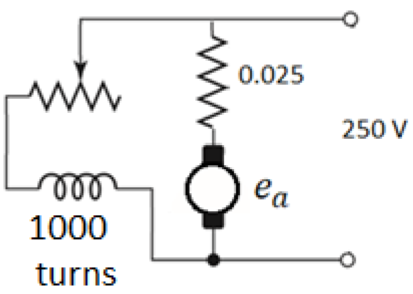
magnetization curves



DC motors characteristics

Example ٢: A 100-hp dc shunt has following magnetizing curves(including armature reaction). Armature resistance including brushes is 0.025 Ω. The field rheostat is adjusted for a no-load speed of 1100 rpm.

a) Determine the motor speed corresponding to an armature current of 400 A.



At no load(no AR):

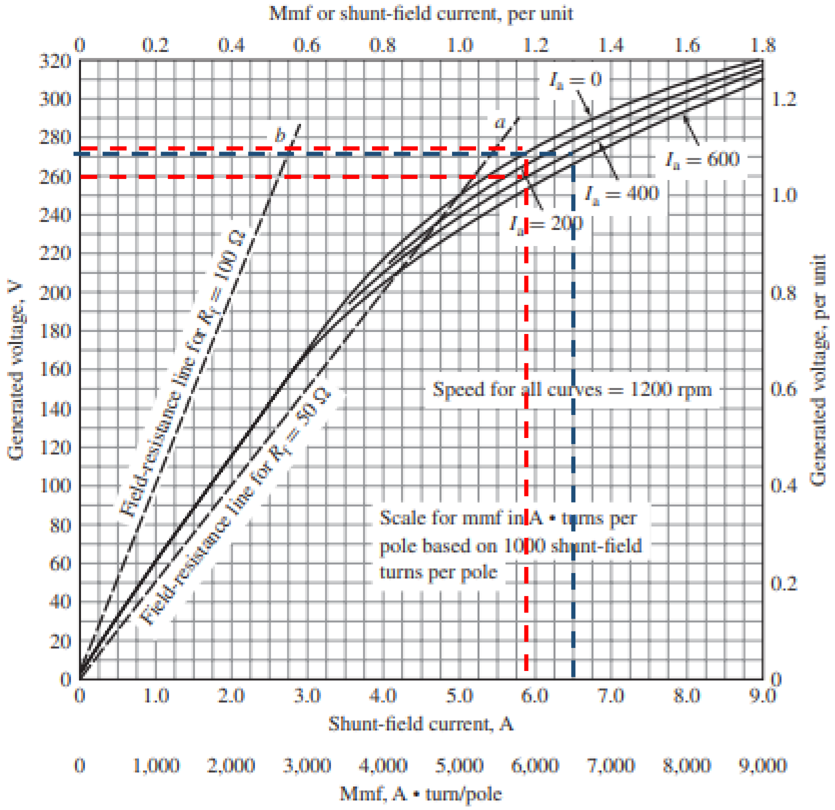
$$E_{am\_1100} = 250 \quad E_{am\_1200} = 250\frac{1200}{1100} = 273$$

$$I_f = 5.9\ A$$

At 400 A(with AR):

$$E_{am\_n} = 250 - 0.025 * 400 = 240$$

$$E_{am\_1200} = 260 \qquad \frac{n}{1200} = \frac{240}{260} \qquad n = 1107$$

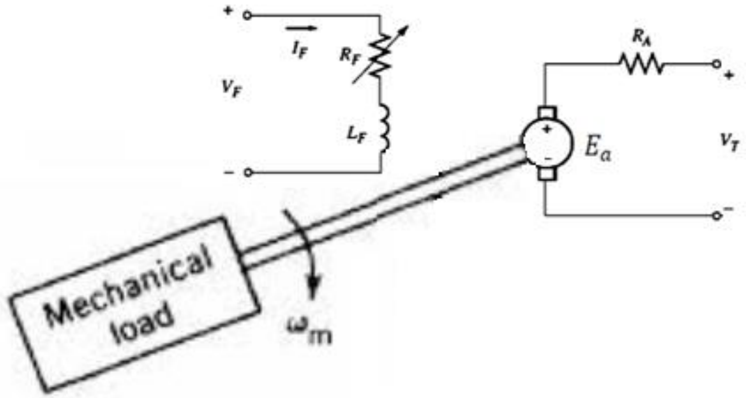


b) Why is this unacceptable? $\quad 1107 > 1100$

c) Use a 1.5 turns cumulative winding as stabilizer.?

$$I_{feff} = 5.9 + 400\frac{1.5}{1000} = 6.5\ A \qquad \frac{n}{1200} = \frac{240}{271} \qquad n = 1063$$

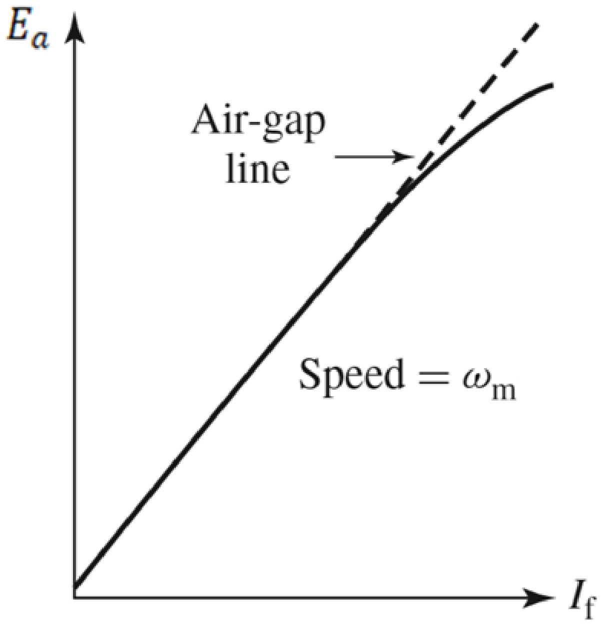
DC motors characteristics



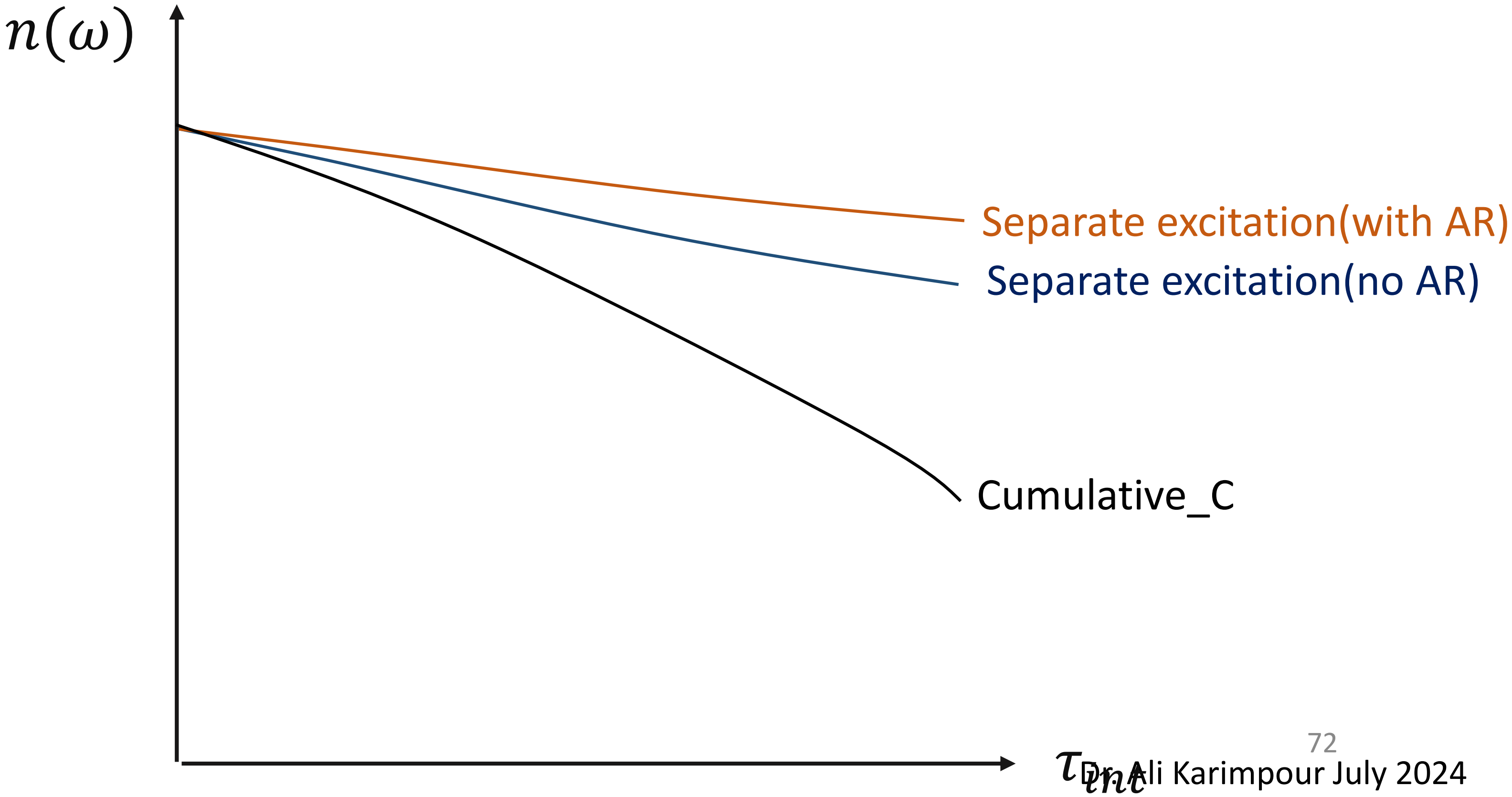
What is the output voltage $n(\omega)$ versus τ_{int}?

$$E_a = K_a\varphi_d\omega_m \qquad \omega_m = \frac{E_a}{K_a\varphi_d} = \frac{V_T - R_A I_a}{K_a\varphi_d} \qquad \tau_{int} = K_a\varphi_d I_a$$

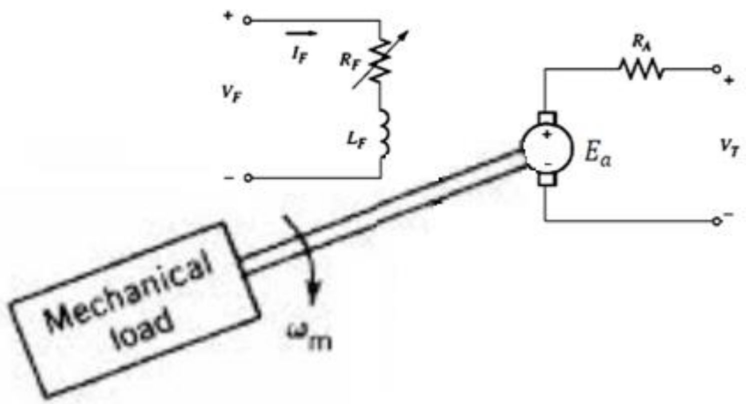
Separate excitation??



magnetization curves

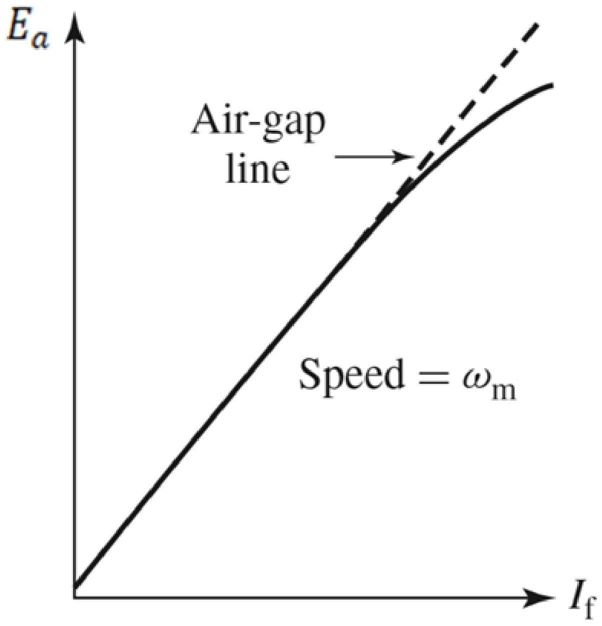


DC motors characteristics

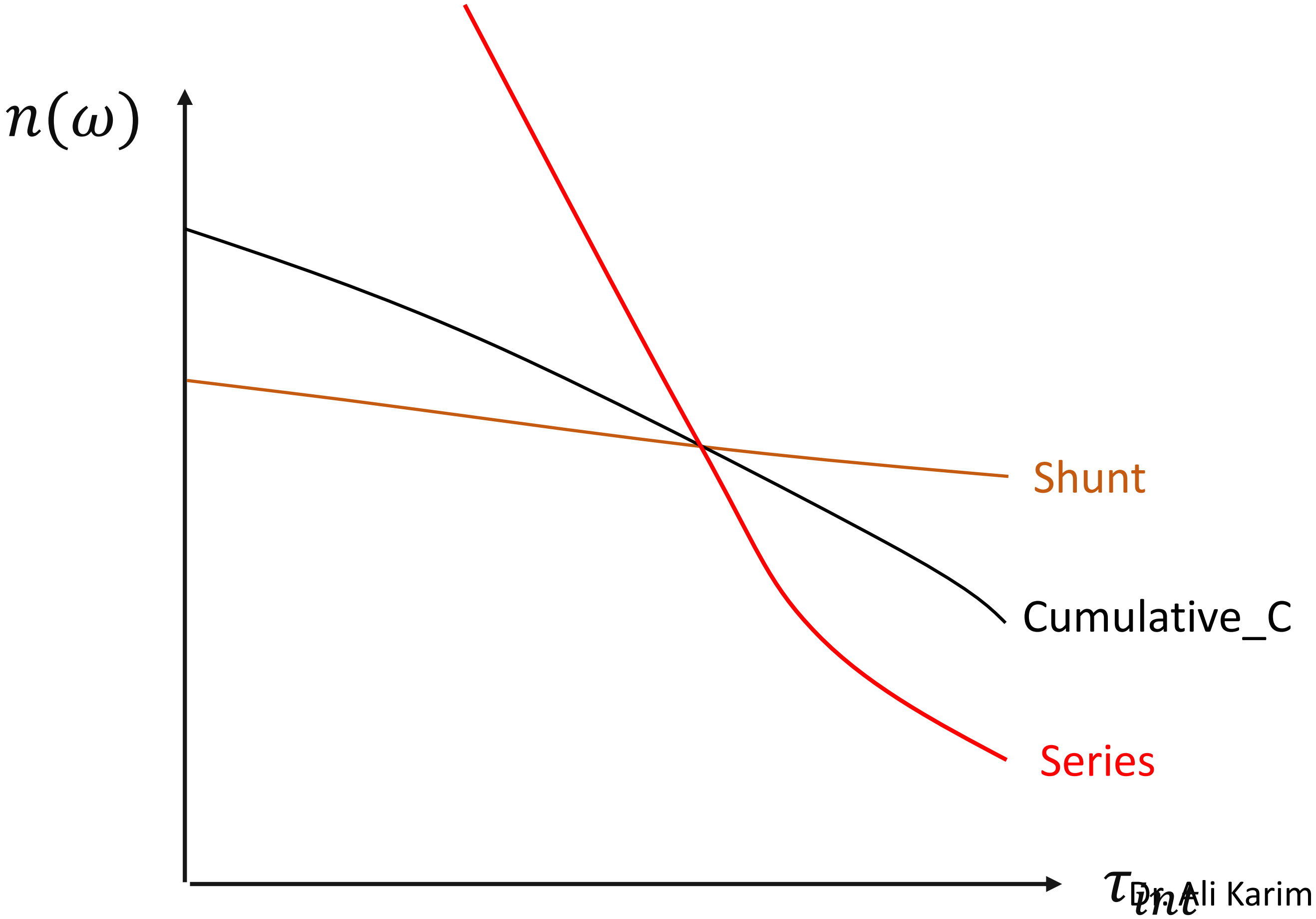


What is the output voltage $n(\omega)$ versus τ_{int}?

$$E_a = K_a \varphi_d \omega_m \qquad \omega_m = \frac{E_a}{K_a \varphi_d} = \frac{V_T - R_A I_a}{K_a \varphi_d} \qquad \tau_{int} = K_a \varphi_d I_a$$



magnetization curves



Efficiency in DC machines

DC machine losses

Different losses in electrical machines

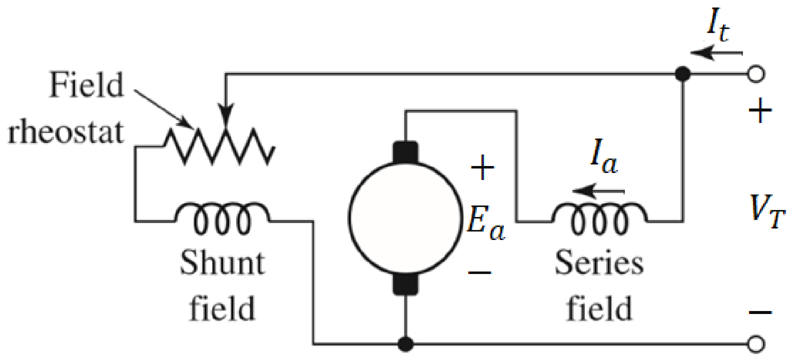
1- RI^2 Losses.

2- Core Losses(hysteresis and eddy-current).

3- Mechanical Losses(friction, windage).

4- Stray Losses(around 1% of output).

DC motors efficiency



$P_{in} = V_t I_t$

$P_{int} = E_a I_a$

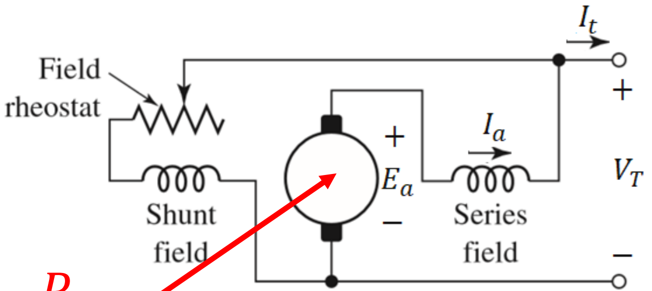
$P_{out} = \tau_{out} \omega_m$

$\eta = \frac{P_{out}}{P_{in}}$

$P_{in} = V_t I_t$

$P_{int} = \tau_{int} \omega_m$

DC generators efficiency



P_{in}

$P_{int} = E_a I_a$

$P_{out} = I_t V_t$

$\eta = \frac{P_{out}}{P_{in}}$

$P_{in} = P_{mec}$

$P_{int} = \tau_{int} \omega_m$

Rotational losses

RI^2 losses

Core losses

Mechanical losses

Stray load losses

DC motors operation

Example 3: A 120-hp, 250 v, dc shunt has the following magnetizing curves. Armature resistance including brushes is 0.025 Ω. The field rheostat is adjusted for a no-load speed of 1100 rpm. There is a 1.5 turns stabilizer winding with resistance of 0.001 Ω. The no-load rotational losses is 2000 w. Shunt winding has 1000 turns.

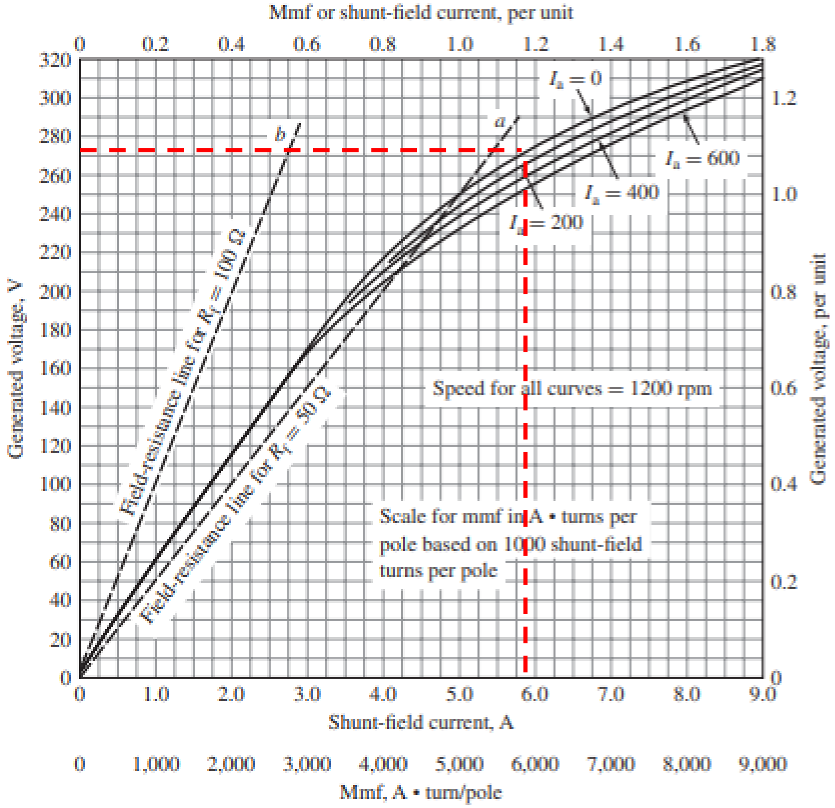
a) Determine the motor speed, output power, output torque and efficiency corresponding to an armature current of 400 A and rated terminal voltage.

At no load(no AR):

$$E_{a\_1100} = 250$$

$$E_{a\_1200} = 250\frac{1200}{1100} = 273$$

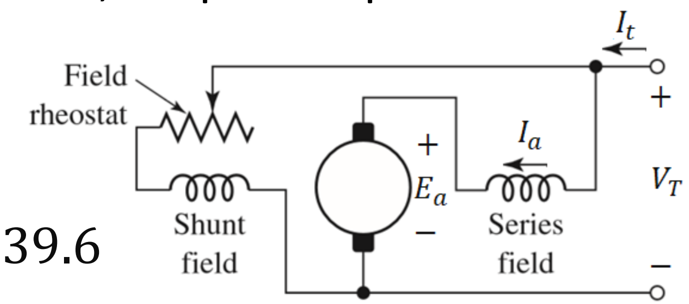
$$I_f = 5.9$$



DC motors operation

Example 3: A 120-hp, 250 V, dc shunt has the following magnetizing curves. Armature resistance including brushes is 0.025 Ω. The field rheostat is adjusted for a no-load speed of 1100 rpm. There is a 1.5 turns stabilizer winding with resistance of 0.001 Ω. The no-load rotational losses is 2000 w. Shunt winding has 1000 turns.

a) Determine the motor speed, output power, output torque and efficiency corresponding to an armature current of 400 A and rated terminal voltage.



At 400 A(with AR):

$$E_{a\_n} = 250 - (0.025 + 0.001)400 = 239.6$$

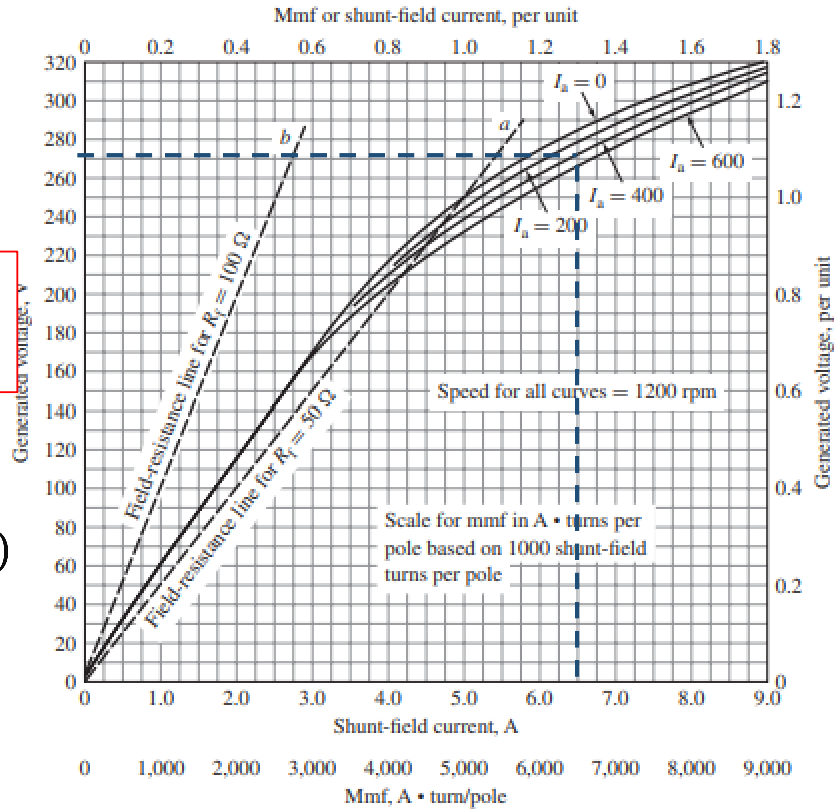
$$I_{f\_eff} = 5.9 + 400\frac{1.5}{1000} = 6.5 \quad E_{a\_1200} = 270 \quad \boxed{n = \frac{239.6}{270}1200 = 1065}$$

$$P_{in} = 250 \times (400 + 5.9) = 101475 \text{ w}$$

$$P_{int} = 101475 - 250 \times 5.9 - 0.026 \times 400^2 = 95840 \text{ w} \quad (E_a I_a = 400 \times 239.6)$$

$$P_{out} = 95840 - 2000 - 0.01P_{out} \qquad \boxed{P_{out} = 92910}$$

$$\boxed{\tau_{out} = \frac{92910}{2\pi 1065/60} = 833.5\ n-m} \qquad \boxed{\eta = \frac{92910}{101475} = \%91.6}$$



- **Speed Control of DC Motors**

Speed control of DC motors

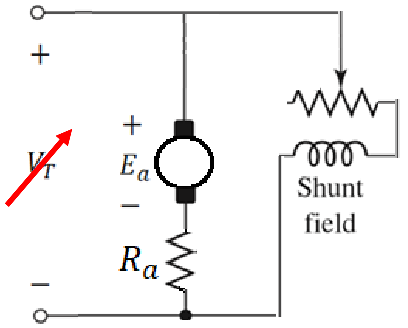
What is the method of speed control?

$$E_a = K_a \varphi_d \omega_m$$

$$\omega_m = \frac{E_a}{K_a \varphi_d} = \frac{V_T - R_A I_a}{K_a \varphi_d}$$

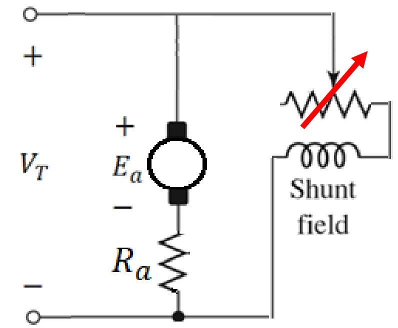
a) Control of terminal voltage.

pros and cons ??



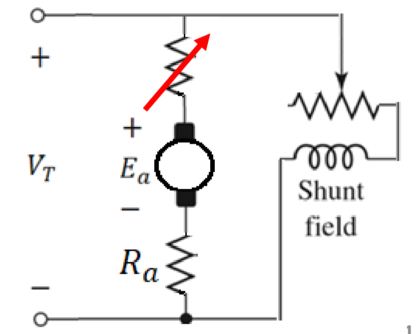
b) Flux control.

pros and cons ??



c) Control of R_a

pros and cons ??



DC motors operation

Example 4: A shunt-connected, 75-kW, 250-V dc motor has an armature resistance of 45 mΩ and a field resistance of 185 Ω. When operated at 250 V, its no-load speed is 1850 r/min(Ignore the armature reaction, stray losses and rotational losses).

a) The motor is operating under load at a terminal voltage of 250 V and a terminal current of 290 A. Calculate (i) the motor speed in r/min, (ii) the load power in kW, and (iii) the load torque in N·m.

b) Assuming the load torque remains constant as a function of speed at the value calculated in part (a), calculate (i) the motor speed and (ii) the terminal current if the terminal voltage is reduced to 200 V.

c) Repeat part (b) if the load torque of part (a) varies with the square of the speed.

DC motors operation

Example 4: A shunt-connected, 75-kW, 250-V dc motor has an armature resistance of 45 mΩ and a field resistance of 185 Ω. When operated at 250 V, its no-load speed is 1850 r/min(Ignore the armature reaction).

a) The motor is operating under load at a terminal voltage of 250 V and a terminal current of 290 A. Calculate (i) the motor speed in r/min, (ii) the load power in kW, and (iii) the load torque in N·m.

b) Assuming the load torque remains constant as a function of speed at the value calculated in part (a), calculate (i) the motor speed and (ii) the terminal current if the terminal voltage is reduced to 200 V.

c) Repeat part (b) if the load torque of part (a) varies with the square of the speed.

a) At no load $E_{a\_1850} = 250\ V$

$$E_{a\_n} = 250 - (0.045)(290 - \frac{250}{185}) = 237$$

$$\frac{E_{a\_n}}{E_{a\_1850}} = \frac{n}{1850}$$

$n = 1754$ r/min

$$P_{load} = P_{out} = E_{a\_n}.I_a = 68715\ W$$

$$\tau_{out} = \frac{P_{out}}{\omega_m} = \frac{68715}{2\pi\frac{1754}{60}} = 374.3\ N.m$$

b) $\tau_{out} = 374.3\ N.m$

c) $\tau_{out} = ?$

Electrical Machine II Syllabus

1. Introduction

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2. Introduction to Rotating Machines

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3. DC Machines
    - Commutator Action
    - Analytical Fundamentals
    - Electric-Circuit Aspects
    - Effect of Armature MMF (Armature reaction, Commutation and Interpoles and Compensating Windings)
    - Steady-State DC Machine Performance
    - Permanent-Magnet DC Machines
    - Series Universal Motors
    - DC Motor starting
4. Induction Machines

….

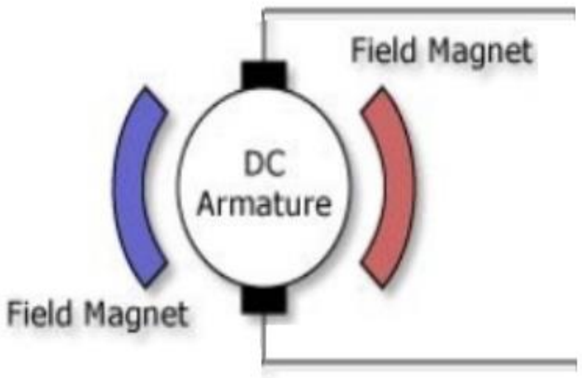
….

Permanent-Magnet DC Machines

Field excitation in DC machines

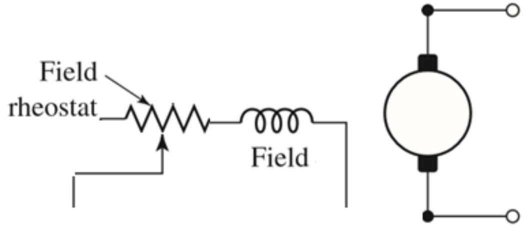
Field energizing ?

1-PM DC machines

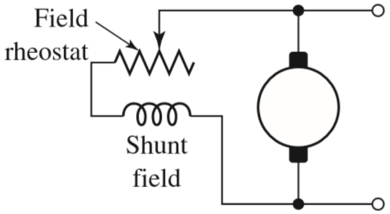


- They are available in a wide variety of low-power applications.
- Simpler construction.
- not require external excitation, so no power dissipation.
- power dissipation
- May be Less space required for the permanent .
- PM machines may be smaller, and in some cases cheaper.

2- Separate excitation DC machines



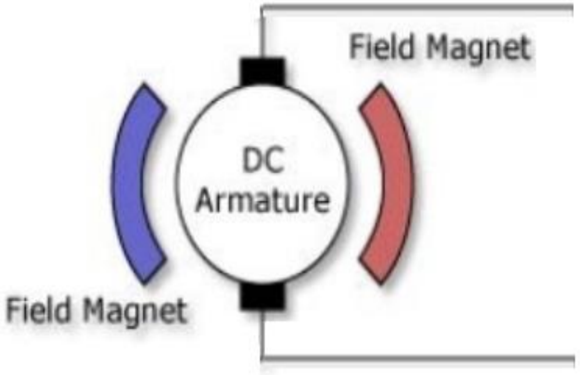
3- Self excitation DC machines



Permanent-magnet DC machines

1-PM DC machines

$$E_a = K_a \varphi_d \omega_m \quad = K_m \omega_m$$



$$\tau_{int} = K_a I_a \varphi_d \quad = K_m I_a$$

DC motors operation

Example 5: A permanent-magnet dc motor is known to have an armature resistance of 1.03 Ω. When operated at no load from a dc source of 50 V, it is observed to rotate at a speed of 2100 r/min and to draw a current of 1.25 A. Find

(a) the torque constant K_m

(b) the no-load rotational losses of the motor, and

(c) the power output of the motor when it is operating at 1700 r/min from a 48-V source.

a) At no load $E_a = 50 - 1.25 \times 1.03 = 48.7\ V$

$$\omega_m = 2\pi \frac{2100}{60} = 219.8\ rad/s \qquad K_m = \frac{48.7}{219.8} = 0.22$$

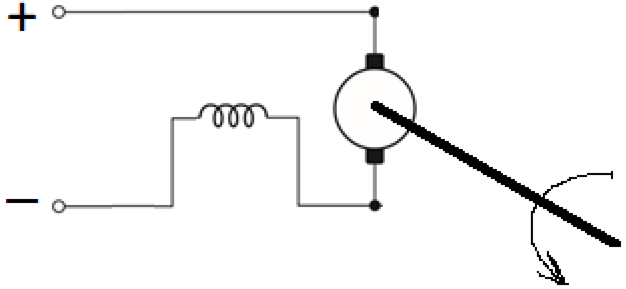
b) $Rotational\_losses = E_a I_a = 61\ w$

c) $E_a = K_m \omega_m = 0.22 \times 2\pi \frac{1700}{60} = 39.2\ V \qquad I_a = \frac{V_t - E_a}{R_a} = 8.54\ A$

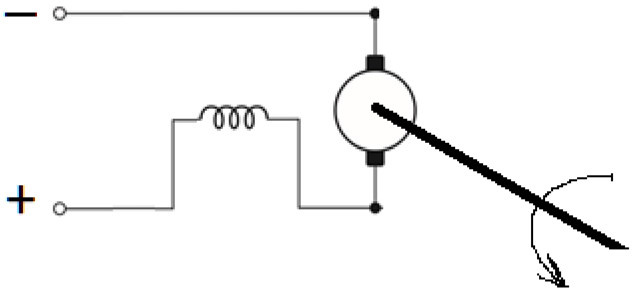
$$P_{out} = E_a I_a - Rotational\_losses = 39.2 \times 8.54 - 61 = 274\ w$$

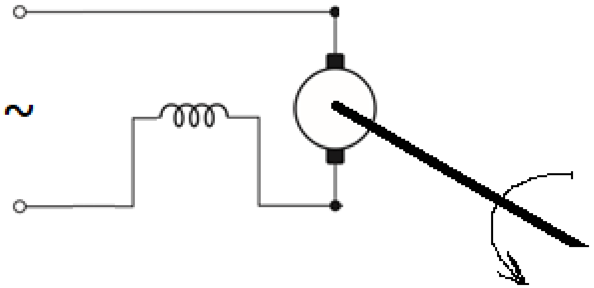
Universal Motors

Universal machines



$$\tau_{int} = K_a I_a \varphi_d = K I_a^2$$





$$\tau_{int} = K_a I_a \varphi_d = K I_a^2 = K I_m^2 sin\omega t^2$$

$$= 0.5 K I_m^2 (1 - \cos 2\omega t)$$

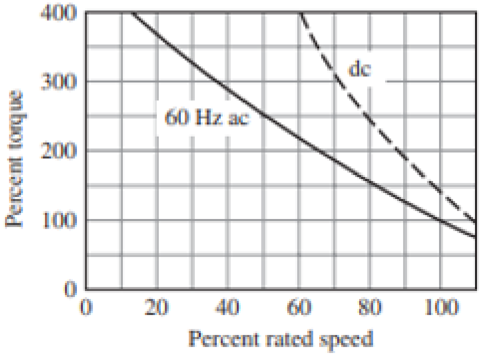
In universal motors both stator and rotor are laminated.

There is a pulsate torque at twice line frequency.

Universal machines

The ac and dc characteristics differ somewhat for two reasons:

(1) Due to inductances
(2) Saturation at peak of current.



The universal motor provides the highest horsepower per dollar in the fractional-horsepower range, at the expense of noise, relatively short life, and high speed.

Small universal motors are used where light weight is important, as in vacuum cleaners, kitchen appliances, and portable tools, and usually operate at high speeds (1500 to 15,000 r/min).

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….

….

Starting of DC Motors

Starting of a DC motor

Exercise 4: A 12.5-kW, 230-V shunt motor has 2400 shunt-field turns per pole, an armature resistance (including brushes) of 0.18 , and a commutating-field resistance of 0.035 . The shunt-field resistance (exclusive of rheostat) is 375 .

When the motor is operated at no load with rated terminal voltage and varying shunt-field resistance, the following data are obtained:

Speed, r/min	1665	1704	1743	1782	1821	1860
I_f, A	0.555	0.517	0.492	0.468	0.447	0.432

The no-load armature current is negligible. When the motor is operating at full load and rated terminal voltage with a field current of 0.468 A, the armature current is 58.2 A and the speed is 1770 r/min.

a. Calculate the full-load armature reaction in equivalent demagnetizing ampere-turns per pole.

b. Calculate the electromagnetic and load torques and the rotational loss at the given operating condition.

c. What starting torque will the motor produce with a field current of 0.555 A if the starting armature current is limited to 85 A? Assume that the armature reaction under these conditions is equal to 175 ampere-turns per pole.

d. Design a series field winding to give a speed of 1575 r/min when the motor is loaded to an armature current of 58.2 A and when the shunt field current is adjusted to give a no-load speed of 1800 r/min. Assume the series field will have a resistance of 0.045 .

Starting of a DC motor

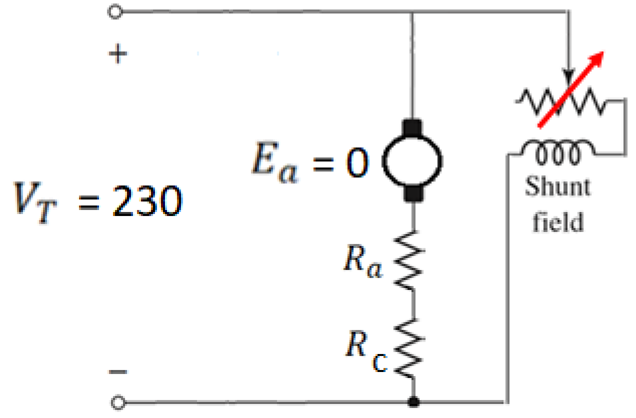
A 12.5-kW, 230-V shunt motor has 2400 shunt-field turns per pole, an armature resistance (including brushes) of 0.18 , and a commutating-field resistance of 0.035 . The shunt-field resistance (exclusive of rheostat) is 375 .

In previous example we saw that the nominal current was about 58.2 A.

What is the starting current if we apply 230 V directly on the motor?

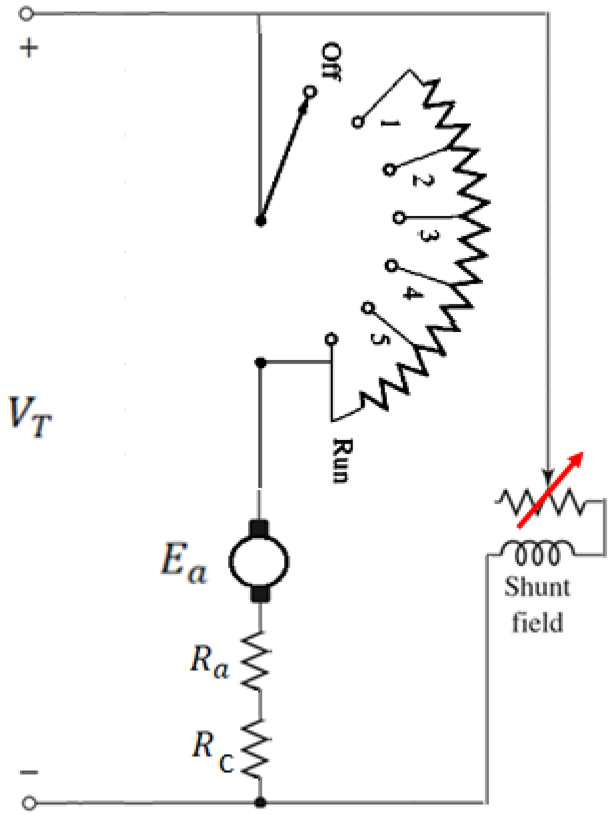
$$I_a = \frac{230}{0.18 + 0.035} = 1070\ A$$

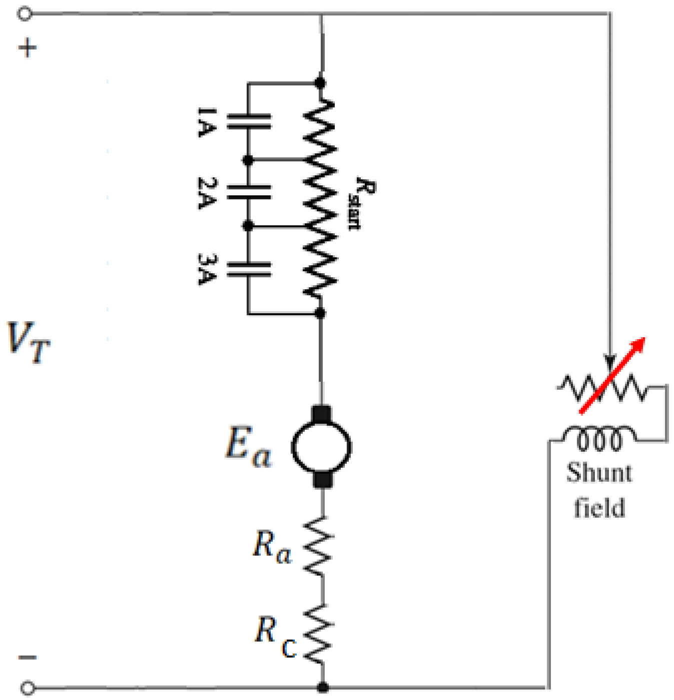
??!!



We must do something to manage the problem.

Starting of a DC motor





Starting of a DC motor