EEP 225 Electric Machines Cheat Sheet [1]
DC Machines

1 Magnetic Field

Magnetic fields are the fundamental mechanism by which energy is converted from one form to another in motors, generators, and transformers.

To generate magnetic field:

- A wire carrying current produces magnetic field around it (right hand rule)
- AC current → time changing magnetic field → induces a voltage in a coil of wire if the field passes through the wire (basis of transformer)
- Magnetic field passes through a wire → force induced on it (basis of motor action) (Fleming left hand rule)
- Moving wire in the presence of magnetic field → voltage induced in it (basis of generator action) (Fleming right hand)

Faraday's law :

$$\text{emf} = -N\frac{\Delta\phi}{\Delta t} \tag{1}$$

emf : inducted voltage
N : number of turns
$\Delta\phi$: change in magnetic flux
Δt : change in time

$$F = BIL\sin(\theta) \tag{2}$$

F : force
B : magnetic flux density
I : current
L : length of the conductor
θ : angle between B and I

[1] Taha Ahmed

2 Drive Systems

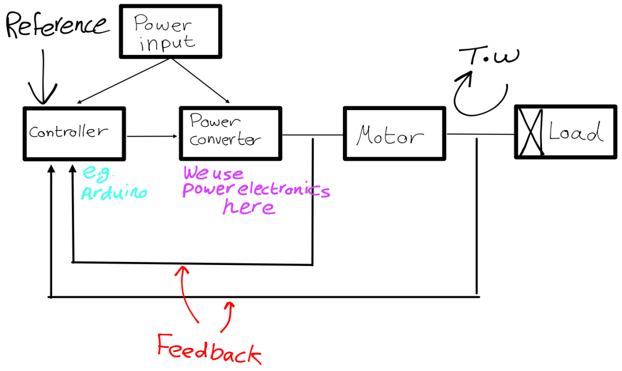

Figure 1: Components of a typical drive system

3 DC Generators

3.1 Working Principle

A moving wire in the presence of a magnetic field has a voltage induced in it.

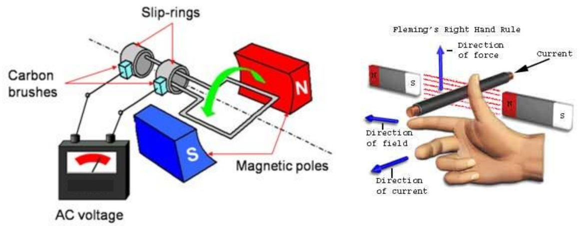

Figure 2

3.2 Construction

3.2.1 Stator

Used to produce magnetic field flux, it is constructed from magnetic poles with field winding
there are two types of magnets : permanent magnets and electro-magnets, permanent magnets are cheaper and smaller, electro-magnets have the ability to control the magnetic field

3.2.2 Rotor

- Rotor:
  1. Brushes:
     - Usage: collect (if motor) or supply (if generator) DC voltage.
     - Material : Graphite (Carbon)
  2. Commutator
     - Usage: Convert AC to DC (mechanical rectifier)
     - Material : Copper
  3. Armature:
     - Usage: Produces emf
     - Material : Silicon steel (iron)

3.2.3 Armature Winding

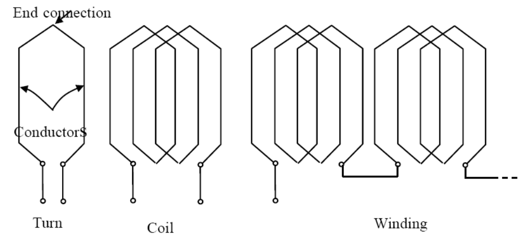

Figure 3: Turn, Coil and Winding

Lab winding:
Group of coils are connected in series, then the groups are connected in parallel (which called parallel paths), the number of paths = the number of poles = number of brushes
Used in **High current, low voltage output**

Wave winding:

There are two paths in parallel no matter what the number of poles is, each path supplying half the total current output.

Used in **high voltage, low current output**

4 EMF Generated in Armature Winding

$$E_a = \frac{P}{a} \times \phi \times Z \times \frac{N}{60} \tag{3}$$

Where:

Z : Number of armature conductors.
ϕ : Useful flux per pole, in Webers (Wb)
P : Number of poles
N : Armature speed in rpm (revolution per minute)
a : Number of armature parallel paths.(either 2 or P)

$$\begin{aligned} E_a &\propto \phi N \\ E_A &= K\phi N \\ E_A &= K_a \phi \omega \end{aligned} \tag{4}$$

$$K_A = \frac{P\,Z}{2\,\pi\,a} \qquad \textbf{(V/Wb-rad/sec)} \tag{5}$$

K_a : Armature voltage constant

ω : Angular speed (rad/sec) $= 2\pi(N/60)$ where N is armature speed (revolution/min)[2]

$$\begin{aligned} E_a &\propto \phi N \\ \phi &\propto I_f \\ \therefore \frac{E_2}{E_1} &= \frac{I_{f_2}}{I_{f_1}} \times \frac{N_2}{N_1} \end{aligned} \tag{6}$$

[2]To obtain ω we used $2\pi(N/60)$ not $2\pi(f/60)$, don't substitute with the electricity frequency

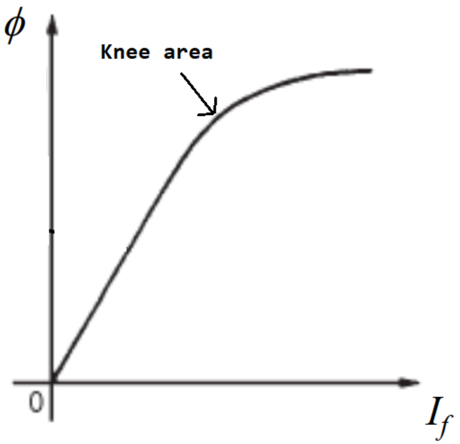

Figure 4: Relation between I_f and ϕ, the relation starts linear, as I_f increases till a point, ϕ saturates, we operate machines in the linear region to avoid saturation, as it is harder to control non linear machines

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$\boxed{\text{1. Q}}$ — A 4-pole generator has a total of 1440 conductors and a flux per pole of 4.6 mWb. When it is driven at 1200 rpm, the generated voltage is 265V. Is the armature wound lap or wave?

A — How to solve?
Use the equation

$$E_a = \frac{P}{a} \times \phi \times Z \times \frac{N}{60}$$

Recognize what each number corresponds to each variable

Z : Number of armature conductors. (1440)
ϕ : Useful flux per pole, in Webers (Wb) (4.6×10^{-3})
P : Number of poles (4)
N : Armature speed in rpm (revolution per minute) (1200)
a : Number of armature parallel paths.(either 2 or P) (unknown)

If $a = 2$, then it is wave winding
If $a = P = 4$, then it is lab winding

5 Magnetization Curve

How to get ? Measure the open circuit voltage while keeping changing the field current I_f.

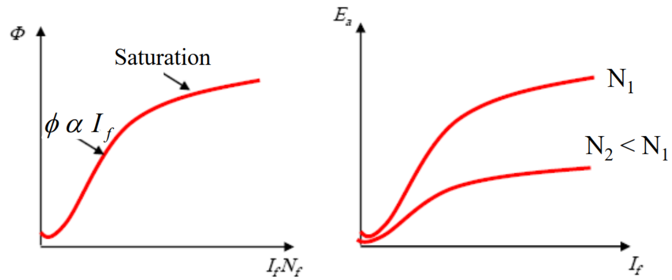

Figure 5: Magnetization curve, note that ϕ doesn't start at zero because of the residual flux

6 Residual Flux

• Residual Magnetism or Residual flux: The magnetic flux density that remains in a material when the magnetic field is zero (switched off). It is important in self excited generator as it will be shown later.

• This produces a small voltage which is called Residual Voltage.

7 Armature reaction

Armature reaction is the effect of the armature field on the main field.

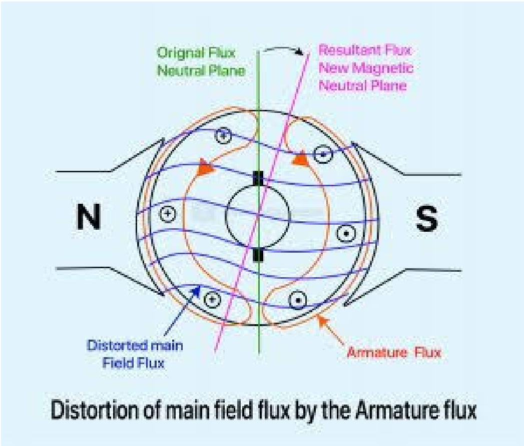

Figure 6: Armature Reaction

note that at 1st and 3rd quadrants fluxes added each other resulting in higher field, and at 2nd and 4th quadrants fluxes opposes each other resulting in lower field.

Disadvantages:

- Lower field.

- Distorted field.

How to compensate armature reaction¿

- Use inner poles

- Move the brushes slightly to keep the brushes main axis perpendicular on

8 Classification of DC Machines

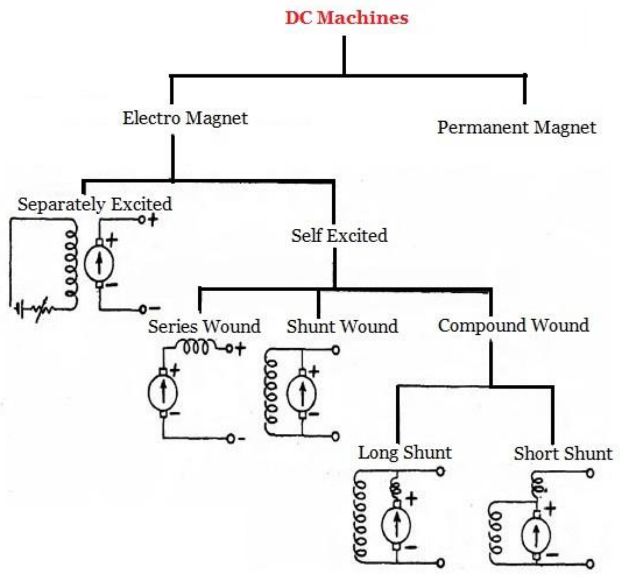

Figure 7: Classification of DC Machines

9 Separately Excited DC Generator

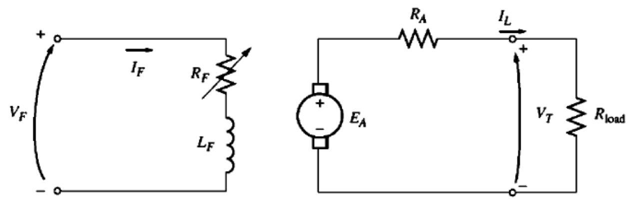

Figure 8: Separately excited DC generator model

Apply KVL

$$V_t = E_a - I_a\,R_a \tag{7}$$

$$V_f = R_f\,I_f \qquad I_a = I_l \qquad V_t = I_l\,R_l \qquad E_a = k_a\,\phi\,\omega_m$$

I_f, V_f, R_f	: field current, voltage and resistance.
I_l, R_l	: load current and resistance
V_t	: terminal voltage or load voltage.
I_a, R_a	: armature current and resistance.
E_a	: is also known as back , induced or generated emf.
$I_a \times R_a$	: armature voltage drop.

9.1 Terminal Characteristics of a Separately Excited DC Generator

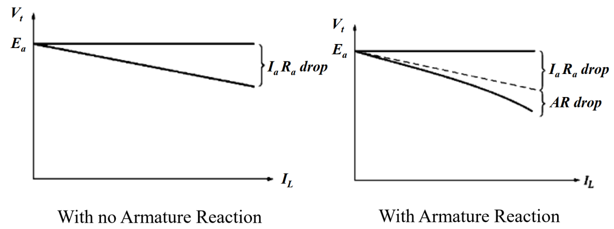

Figure 9: Terminal characteristics of a separately excited DC generator

How to overcome armature voltage drop?

By control unit with feedback, whenever terminal voltage decreases, the control unit increases I_f.

10 Self Excited DC Generator

10.1 Shunt Generator

In a shunt generator, the field flux is derived by connecting the field circuit directly across the terminals of the generator.

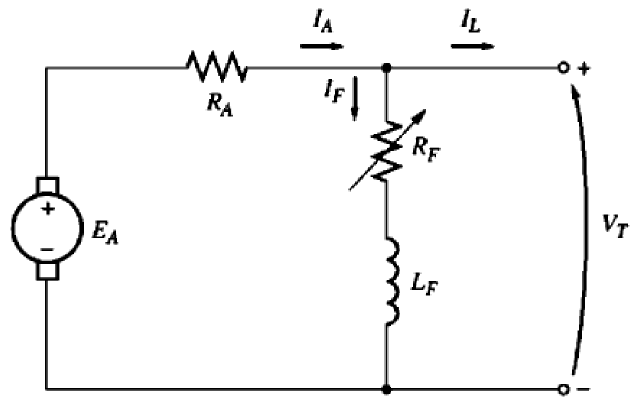

Figure 10: Self excited DC generator model

Apply KVL

$$V_t = E_a - I_a R_a \tag{8}$$

$$V_t = V_f = R_f I_f \qquad I_a = I_l + I_f \qquad E_a = k_a \phi \omega_m$$

$\boxed{2.\ Q}$ — If the generator supplies its own field current, how does it get the initial field flux to start when it is first turned on?

A — Residual flux

$\boxed{3.\ Q}$ — If the Voltage build-up fails, what could be the reasons?
What if a shunt generator is started and no voltage builds up? What could be wrong?

(*midterm 2022*)

A —

- There are no residual flux (Very low probable to happen)
  The solution, shut down the generator, then connect the field circuit to a DC voltage for a short time to build residual flux, then reconnect the generator.

- Residual flux opposite to the field circuit flux.
  Residual flux and field flux must be in the same direction, if they are in opposite directions, there will no be a cumulative increase in in field current and no voltage build-up.

- Critical Field Resistance:

  It is the field circuit resistance above which the generator fails to excite.

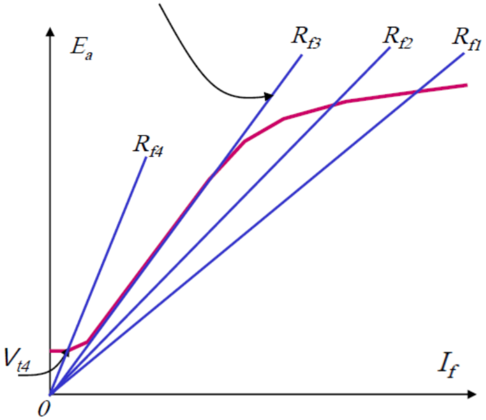

Figure 11: Critical Field Resistance

if the resistance is higher than critical field resistance, no point of intersection exists between the line and the magnetization field.

- Critical Speed:

  if the resistance is higher than critical field resistance, no point of intersection exists between the line and the magnetization field.

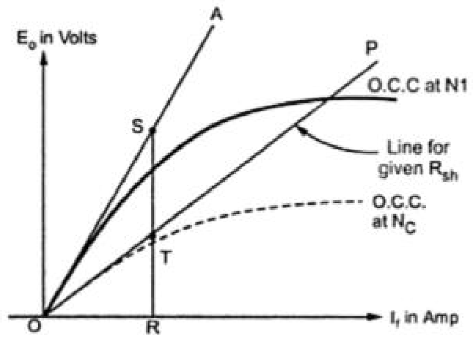

Figure 12: Critical speed

if the speed is lower than critical speed ,no point of intersection exists between the line and the magnetization field

10.1.1 Terminal Characteristics of a Shunt DC Generator

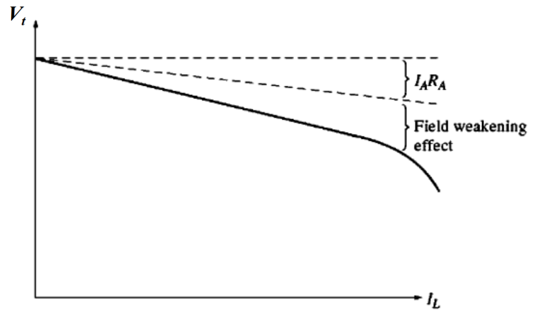

Figure 13: Terminal characteristics of a shunt DC generator

$\boxed{4.\ Q}$ — At the same speed, is terminal characteristics of the separately excited DC generator curve **higher than** terminal characteristics of the shunt DC generator curve ?

A — True, since in separately excited DC generator the field is generated from a separate circuit, emf is constant, on the other hand, in shunt DC generator the armature supplies the field current therefore emf is not constant due to armature reaction, when E_a decreases, I_f decreases

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$\boxed{5.\ Q}$ — A 5 kW, 100 V, 1000 rpm, shunt generator has the following open circuit curve at rated speed:

$I_f(A)$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2
$E_a(V)$	6	16	32	48	63	76	85	94	100	102

The generator has armature and field winding resistances of 0.4 Ω and 120 Ω respectively. If the generator is driven at 1200 rpm, determine:
1. The no load terminal voltage.
2. The critical field resistance.
3. if you insert a variable resistance to control the field, what is the operating range.
4. The maximum value of the armature current the generator can deliver; determine the terminal voltage in this case. Neglect armature reaction effect.

5. The critical speed.

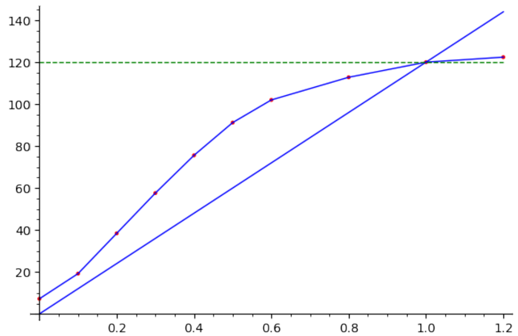
A — How to solve:

1.
Give table is given at 1000 rpm and the generator on driven at 1200 rpm, new table must be created

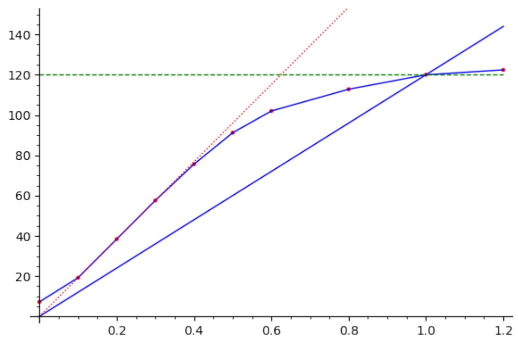
$$\because \frac{E_1}{E_2} = \frac{N_1}{N_2} \qquad \therefore E_2 = 1.2E_1$$

I_f	0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2
$E_{a\,1}$	6	16	32	48	63	76	85	94	100	102
$E_{a\,2}$	7.2	19.2	38.4	57.6	75.6	91.2	102	112.8	120	122.4

Draw the magnetization curve from the table and current field line from $V_t = I_f R_f = 120 I_f$



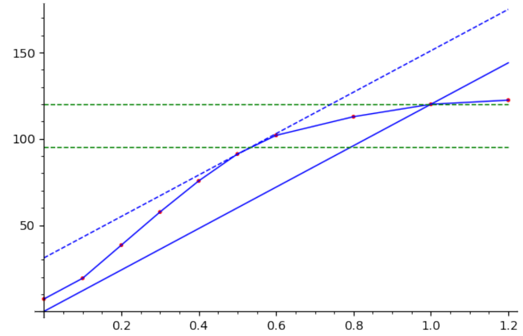
As shown, the intersection point (no load terminal voltage) = 120 V
2. To get the critical field resistance, draw a tangential line to the magnetization curve at the linear region and calculate its slop



Slope equals $19.2/0.1 = 192\,\Omega$
3. Initial resistance is $120\,\Omega$, critical field resistance $192\,\Omega$, so the range is $[0,\ 72]\ \Omega$
4. R_f is constant $\rightarrow$ we will not change the slope.
Recall:

$$E_a = V_t + I_a R_a$$

We tune the value of $I_a R_a$ till the line becomes tangential to the magnetization curve without changing its slope.



as shown in the figure

$$I_a R_a = 31V$$
$$I_a = \frac{31}{0.4} = 77.5A$$

intersection point is at E_a (no load voltage at maximum current) = 95 V

$$V_t = E_a - I_a R_a$$
$$V_t = 95 - 31 = 64V$$

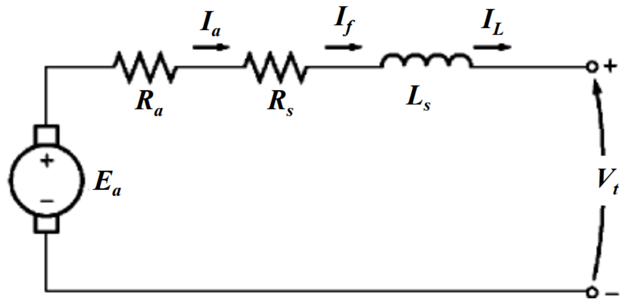
5. critical speed:
start with the linear region of magnetization curve, adjust the slope of this region which is $\frac{\Delta y}{\Delta x}$ to be equal the slope of $E_a - I_f$ line, which is 120.

$$n \times \frac{19.2}{0.1} = 120$$
$$n = 0.625$$
$$\therefore \text{critical speed} = 0.625 \times 1200 = 750 \text{ rpm}$$

10.2 Series generator

In a series generator, the field flux is produced by connecting the field circuit in series with the armature of the generator

No load voltage = residual voltage



$$I_a = I_l = I_f \qquad V_t = E_a - I_a(R_a + R_s) \qquad E_a = K_a \phi_s \omega_m \tag{9}$$

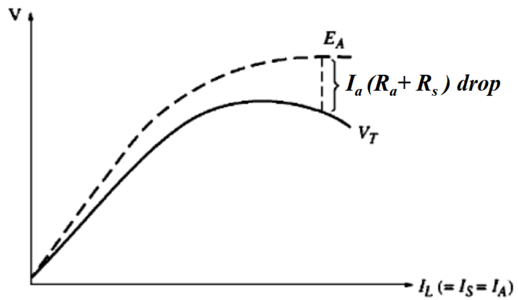
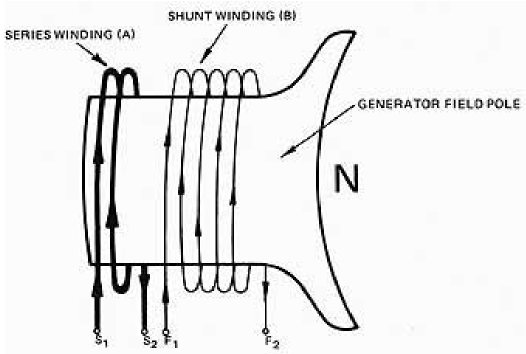


Figure 14: Terminal characteristics of series motor

10.3 Shunt and Series Field Winding



Shunt field winding :

- Large number of turns.
- Thin wire with high resistance (100s of Ohms).
- Carry small field current.
-

$$AT_{sh} = N_{sh} I_f$$

AT : Ampere turn

N : Number of turns

I : Current

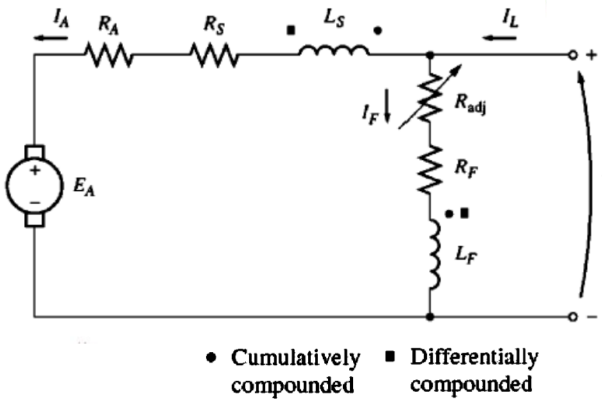
Series field winding:

- Small number of turns.
- Thick wire with low resistance (0.1 $\sim$ 1 Ohms).
- Carry Large field current.
-

$$AT_s = N_s I_a$$

10.4 Compound Generator

10.4.1 Long Shunt

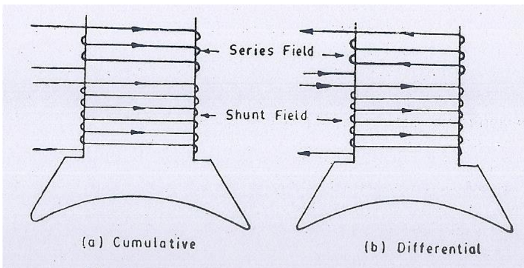


$$I_a = I_l + I_f \qquad V_t = I_f R_f \tag{10}$$

$$E_a = V_t + I_a(R_a + R_s) \qquad E_a = K_a(\phi_{sh} \pm \phi_s)\omega_m \tag{11}$$

- In a cumulatively compounded generator, both a shunt and a series field are in the same direction, and their effects are additive.
- In a differentialy compounded generator, both a shunt and a series field are in opposite directions, and their effects are subtractive.

Cumulative and Differential Field Flux



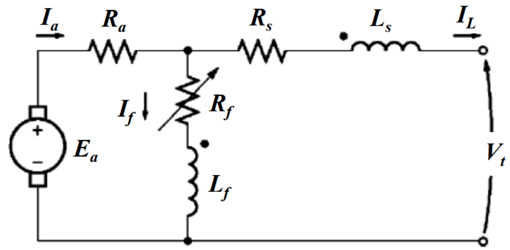
• Cumulative field flux : when series and shunt flux are in the same direction

$$\phi_{\text{net}} = \phi_{sh} + \phi_s$$

• Differential field flux : when series and shunt flux are in opposite directions.

$$\phi_{\text{net}} = \phi_{sh} - \phi_s$$

10.4.2 Short Shunt



$$I_a = I_L + I_f \qquad V_t = I_f R_f - I_L R_s \tag{12}$$

$$E_a = V_t + I_a R_a + I_L R_s \qquad E_a = K_a(\phi_{sh} \pm \phi_s)\omega_m \tag{13}$$

Note that V_t in short shunt is greater than V_t in long shunt .

10.4.3 Terminal Characteristics of Compound Generators

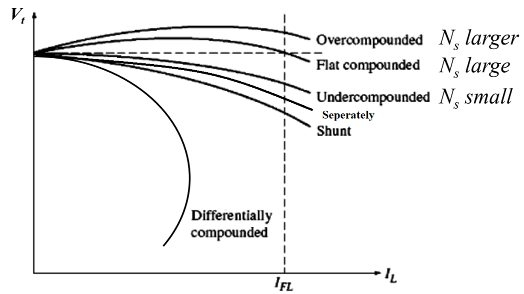


Figure 15

11 Voltage Regulation

• **Voltage regulation**: It is the change in terminal voltage when the load is switched off

• Voltage regulation is a measure of internal voltage drop inside generator due to internal resistance and armature reaction • Smaller voltage regulation means better generator

$$VR = \frac{V_{\text{no load}} - V_{\text{full load}}}{V_{\text{full load}}} \tag{14}$$

$$VR = \frac{E_a - V_t}{V_t} \tag{15}$$

12 Power Flow, Losses and Efficiency

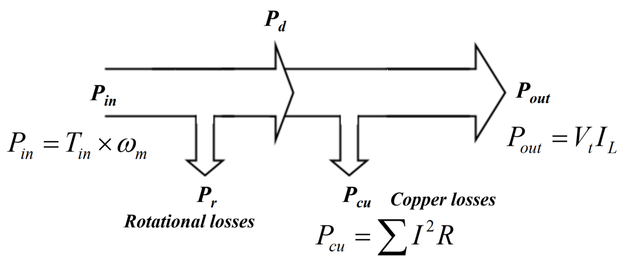


Figure 16: Power Flow

$$P_{\text{in}} = T_{\text{in}} \times \omega_m$$

P_{in} : Input power (Watt)
T_{in} : Input torque (N.m)
ω_m : Radial speed (rad/sec)

$$P_d = E_a I_a = P_{\text{in}} - P_r \tag{16}$$

P_d : Developed power
P_r : Rotational losses

$$P_{\text{cu}} = \sum I^2 R \tag{17}$$

P_{cu} : Copper losses

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{out}}}{P_{\text{out}} + P_r + P_{cu}} \tag{18}$$

In practice, the efficiency for real generators is around 85% - 90%
Note that we can obtain the maximum efficiency when rotational losses = copper losses

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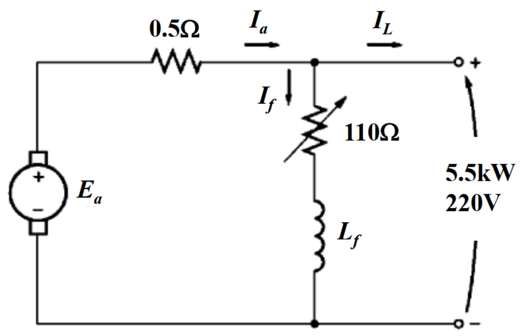
6. Q — A 5.5 kW, 220 V DC shunt generator has a field resistance of 110 W, an armature resistance of 0.5 W, and rotational losses of 100 W. Find at rated load

- The armature current.
- The generated voltage.
- The voltage regulation.

A — How to solve?



Find I_L by $P_{\text{out}} = V_t P_{\text{out}}$
Find I_f by $v_t = I_f R_f$
then $I_a = I_L + I_f$
Apply KVL → $E_a = V_t + I_a R_a$
Voltage regulation

$$VR = \frac{E_a - V_t}{V_t}$$

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{out}}}{P_{\text{out}} + P_r + P_{cu}}$$

$$P_{\text{cu}} = \sum I^2 R$$

13 DC Motors

DC motors are self starting motors.

13.1 Working Principle

A current-carrying wire in the presence of a magnetic field has a force induced on it.

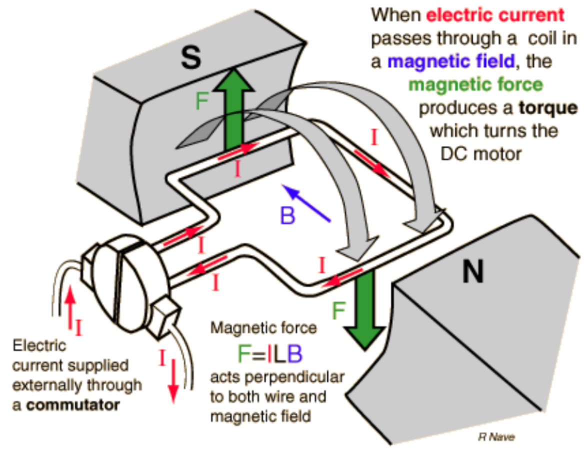


Figure 17

14 Separately Excited DC Motor

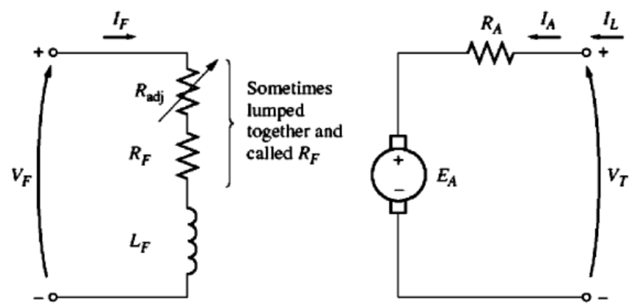


Figure 18: Separately excited DC motor model

Apply KVL

$$V_t = E_a + I_a\,R_a \tag{19}$$

$V_f = I_f\,R_f \qquad I_a = I_L \qquad V_t = k_a\,\phi\,\omega_m + I_a\,R_a \qquad E_a = k_a\,\phi\,\omega$

15 Self Excited DC Motor

15.1 Shunt motor

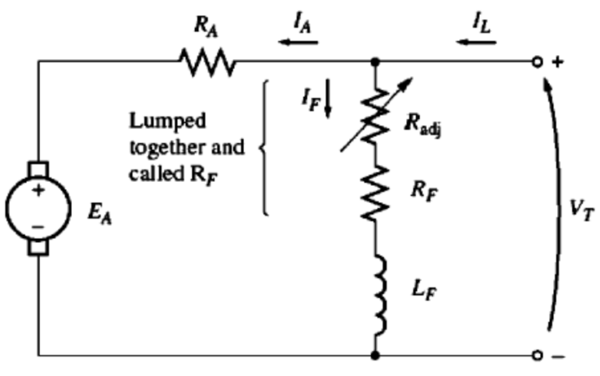


Figure 19: DC shunt motor model

Apply KVL

$$V_t = E_a + I_a\,R_a \tag{20}$$

$V_f = I_f\,R_f \qquad I_a = I_L - I_f \qquad V_t = k_a\,\phi\,\omega_m + I_a\,R_a \qquad E_a = k_a\,\phi\,\omega_m$

15.1.1 Terminal Characteristics of DC Shunt Motor

We know that:

$$V_t = E_a + I_a\,R_a$$
$$V_t = K_a\,\phi\,\omega_m + I_a\,R_a$$
$$\omega_m = \frac{V_t - I_a\,R_a}{K_a\,\phi}$$

Therefore the speed is inversely proportional with the field.

$$\omega_m = \frac{V_t}{K_a\,\phi} - \frac{R_a}{(K_a\,\phi)^2}\,T_d$$

What happens at no load ?

T_d is approximately zero, so $\dfrac{V_t}{K_a\,\phi}$ is called **no load speed**

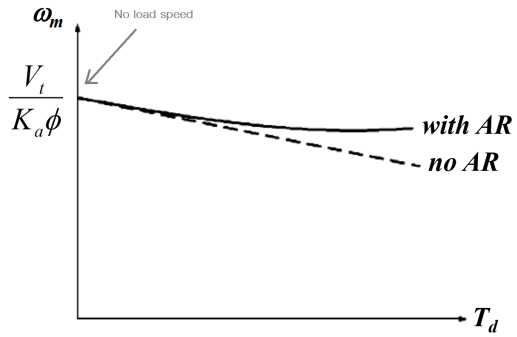


Figure 20: Terminal characteristics of DC shunt motor. note the armature reaction increases the speed because it reduces the field

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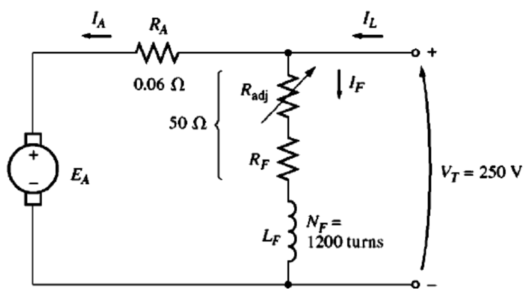
$\boxed{\text{7. Q}}$ — A 50 hp, 250 V, 1200 rpm DC shunt motor has an armature resistance of 0.06 Ω. Its field circuit has a total resistance of 50 Ω, which produces a no load speed of 1200 rpm

1. Find the speed of this motor when its input current is 100 A and 200 A.
2. Plot the torque-speed characteristic of this motor.

A — How to solve?



At $I_l = 100$ A
Get I_f by $V_t = I_f R_f$
Get I_a by $I_l = I_f + I_a$
Apply KVL to get E_a

$$E_a = V_t - I_a R_a$$

How to get N

Since $E_a = K\phi N$ then

$$\frac{E_2}{E_1} = \frac{I_{f2}}{I_{f1}} \times \frac{N_2}{N_1}$$

Note that $V_t = I_f R_f$, so $I_{f1} = I_{f2}$

So

$$N_2 = \frac{E_2}{E_1} \times N_1$$

To get ω :

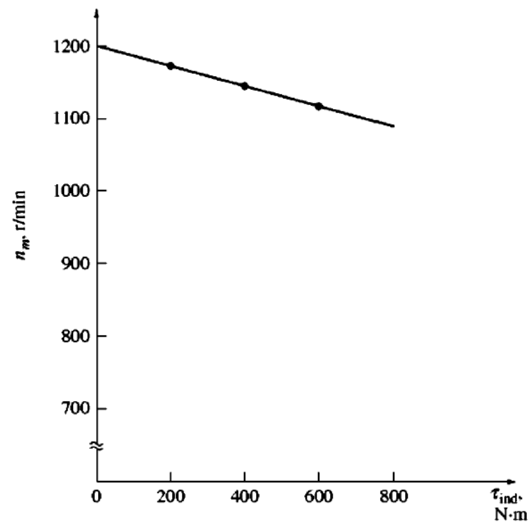
$$\omega = 2\pi \times \frac{N}{60}$$

To get the developed torque:

$$T_d = \frac{P_d}{\omega} = \frac{E_a I_a}{\omega}$$

Repeat with $I_L = 200$ A and $I_L = 300$ A

The goal is to draw torque-speed characteristics, since you calculated N and T_d at more than two points (two points are enough), draw a line passing through these two points.



15.2 Series Motor

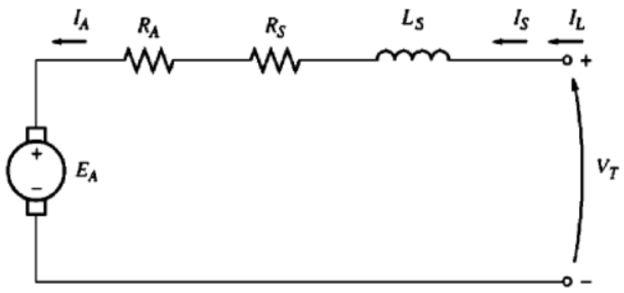


Figure 21: Series DC motor model

$$I_a = I_f = I_L \tag{21}$$

$$E_a = V_t - I_a(R_a + R_s) \qquad E_a = K_a\phi\omega_m = k_s I_a \omega_m$$

15.2.1 Terminal Characteristics of Series DC Motor

$$\omega_m = \frac{V_t}{\sqrt{K_s T_d}} - \frac{R_a + R_s}{K_s} \tag{22}$$

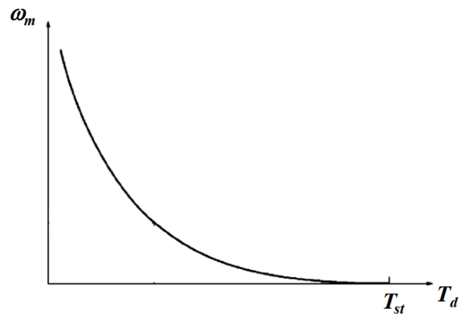


Figure 22: Series DC motor terminal characteristics

15.3 Compound Motor

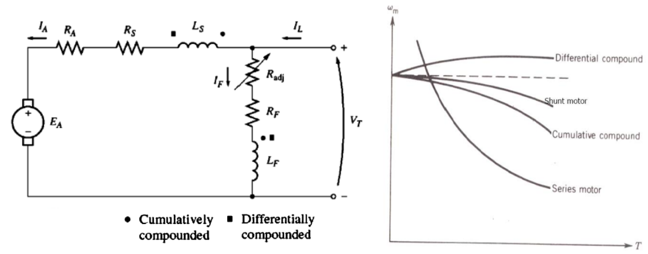


Figure 23: Compound DC motor and terminal characteristics for different types of DC motor.

$$I_L = I_a + I_f \qquad V_t = I_f\, R_f \tag{23}$$

$$V_t = E_a + I_a(R_s + R_s) \tag{24}$$

$$\phi_t = \phi_{sh} \pm \phi_s \tag{25}$$

$$\omega_m = \frac{V_t}{K_a\,\phi} - \frac{R_a}{(K_a\,\phi)^2}\,T_d \tag{26}$$

$$AT_{\text{effective}} = AT_{sh} \pm AT_s - AT_{AR} \tag{27}$$

$$I_{f(\text{effective})} = I_f \pm \frac{N_s}{N_f} I_a - \frac{AT_{AR}}{N_f} \tag{28}$$

16 Speed Control of DC Motors

$$\because \omega_m = \frac{V_t - I_a R_a}{K_a \phi} \tag{29}$$

Therefore, the speed of DC motors can be controlled by controlling V_t, R_a or ϕ.

16.1 Armature Voltage Control

• The motor must be separately excited to use armature voltage control.
• In this method R_a and I_f (i.e. ϕ) are kept constant, and V_t is varied to change the speed.
• Armature voltage control can control the speed of the motor from zero to speeds below rated speed but not for speed above rated speed.
• This method is expensive because it requires a variable DC supply for the armature circuit.
• If you operate at speeds above rated speed, the motor will burn out.

16.2 Field Current Control

• Can be used at all types of DC motors *except* series motors.

• In this method V_t and R_a are kept constant, and I_f is varied to change the speed.

• This is normally achieved by using a field rheostat.

• Field control can control the speed of the motor for speeds above base speed but not for speeds below base speed.

• This method is simple to implement and less expensive, because the control is at the low power level of the field circuit.

16.3 Armature Resistance Control

• Can be used at all types of DC motors

• In this method V_t and I_f are kept constant, and R_a is varied to change the speed.

• The speed is controlled by changing the resistance in the armature circuit.

• Armature resistance control is simple to implement

• However, this method is less efficient because of losses in the resistance.

• Armature resistance control can control the speed of the motor for speeds below base speed.

16.4 Solid State Control

16.5 Power and Torque Limits as a Function of Speed for a Shunt Motor Under Armature Voltage and Field Resistance Control

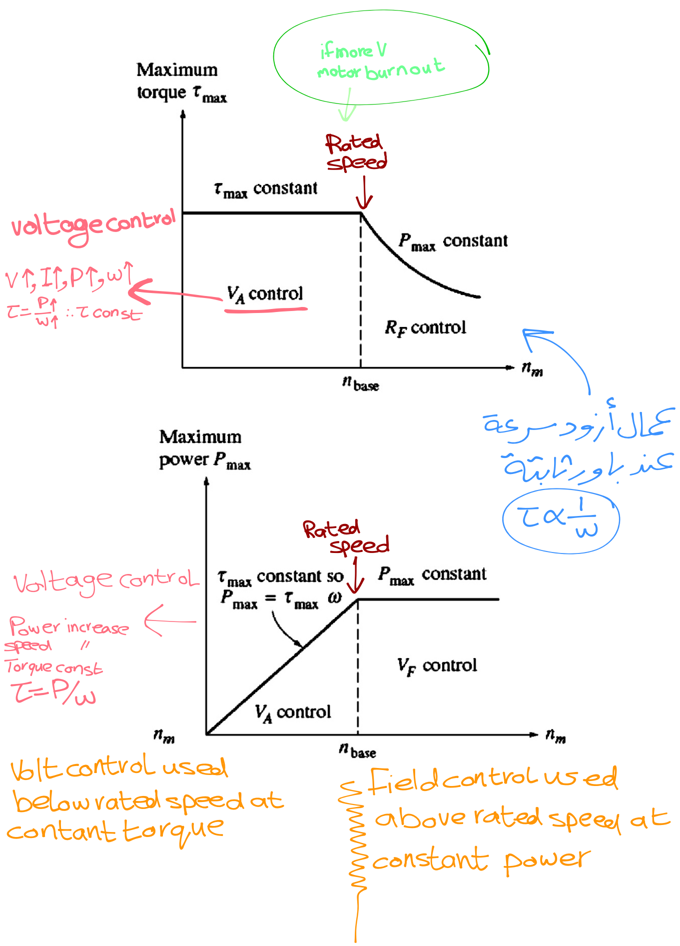


Figure 24

Any drive system can do four things:

- Soft starting.
- Speed control.
- Inverting.
- Electrical breaking. (Apply opposite torque on the motor. It is faster and more efficient than mechanical breaking)

17 Starting of DC Motors

$$\because I_a = \frac{V_t - E_a}{R_a}$$

At starting, $N = 0$, therefore $E_a = 0$.

$$\therefore I_{st} = \frac{V_t}{R_a}$$

If the rated voltage is applied to the DC motor(This is called DOL (Direct online starter), the current will be over 20 times the motor's rated full load current. That will damage the motor even if it lasts for a moment.

A solution to the problem of excess current during starting is to insert a starting resistor in series with the armature to limit the current flow until E_a can build up to do the limiting.

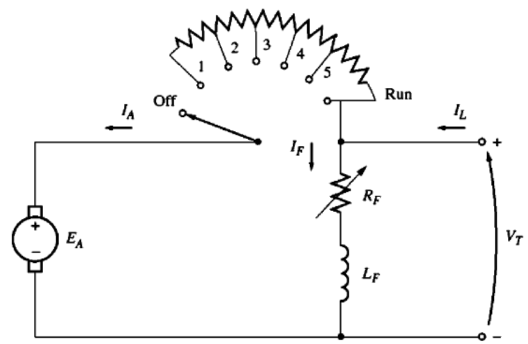


Figure 25: Starting resistor

Because this way depends on a person moving the handle, automatic starters are used nowadays which are human-error-free.

18 Power Flow, Losses and Efficiency

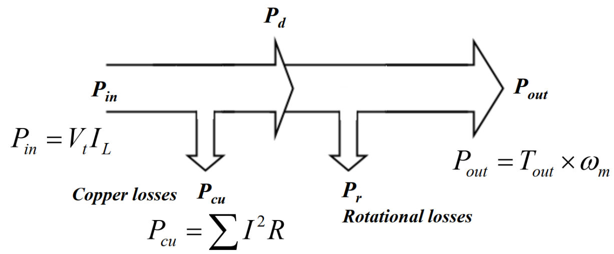


Figure 26: Power flow

$$P_{\text{in}} = V_t I_L$$

$$P_d = E_a I_a = P_{\text{in}} - P_{\text{cu}}$$

P_d : Developed power

$$P_{\text{cu}} = \sum I^2 R$$

P_{cu} : Copper losses

$$\boxed{\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{out}}}{P_{\text{out}} + P_r + P_{\text{cu}}}}$$

---

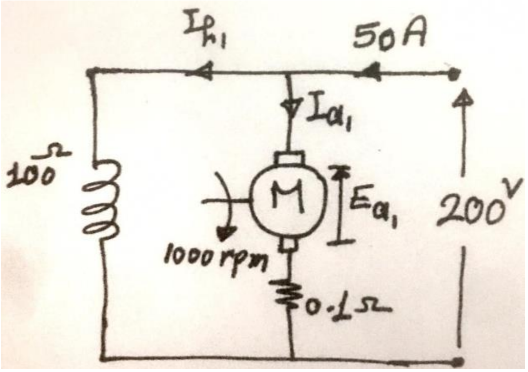
8. Q — A DC shunt motor drives a centrifugal pump whose torque varies as the square of the speed. The motor is fed from 200 V supply and takes a 50 A when running at 1000 rpm.

1. What resistance must be inserted in the armature circuit in order to reduce the speed to 800 rpm? The armature and field resistances of the motor are 0.1 Ω and 100 Ω respectively. Neglect saturation.

2. Find the starting resistance required to limit the starting current to 1.5 line current.

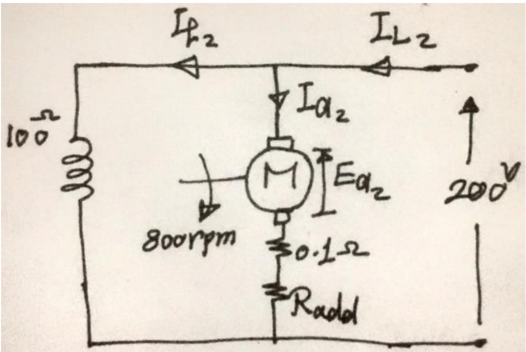
A — How to solve?

1.



At $I_l = 50$ A
Get I_f by $V_t = I_f R_f$
Get I_a by $I_l = I_f + I_a$
Apply KVL to get E_a

$$E_a = V_t - I_a R_a$$



Note that I_f will not change
Get E_{a2} from

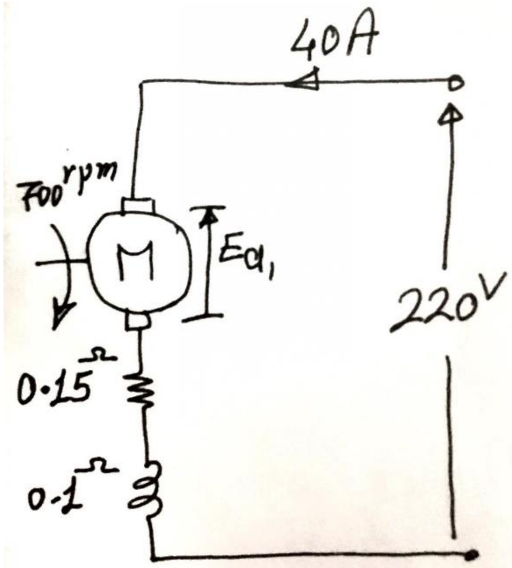
$$\frac{E_2}{E_1} = \frac{I_{f2}}{I_{f1}} \times \frac{N_2}{N_1} = 1 \times \frac{N_2}{N_1}$$

2.
Get R_{add} from

$$75 = \frac{V_t}{R_a + R_{\text{add}}}$$

$\boxed{9.\ \text{Q}}$ — A 220 V DC series motor has an armature and series field resistances of 0.15Ω and 0.1Ω respectively. It takes a current of 40 A when running at 700 rpm. Calculate the current taken from the supply and the speed if the field is shunted by a resistance equal to the field resistance and the load torque is decreased by 25%. Neglect saturation.

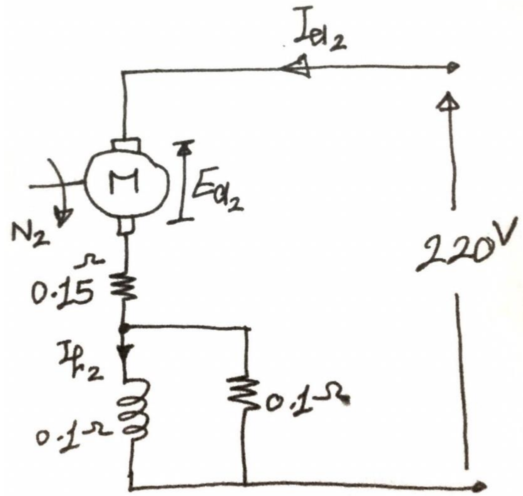
A — How to solve?



$$I_{a1} = I_{f1}$$

Apply KVL

$$E_{a1} = V_t - I_{a1} \times (R_a + R_f)$$



$$I_{f2} = 0.5 I_{a2}$$

Get I_{a2} and I_{f2} from :

$$\frac{T_2}{T_1} = \frac{I_{f2}}{I_{f1}} \times \frac{I_{a2}}{I_{a1}}$$

Apply KVL

$$E_{a1} = V_t - I_{a1} \times (R_a + R_f || R_f)$$

Get E_{a2} from

$$\frac{E_{a2}}{E_{a1}} = \frac{N_2}{N_1} \times \frac{I_{f2}}{I_{f1}}$$

And note that $I_{f2} \neq I_{f1}$

19 Advantages and Disadvantages of DC Machines

Advantages
- High starting torque.
- Stable at all speed.
- Rapid acceleration and deceleration.
- Easy control of speed over wide speed range.
- Used in high torque applications .
- Wide range of power ratings.

Disadvantages
- Needs regular maintenance.
- Speed limitations.

- Can't be used in explosive areas.
- High cost.

20 Advantages and Disadvantages of Series DC Motors

Advantages

- Starting load (at zero speed) the torque is very high.

Disadvantages

- series DC motor cannot be used at no load, because it will operate at dangerous high speed so it will be destroyed.

Therefore it is only used in applications in which load always exists, e.g. Traction loads, Trolley, Electric Locomotive, Cranes, hoists

21 Applications

- Automobiles.
- Robots.
- VCRs.
- Movie camera.
- Electric vehicles.
- Steel and aluminum rolling mills.
- Electric trains.
- Overhead cranes.
- Control devices.

22 Applications of DC Generators

1. **Separately Excited Generations**[3]
   - Lighting systems.
   - Power supply.
   - Battery charges.
2. **Series Excited Generations**[4]
   - Lighting systems.
   - Power supply.
   - Battery charges.
3. **Series Generators**
   - Boosters in DC distributed systems in railway service. [5]
4. **Compound Generators**
   (a) **Cumulative Compound**
      - Lamp loads.
      - Heavy power service such as electric railways
   (b) **Differential Compound**
      - Arc welding[6]

23 Applications of DC Motors

1. **Separately Excited Motor**
   - Machine tools.
   - Fans.
   - Pumps.
   - Blowers.
   - Lathers.
2. **Shunt Motor**
   - Machine tools.
   - Fans.
   - Pumps.
   - Blowers.
   - Lathers.
3. **Compound Motor**
   (a) Cumulative Compound:
      - High torque loads.
      - Shearing and punching machines.
      - Conveyors.
      - Elevators.
      - Rolling mills.
      - Planers.
      - Printing presses.
   (b) Differential Compound:
      Rarely used due to instability in its increasing speed with field weakening.

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[3] Why these applications? cuz we want constant volt and variable current, as all loads are connected in parallel
[4] Same as separately excited
[5] Nowadays, power electronics (Solid state boosters) are used instead.
[6] Because we want high current low voltage