

2X-Machine Losses and Ratings

ECEGR 3500

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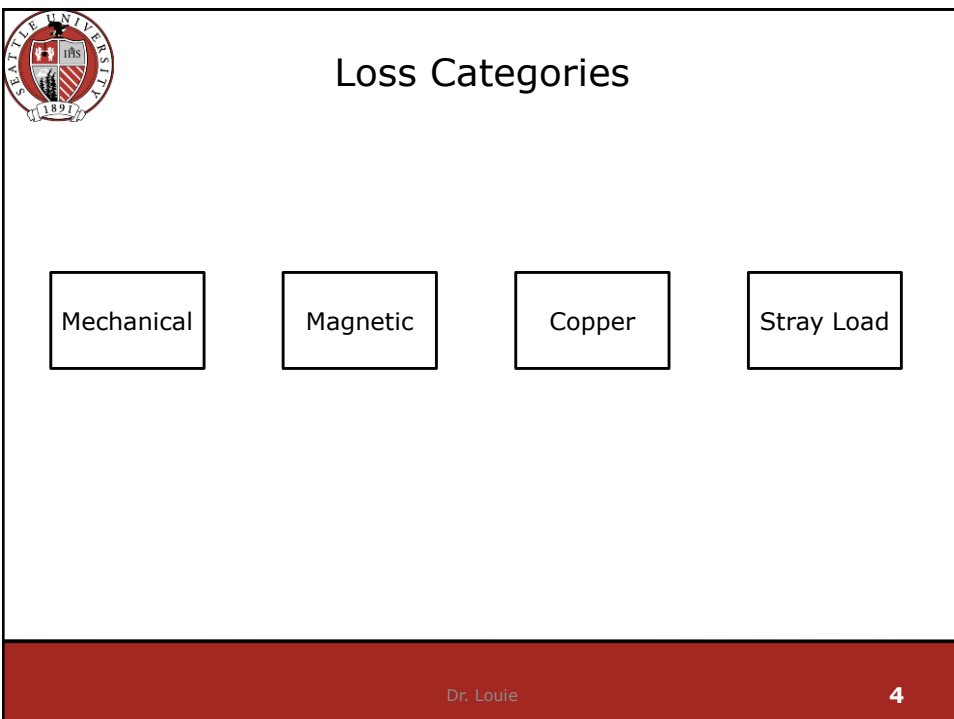
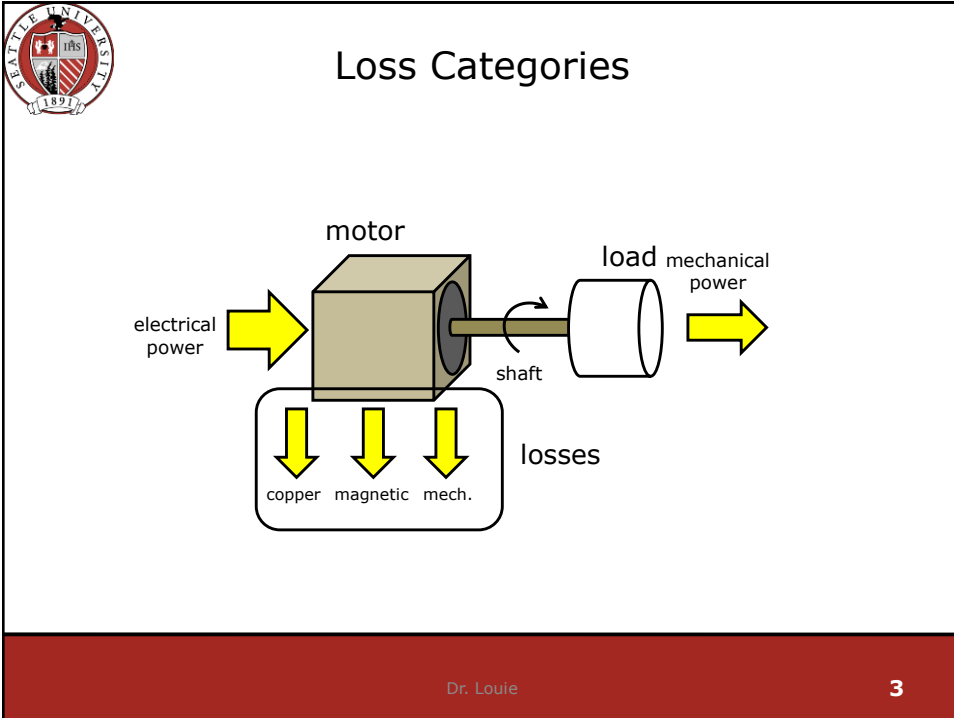
Electrical Energy Systems

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Overview

- Loss Categories
- Rotational Losses
- Electrical Losses
- Stray Losses
- Efficiency
- Life Expectancy
- Insulation
- Temperature Rise





Mechanical Losses

- Causes:
 - Friction of bearings
 - Friction between brushes and commutator
 - Windage (drag on the armature caused by the air around it)
- Tend to increase with rotational speed



Magnetic (Iron) Losses

- Causes:
 - Hysteresis
 - Eddy-currents
- Tend to increase with rotational speed
- Range from 0.5W/kg to 20 W/kg
- Operating the machine in the linear region and at a low flux density (make the machine physically larger) decreases magnetic losses



Rotational Losses

Mechanical and magnetic losses are often grouped together as “rotational losses”

$$\begin{array}{|c|} \hline \text{Mechanical} \\ \hline \text{Loss} \\ \hline \end{array} + \begin{array}{|c|} \hline \text{Magnetic} \\ \hline \text{Loss} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Rotational} \\ \hline \text{Loss} \\ \hline \end{array}$$



Copper Losses

- Power loss is equal to i^2R
- Contributors to copper losses:
 - Armature-winding loss
 - Field winding loss
 - Interpole field-winding loss (see Armature Reaction)
 - Compensating field-winding loss



Stray Load Loss

- Stray load loss: a “catch all” term for the losses that are unaccounted for in the previous categories
 - Commutation losses
 - Distorted flux due to armature reaction
- Approximately equal to 1% in large machines (>100 horsepower)



Efficiency (Generator)

- Efficiency of a machine is the ratio of output power to input power
- Output power

$$P_o = P_{in} - P_{Loss} = T_s \omega_m - P_r - P_{cu}$$
 - T_s : shaft torque (Nm)
 - P_o : output power (W)
 - P_r : rotational losses (W)
 - P_{cu} : copper losses (W)
- Efficiency is:

$$\eta = \frac{P_o}{P_{in}} \times 100 = \frac{P_o}{T_s \omega_m} \times 100$$



Efficiency (Motor)

- Output power
 - $P_o = P_{in} - P_{Loss} = v_s i_s - P_{cu} - P_r$
 - v_s : source voltage (v)
 - i_s : source current (A)
 - P_r : rotational losses (W)
 - P_{cu} : copper losses (W)
- Efficiency is:

$$\eta = \frac{P_o}{P_{in}} \times 100 = \frac{P_o}{v_s i_s} \times 100$$



Example

A DC motor outputs 1.2kW. The rotational losses are 80W and the copper losses are 60W. Compute the input power.



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$$P_{in} = P_o + P_L = 1200 + 80 + 60 = 1340W$$



Efficiency

- At a given speed (independent of power output) rotational losses are nearly constant
 - Constant loss
- Copper losses are dependent on load (i^2R)
 - Variable loss
- Total losses = constant loss + variable loss
- Expect efficiency to vary with load



Example

The copper losses of a series dc motor are:

- Armature winding: 500W
- Series field winding: 25W

Estimate the copper losses when the motor is at 50% load.



Example

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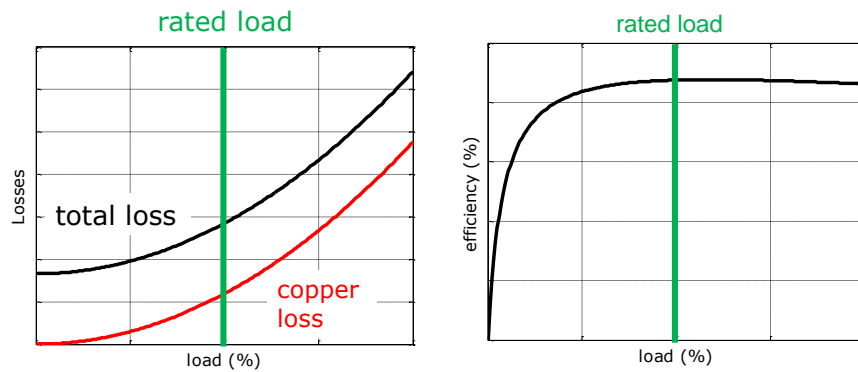
$$\text{Armature loss} = 0.5^2 \times 500 = 125\text{W}$$

$$\text{Field winding loss} = 0.5^2 \times 25 = 6.25 \text{ W}$$

Note: both armature and field winding current increase by the same amount in a series dc motor.



Efficiency



Machines often designed for maximum efficiency at rated power



Life Expectancy

What determines the power rating of a machine?

How do operating conditions effect the life expectancy of a machine?

Deleterious Insulation Factors

- Time
- High temperature
- Humidity
- Chemicals
- Fungus
- Dust
- Rodents
- Ozone
- Vibration



Life Expectancy

Common insulation deterioration causes

1. Heat (both high and extreme low)
2. Humidity
3. Vibration
4. Acidity
5. Oxidation
6. Time

Common failure mode: Organic insulators crystallize and become brittle. Vibration causes cracking and failure.



Life Expectancy

- Excessive temperature reduces insulation life
 - Insulation failure causes machine failure
- Empirical testing:
 - Service life decreases by 50% for every 10° C increase in temperature (Arrhenius Equation)
 - A motor designed for 8 years of life at 105° C will only last one year at 135° C



Example Insulation Classes

Class	Temp. (°C)	Example Materials (rated for 20,000 to 40,000 hours continuous)
A	105	Cotton, silk, impregnated paper
B	130	Mica, fiber glass, asbestos
H	180	Silicone elastomer, mica, fiber glass with bonding substances such as resins
R	220	See Std.
S	240	See Std.
C	+240	Porcelain, glass, quartz

See IEEE Standards 96, 97, 98, 99 and 101.



Temperature Rise

- Temperature rise under rated conditions determines required insulation
- Test procedure outline:
 - Control environment temperature between 10° C and 40° C
 - Load machine to rated value
 - Wait for thermal equilibrium
 - Measure temp. of hottest spot of machine
 - temp. rise = hot spot temp. – ambient temp
 - Consult insulation rating for maximum temperature rise



Temperature Rise

- Conversion of insulation class to maximum temperature rise:
 - maximum temp. rise = insulation class – 40° C (maximum ambient)
- Example: Class A (105° C) has a 65° C maximum temperature rise



Temperature Rise

A 10kW machine is operated in a controlled environment until thermal equilibrium is obtained. The ambient temperature is 30° C and the temperature of the motor is 125° C. Can insulation Class B (130° C, temperature rise of 90° C) be utilized?



Temperature Rise

A 10kW machine is operated in a controlled environment until thermal equilibrium is obtained. The ambient temperature is 30° C and the temperature of the motor is 125° C. Can insulation Class B (130° C) be utilized?

No. Temperature rise for Class B is 90° C. The temperature rise of the motor is 95° C.

How might the manufacturer redesign the motor for it to be compliant?



Summary

- Machines have mechanical, magnetic, copper and stray load losses
- Copper losses increase with loading of machine, rotational losses increase with speed of the machine
- Maximum efficiency of machines occurs near rated power ($\sim 80-90\%$)
- Excess heat shortens life expectancy of machine insulation