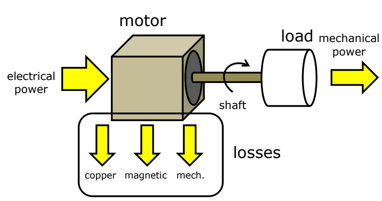
27-Machine Losses and Ratings

ECEGR 450
Electromechanical Energy Conversion

Overview

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

Loss Categories



Loss Categories

Mechanical	Magnetic	Copper	Stray Load

All machines have these losses, not only DC machines

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"

Mechanical Loss + Magnetic Loss = Rotational Loss

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

The copper losses of a series dc motor are:

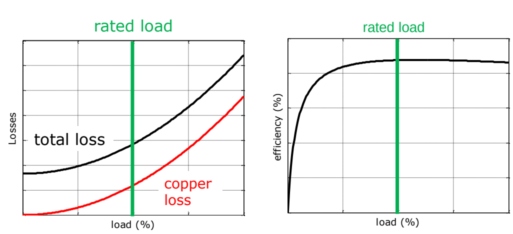
- Armature winding: 500W
- Series field winding: 25W

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

Field winding loss = $0.5^2 \times 25 = 6.25$ 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 10º C increase in temperature
  - A motor designed for 8 years of life at 105º C will only last one year at 135º C

Example Insulation Classes

Class	Temp. (ºC)	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 boding 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 10º C and 40º 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 – 40º C (maximum ambient)
- Example: Class A (105º C) has a 65º C maximum temperature rise

Temperature Rise

A 10kW 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?

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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 (~80-90%)
- Excess heat shortens life expectancy of machine insulation