

Welcome to

Electric Machines & Drives

thomasblairpe.com/EMD



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Session 2:
DC Machines
and Efficiency

Fall 2011




Session 2

- Chapter 3 – Fundamentals Mechanics & Heat
- Chapter 4 – DC Generators



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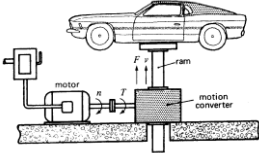

Chapter 3 – Fundamentals of Mechanics & Heat



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Rotary vs Linear Power



$$P_r = P_l$$

$$\eta T = 9.55 F v$$



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Example 3-13

A train needs 25kN force at speed of 90 km/h
If motor driving train turns at 1200RPM, what is Motor Torque and Motor HP?
Force (linear) = 25kN
Speed (linear) = 90 km/h
Speed (rotational) = 1200 RPM

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Heat Transfer

Specific heat capacity values in Table AX2

$$Q = m c \Delta t$$

Q = quantity of heat transferred (J)
m = mass (kg)
c = specific heat capacity of material [J/(kg °C)]
 Δt = change in temperature (°C)

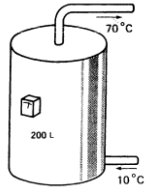
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Example 3-14

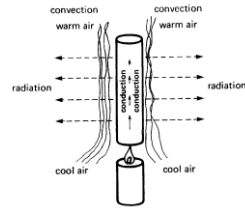
Calculate heat to raise 200L of water 60OC
(Specific heat is 4180 J/kg*OC)



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Heat Transfer

Conduction, Convection, Radiation



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Heat Transfer - Conduction

Thermal conductivity values in Tables AX1 and AX2
Energy transfer through material w/o material movement

$$P = \lambda A \Delta t / d$$

- P = power (heat) transmitted (W)
- λ = thermal conductivity of body [W/(m °C)]
- A = surface area (m²)
- Δt = difference in temp at opposite faces (°C)
- d = thickness of body (m)

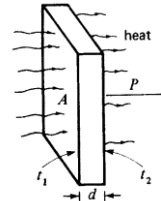
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Chapter 3

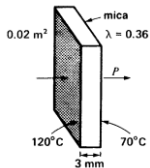
$$P = \lambda A \Delta t / d$$



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Example 3-15

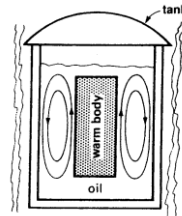
Temperature difference across a mica sheet
of 200 cm² area and 3mm thickness
is 50OC. Calculate heat flow.



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Heat Transfer - Convection

Energy transfer by material movement



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Natural Convection

$$P = 3 A \Delta t^{1.25}$$

P = heat loss by natural convection (W)
 A = surface of body (m)
 Δt = difference between body and ambient temperature ($^{\circ}\text{C}$)

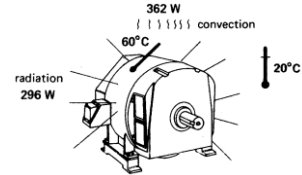
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Example

Motor has surface area of 1.2 m^2 and at full load the temperature rise is 40°C .
 What is heat loss by natural convection?



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Forced Convection

$$P = 1280 V_a \Delta t$$

P = heat loss by forced convection (W)
 V_a = volume of cooling air (m^3/s)
 Δt = Temperature of outgoing (warm) air minus incoming (cool) air ($^{\circ}\text{C}$)

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Example 3-17

A 3.75kW fan circulates $240 \text{ m}^3/\text{min}$ of air through a 750kW motor.
 If $T_{in} = 22^{\circ}\text{C}$ and if $T_{out} = 31^{\circ}\text{C}$,
 what are motor losses?

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Heat Transfer - Radiation

K constants shown in Table 3B
 Heat transfer through space

$$P = k A (T_1^4 - T_2^4)$$

P = heat radiated (W)
 A = surface area (m^2)
 T_1 = absolute temperature of body (K)
 T_2 = absolute temperature of surrounding objects (K)
 K = constant (depend upon the nature of body surface.)

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Radiation Constants

TABLE 3B RADIATION CONSTANTS

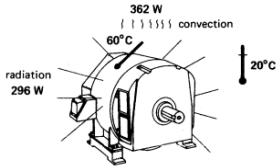
Type of surface	Constant $k \text{ W}/(\text{m}^2 \cdot \text{K}^4)$
polished silver	0.2×10^{-8}
bright copper	1×10^{-8}
oxidized copper	3×10^{-8}
aluminum paint	3×10^{-8}
oxidized Nichrome	2×10^{-8}
tungsten	2×10^{-8}
oxidized iron	4×10^{-8}
insulating materials	5×10^{-8}
paint or nonmetallic enamel	5×10^{-8}
perfect emitter (blackbody)	5.669×10^{-8}



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Example 3-18

The motor in Example 3-16 is coated with Non-metallic enamel.
What is heat loss to ambient of 20°C?



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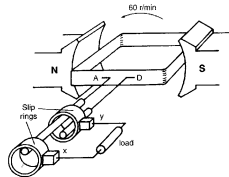
Chapter 4 – DC Generators



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Chapter 4 - DC Generators

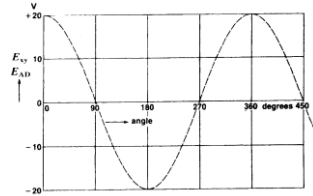
AC generator
 $E = B \cdot L \cdot V$
Slip Ring
Component of V perpendicular to B



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Chapter 4

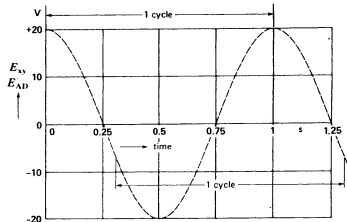
Voltage induced in the AC generator as function of angle of rotation



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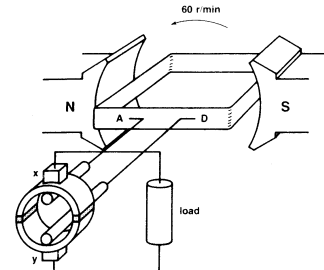
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Voltage as function of time



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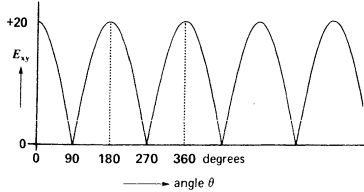
Commutator Chapter 4



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Chapter 4

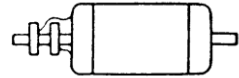
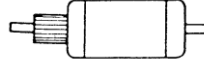
Waveform of load due to commutation



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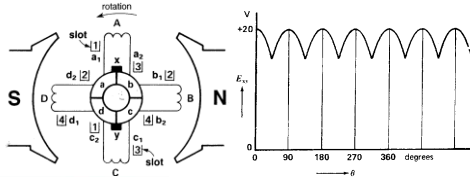
Which unit below is AC machine and which is DC machine?



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Increased Coils = Reduced Ripple



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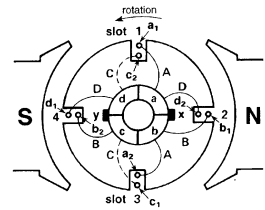
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Slot construction Lap Winding

4 coils = 4 slots =
4 commutator bars

2 poles = 2 brushes

$eA+eB+eC+eD = 0$
(no circ current)
Brush Volt =
 $eB+eC$ or $eA+eD$

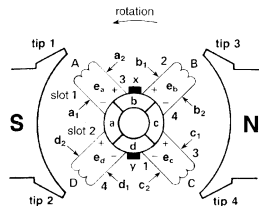


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$E = B l v$

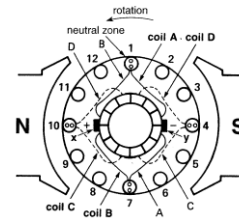
Magnitude -> angle between V and B



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Voltage in slot 4/10 max
Voltage in slot 1/7 min



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Brush Neutral Position

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Off neutral – Reduced Volt Arcing

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Proportional to flux and speed
Off neutral brush effectively reduces Z

$$E_o = Z n \phi / 60$$

E_o = voltage between brushes (V)
Z = total number of conductors on armature
n = speed of rotation (rpm)
 ϕ = flux per pole (Wb)

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Example 4 - 1

The armature of a 6 pole, 600 rpm generator, has 90 slots. Each coil has 4 turns and the flux per pole is 0.04 Wb. Calculate the value of the induced voltage.

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Force opposite to driving Force

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Armature reaction
Current produces
Magnetic Field

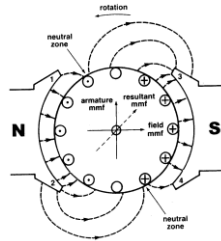
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Armature induced field adds to pole induced field.

Resultant field shifts neutral point.

Also, saturation of points 2,3 (Pole Tip Saturation) causes reduced EO



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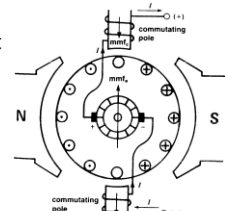


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Commutating Pole
Field proportional to load

Compensate neutral shift
Due to armature reaction
(Slightly greater than Armature reaction flux)

Note, does not change Saturation at main poles
-> EO still effected.



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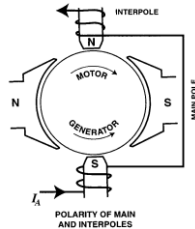


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Note polarity of interpoles with respect to the polarity of main poles.

For motor, polarity of interpole is same as main pole preceding it in direction of rotation.

For generator, polarity of interpole is same as main pole following it in direction of rotation.

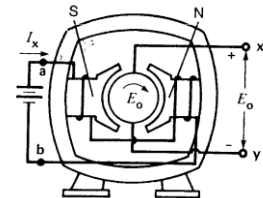


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Separate Excited Generator
Field Poles – electromagnets

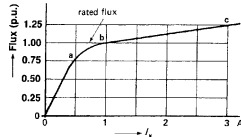


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No Load operation
Saturation Curve
Field Flux vs Exciting amps
(similar to B-H Curve)
Designed to operate at "knee" of point a & b.

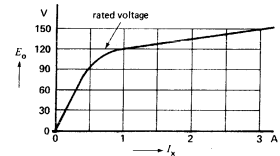


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No load saturation curve
Reversing field amps
reverses polarity.
Reversing rotation
reverses polarity

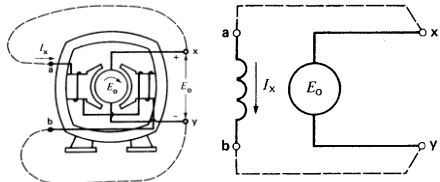


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Shunt Generator – no external field source needed



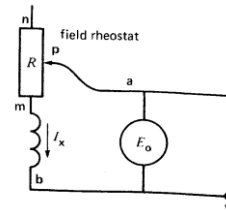
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Voltage Control Nonlinear

Moving P to N, reduced E_o

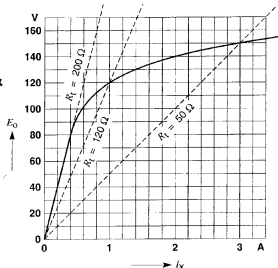
Moving P to M, increases E_o



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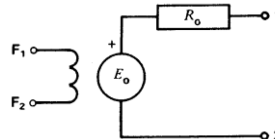
E_o no-load – intersection of Saturation curve & R_F
For this example:
R_F > 200 Ω E_o=0
Critical Value



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E_o = no-load terminal voltage
R_o = Armature resistance
1&2 are armature terminals
F₁&F₂ are field terminals



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Exciting current constant, speed constant, E_o constant
E₁₂ depend on drop across R_o
Load Curve Shown – typical drop less than 10%
(Pole Tip Saturation also leads to E₁₂ drop)
Shunt Generator – typical drop about 15% due to E_o drop

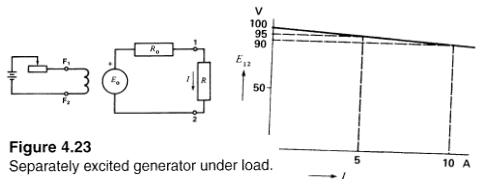


Figure 4.23 Separately excited generator under load.



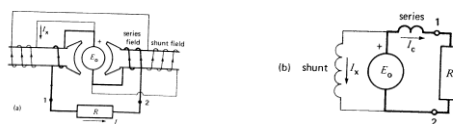
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Compound Generator – Series & Shunt Coils

Series coil same direction as Shunt – mmf adds

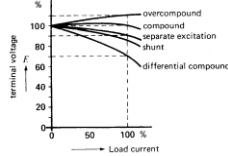
E_o raises as load increases maintaining E₁₂



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Over-compound generator E_{12} increases.
 Differential-compounded – Series coil
 opposite direction – mmf subtracts, E_O drops
 as load increases.

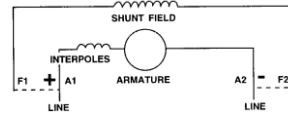


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Shunt Generator

All connections for counterclockwise rotation facing OE. For
 clockwise rotation, interchange A1 and A2.

(Some OEMs connect interpole winding on the A2 side of the
 armature.)

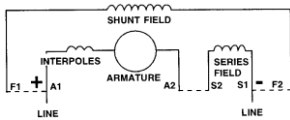


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Compound Generator

Shunt field may be either self-excited or separately excited.

When the shunt field is
 separately excited, the same polarities must be observed for a
 given rotation.



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Poles = # Brush sets
 Larger Machine -> More poles -> More brush sets
 Control amps per brush (current density)

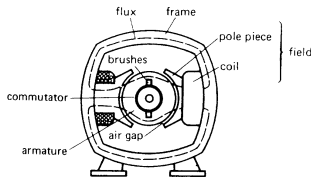
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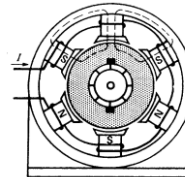
Generator construction
 Field Stationary Electromagnet – Salient Poles
 Air Gap 1mm - 5mm



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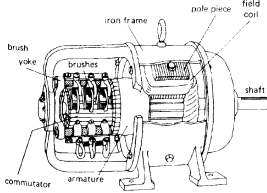
Pole Polarity – Bonus Question:
 What is wrong with this figure?



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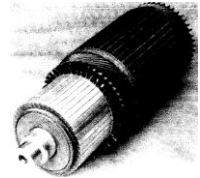
4 pole shunt generator that has 3 brushes per brush set



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Armature Construction
Rotating
Commutator, Iron Core, & Coils



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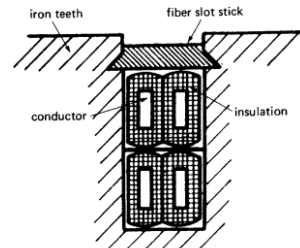
Laminated iron
Slots for
conductors,
Insulated with
mica / paper



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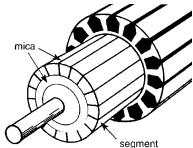
Slot Sticks
retain
conductor
Round vs
rectangular
conductor



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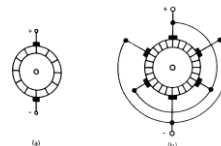
slots = # coils = # commutator sections
Mica insulator between commutator
Coils connected to commutator
Eccentricity causes brush bounce -> arcing



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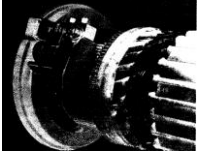
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Brush set connection – alternating + and –
(a) Two pole generator
(b) 6 pole generator

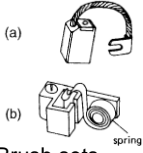


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a. Carbon brush and lead
b. Brush holder and spring



(a)
(b)

Brush sets –
Yoke – rotate to neutral zone
Spring maintain force

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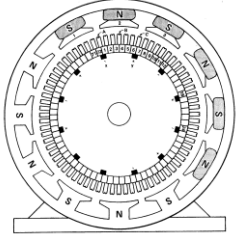
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slots = # coils = # commutator sections
72 slots

poles = # Brush groups
12 poles

12 pole-72 coil
DC Generator



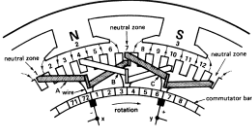
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A & C coil in neutral zone and connected to brush
Coil B under pole
Coil Pitch width of Pole.
For this example, coil pitch = $360^\circ/12 = 30^\circ$

$E_{xy} = E_{12} + E_{23} + E_{34} + E_{45} + E_{56}$



Interpoles not shown

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Example 4-2

The generator in Fig. 4.38 generates 240V between adjacent brushes and delivers a current of 2400A to the load.

Calculate

- The current delivered per brush set
- The current flowing in each coil
- The average voltage induced per coil

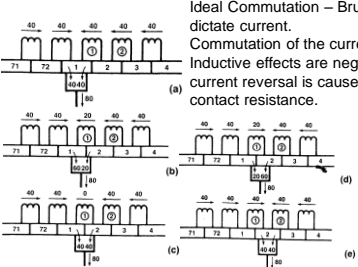
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Ideal Commutation – Brush resistance dictate current.
Commutation of the current in coil 1.
Inductive effects are neglected and current reversal is caused by the brush contact resistance.



(a) (b) (c) (d) (e)

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Practical Commutation – inductance opposes change in current

$E = L \Delta i / \Delta t$

$E =$ induced voltage (V)
 $L =$ inductance of coil (H)
 $\Delta i / \Delta t =$ rate of change of current (A/s)

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Practical Commutation – High current density -> overheating - Reducing turns per coil reduces L -> more coils = less turns per coil - Large Machines more coils to minimize overheating

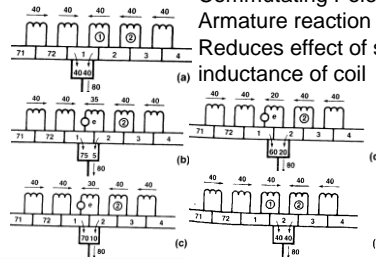
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Commutating Pole mmf > Armature reaction mmf
Reduces effect of self inductance of coil



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Chapter 5 next session



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End of Session 2:
DC Machines
and Efficiency

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