Lecture Notes
EEE 360

TOPIC 8
DC Machine

Read Chapter: 6.1-6,5, 6.7

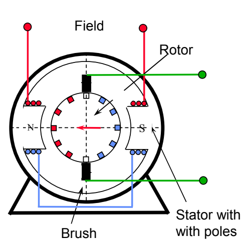
LECTURE 21

DIRECT CURRENT MACHINES

DC machine Construction

- The major advantages of DC machines are: easy speed and torque regulation.
- The stator of the DC motor has poles, which are excited by DC current to produce magnetic fields.
- The rotor has a ring-shaped laminated iron-core with slots.
- Coils with several turns are placed in the slots. The distance between the two legs of the coil is about 180 electric degrees.

Dc motor construction

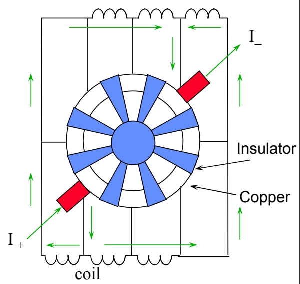


DIRECT CURRENT MACHINES

DC machine Construction

- The coils are connected in series.
- The junction points of the coils are connected to a commutator.
- The commutator consists of insulated copper segments mounted in a cylinder.
- Two brushes are pressed to the commutator to permit current flow.
- The brushes are placed in the neutral zone (magnetic field is close to zero) to reduce arcing.

Concept of the commutator

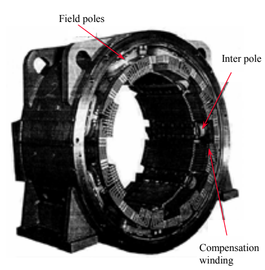


DIRECT CURRENT MACHINES

DC machine Construction

- The picture shows the stator of a large DC machine with several poles.
- Note the interpoles between the main poles. These poles reduce the field in the neutral zone and eliminate arcing of the commutator.
- A compensation winding is placed on the main poles to increase field during high load.
- The iron core is supported by a cast iron frame.

Dc motor stator construction

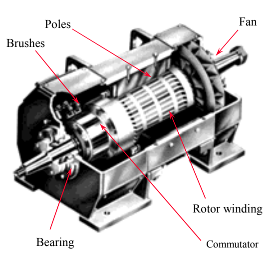


DIRECT CURRENT MACHINES

DC machine Construction

- The adjoining picture shows the rotor of a DC machine.
- The rotor iron core is mounted on the shaft.
- Coils are placed in the slots.
- The end of the coils are bent and tied together to assure mechanical strength.
- Note the commutator mounted on the shaft. It consists of several copper segments, separated by insulation.

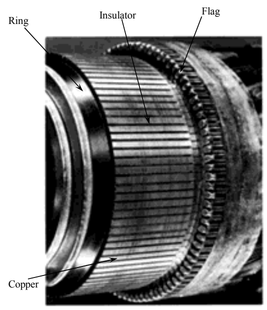
DC motor rotor construction



DIRECT CURRENT MACHINES

DC Machine Construction

- The adjoining picture shows the commutator of a large DC machine.
- The segments are made out of copper and mica insulation is placed between the segments.
- The end of each segment has a flag attached. The coil endings are welded to these flags.
- An insulated ring is placed on the coil ends to assure proper mechanical strength.

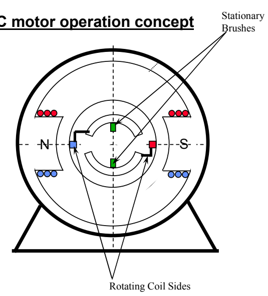


DIRECT CURRENT MACHINES

Operation principles

- The poles are supplied by DC current producing a DC magnetic field.
- The poles are shaped in such a way the field distribution along the pole is more or less sinusoidal.
- When the rotor coil is rotated, the flux linkage changes during the rotation. It is maximum when the coil is in vertical position and zero when it is in horizontal position.

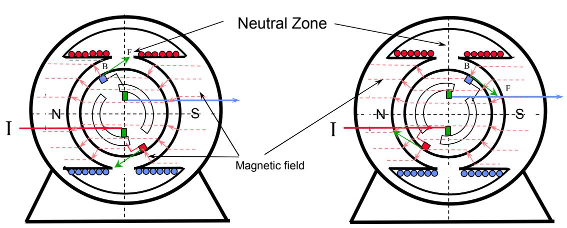
DC motor operation concept



DIRECT CURRENT MACHINES

Concept of commutation

- The current direction changes as the conductor passes through the neutral zone.
- The direction of magnetic field also changes as the conductor passes through the neutral zone.



DIRECT CURRENT MACHINES

Induced voltage and torque calculation.

- The magnetic field is generated by the field current I_f.
- The flux Φ_f is proportional to the field current.
  $\Phi_f = K_f I_f$.
- The K_f factor is calculated from the magnetic circuit using Amperes Law.
- The flux change is proportional to the motor speed ω_m.

DIRECT CURRENT MACHINES

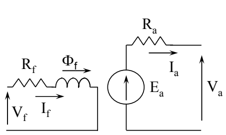
Induced voltage and torque calculation.

- The induced voltage after rectification is:
  $E_a = K \Phi_f \omega_m = K K_f I_f \omega_m = K_m I_f \omega_m$
- The out put power if the losses are neglected is:
  $P_{dc} = I_a E_a = T_m \omega_m$.
- The torque is:
  $T_m = I_a E_a / \omega_m = K \Phi_f I_a = K_m I_f I_a$

DIRECT CURRENT MACHINES

Equivalent circuit.

- The DC machine can be represented by a voltage source and a resistance connected in series. The armature winding has a resistance, R_a.
- The field circuit is represented by a winding that generates the magnetic field and a resistance connected in series. The field winding has resistance R_f.



DIRECT CURRENT MACHINES

Equivalent circuit.

The equations are:

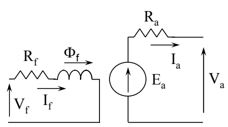
$\Phi_f = K_f I_f$

$E_a = K \Phi_f w_m = K_m I_f \omega_m$

$E_a = V_a + I_a R_a$

$V_f = I_f R_f$

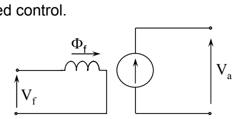
$T_m = K \Phi_f I_a = K_m I_f I_a$



DIRECT CURRENT MACHINES

Type of DC machines.

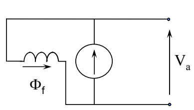
- **Separately excited machine.**
  - The main winding supplies the load.
  - The field winding is supplied by a separate DC source whose voltage is variable.
  - Good speed control.



DIRECT CURRENT MACHINES

Type of DC machines.

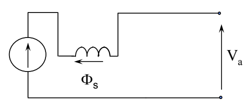
- **Shunt DC machine.**
  - The armature and field windings are connected in parallel.
  - Constant speed operation.



DIRECT CURRENT MACHINES

Major Types of DC machines.

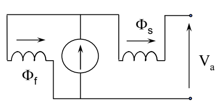
- **Series DC machine**.
  - The armature and field winding are connected in series.
  - High starting torque.



DIRECT CURRENT MACHINES

Major Types of DC machines.

- **Compound DC machine**.
  - The machine has two field windings: One connected in series; the other in parallel.
  - The series winding provides additional, load dependent excitation. Reduced voltage drop at high load.



DIRECT CURRENT MACHINES

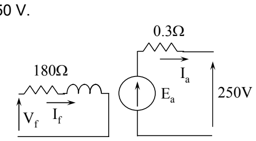
Numerical Example.

GENERATOR:

A 20 kW, 250 V, 1300 rpm, separately excited generator has an armature resistance of R_a = 0.3 ohm, and a field coil resistance of R_f = 180 ohms.

- At no load, the terminal voltage is 250 V, the field current is 1.5 A.
- At full load, the terminal voltage is also 250 V.

a) Draw the equivalent circuit.
b) At full load, calculate:
  - the generated voltage E_a
  - the developed torque
  - the Field circuit current and voltage



DIRECT CURRENT MACHINES

Numerical Example. GENERATOR:

- Calculation of the machine constant K from no-load data:
  - Machine speed: $\omega_m = 2\ p\ n/60 = 2\ p\ 1300/60 = 136.13$ 1/sec
  - Machine constant: $E_{a\_nl} = K\ \Phi_f\ \omega_m = K_m\ I_f\ \omega_m$
    $K_m = E_{a\_nl}\ /\ I_f\ \omega_m = 250\ /\ (1.5)(136.13) = 1.224$
- Load current: $I_a = 20000\ /\ 250 = 80$ A

DIRECT CURRENT MACHINES

Numerical Example. GENERATOR.

- Generated voltage:
  $E_a = V_t + I_a R_a = 250 + (80)(0.3) = 274$ V
- Torque:
  $T_e = E_a I_a / \omega_m = (274)(80) / 136.131 = 161.0$ Newton m
- Excitation/ field current and voltage at full load:
  $I_f = E_a / (K_m\ \omega_m) = 274 / (1.224)(136.131) = 1.64$ A
  $V_f = R_f I_f = (1.64)(180) = 296$ V

LECTURE 22

DIRECT CURRENT MACHINES

Motor speed characteristics
Numerical Example

- Motor equations

  $E_a = K_m \mathbf{I_f\ \omega_m}$

  $E_a = V_a - I_a R_a - V_{brush}$

  $\mathbf{V_f = I_f\ R_f}$

  $\mathbf{T_m = K_m\ I_f\ I_a}$

- The first two equations yield:

$$\omega_m = \frac{V - V_{Brush}}{K_m I_f} - \frac{R_a \cdot I_a}{K_m I_f}$$

DIRECT CURRENT MACHINES

Motor speed characteristics.

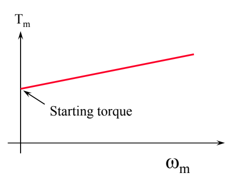
The substitution of I_a from the fourth equation results in :

$$\omega_m = \frac{V - V_{Brush}}{K_m I_f} - \frac{R_a}{(K_m I_f)^2} \cdot T_m$$

$$\omega_m = \frac{300}{0.9352} - \frac{0.2}{(0.9352)^2} \cdot T_m$$

$$\omega_m = 140.25 - 0.0571 \cdot T_m$$

$$T_m = 2456.21 + 17.51\, \omega_m$$

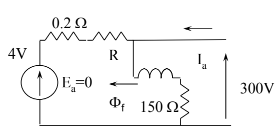


DIRECT CURRENT MACHINES

Motor starting
Numerical Example

- This current is too high. It must be limited to 2-3 times the rated current by a resistance connected in series with the armature.
- $2\ I_a = (2)(62.3) = (300\text{-}4)/(0.2\text{+}R)$
- From this equation R = 2.17 ohm

Equivalent circuit for starting



DIRECT CURRENT MACHINES

Motor starting

Numerical Example

- The torque equation is :

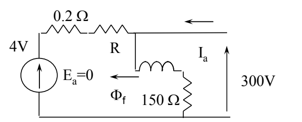
  $T_m = K_m \ I_f \ I_a$
- The K_m is calculated from the no-load data.

  $K_m = 0.935$ Vsec /A
- The field current is :

  300 / 150 =2 A
- The load current is :

  (300-4) /(0.2+2.17) = 124.8 A
- The starting torque is

  $T_m = (0.935)(2)(124.8) = 233.4$ Newton m



DIRECT CURRENT MACHINES

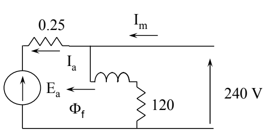
Numerical Example

MOTOR.

A 15 kW, 240 V, shunt motor has an armature resistance of R_a = 0.25 ohm, and a field coil resistance of R_f = 120 ohms. At rated terminal voltage the motor current is 8 A and runs at 1000 rpm.

a) Draw the equivalent circuit.
b) Calculate the motor constant
c) Calculate the speed and torque characteristics

Equivalent circuit



DIRECT CURRENT MACHINES

Numerical Example.

MOTOR.

- Calculation of field current:

  $I_f = 240 / 120 = 2$ A
- The armature current at no load is:
- $I_a = 8 - 2 = 6$ A
- Generated voltage at no load is:

  $E_a = V_t - I_a R_a = 240 - (6)(0.25) = 238.5$ V
- No load speed:

  $\omega_{m\_nl} = 2 \pi n / 60 = 2 \pi 1000 / 60 = 104.72$ / sec

DIRECT CURRENT MACHINES

Numerical Example

MOTOR.

- Machine constant:

  $E_a = K\,\Phi_f\,\omega_{m\_nl} = K_m\ I_f\,\omega_{m\_nl}$

  $K_m = E_a\ / I_f\,\omega_{m\_nl} = 238.5 / (2)\,(104.72) = 1.139$

- Load current:

  $I_m = 15000 / 240 = 62.5$ A

- The armature current is:

  $I_a = 62.5 - 2 = 60.5$ A

DIRECT CURRENT MACHINES

Numerical Example.

MOTOR.

- Generated voltage at full load is:

  $E_a = V_t - I_a R_a = 240 - (60.5)(0.25) = 224.9$ V

- Motor speed at full load:

  $E_a = K\,\Phi_f\,w_m = K_m\ I_f\,\omega_m$

  $w_m = E_a\ / K_m I_f = 224.8 / (1.139)(2) = 98.8$ rad./sec

  $n_m = 60\,\omega_m / 2\,\pi = 942.7$ rpm.

- Torque:

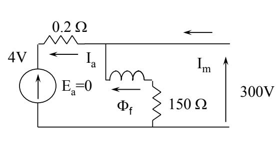
  $T_e = E_a I_a / \omega_m = (224.8)(60.5) / 98.8 = 137.65$ Newton m

DIRECT CURRENT MACHINES

Motor starting.

Numerical Example

Equivalent circuit for starting



a) Calculate the staring current of the previous example.

- The induced voltage is zero because the speed is zero.
- The starting current is :

  $I_{start} = (300 - 4) / 0.2 = 1480$ A.

DIRECT CURRENT MACHINES

Student Class Room Exercise

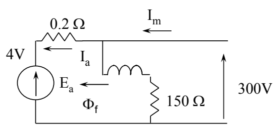
Numerical Example

A 25 Hp, 300V, shunt motor has an armature resistance of R_a = 0.20 ohm, and a field coil resistance of R_f = 150 ohms. The brush voltage drop is 4 V. At no load and rated voltage, the motor current is13 A and the speed is1500 rpm.

a) Draw the equivalent circuit.

b) Calculate the speed and torque at full load.

Equivalent circuit



DIRECT CURRENT MACHINES

Questions to ponder

- For each of the basic types of DC motors (shunt, series, compound) which is used for railways?
- What type of motor is recommended for electric cars?
- How is the speed of electric cars controlled?
- What type of motor would you select for conveyor belt, punch press and fan?
- What are the components of a DC drive system?

TEST 4

Induction Machine

LECTURE 23

DCshunt motor

A dc shunt motor is supplied through a feeder with a battery. The motor drives a pump.

Motor data are $rpm := min^{-1}$

$P_{rated} := 1hp$ $V_{rated} := 24V$ $R_a := 0.1\Omega$ $R_f := 10\Omega$

Motor is tested and the test results are:

$V_{test} := V_{rated}$ $I_{test} := 90A$ $n_{test} := 850rpm$

Battery and feeder data are:

$V_{batt} := 25V$ $R_{batt} := 0.1\Omega$ $R_{feeder} := 0.2\Omega$

The pump torque vs speed characteristcs $n := 600rpm$

$a := 1N \cdot m$ $b := 0.002 \cdot N \cdot m \cdot sec^2$ $T_{pump}(n) := a + b \cdot n^2$ $T_{pump}(n) = 1.2 N \cdot m$

$P_{pump}(n) := T_{pump}(n) \cdot 2 \cdot \pi \cdot n$ $P_{pump}(n) = 0.101hp$ $T_{pump}(0rpm) = 1J$

1) Draw the equivalent circuit nad calculate motor parameters
2) Calculate the curents and voltages as a function of the speed
3) Plot the motor and pump torque vs. speed charcteristics
4) Determine to operation point, speed and torque

DC Series motor operation analysis

A 40 kW, 240 V, series motor has an armature resistance of R_a = 0.25 ohm, and a field coil resistance of R_f = 0.3 ohms.

The motor current, speed and voltage are measured to determine the motor constant. The measured values are: At rated terminal voltage the motor current is 8 A and runs at 500 rpm

Derive the motor operation characteristics, which are efficiency vs. speed, torque vs. speed.

Data of the shunt motor are: $rpm := \frac{1}{min}$

Rated values

$P_m := 20kW$ $V_{dc} := 240V$ $R_a := 0.25\Omega$ $R_f := 0.3\Omega$

Measured values for motor constant calculation

$I_{mo} := 8A$ $n_{mo} := 500rpm$ $V_{mo} := V_{dc}$

Draw the motor equivalent circuit in no-load condition to determine the motor constant