EEEN313/ECEN405

Motor Parameters

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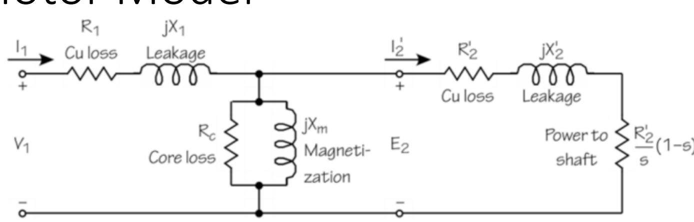
Induction Motor Model



- Complete single-phase equivalent IM motor model with rotor reflected

$$P_{devel} = P_{airgap} - P_{Cu} = |I_2|^2 R_2\left[\frac{1-s}{s}\right]$$

- Data for the model are obtained from motor tests such as DC Test, Blocked-rotor and no-load test (not discussed here)

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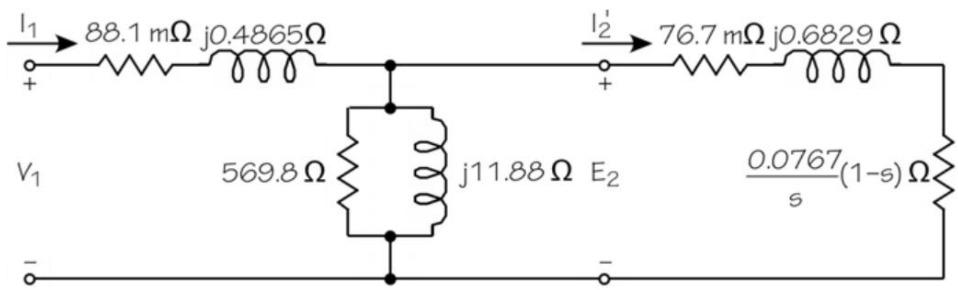
Using the model

- This motor is a 460-V, three-phase, 50-hp, 60-Hz, 4-pole induction motor. Its full-load speed is 1,770 rpm.



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Some highlights

$$s = \frac{1800 - 1770}{1800} = 0.01667$$

Shaft Resistance

$$R_{shaft} = \frac{0.0767}{0.01667}(1 - 0.01667) = 4.5244 \ \Omega$$

I_2' (with a chosen angle of 0°)

$$\%\eta = 100\frac{50 \times 746}{39.21 \times 10^3} = 95.1\%$$

$$P_{out} = \frac{50}{3}746 = 12.43 \text{ kW}$$

$$I_2^{'} = \sqrt{\frac{P_{out}}{R_{shaft}}} = \sqrt{\frac{12.43 \times 10^3}{4.5244}} = 52.42\angle 0° \text{ A}$$

Rotor Voltage

$$E_2 = I_2^{'}(0.0767 + j0.6829 + 4.4244) = 243.83\angle 8.4° \text{ V}$$

$$I_{parallel} = \frac{E_2}{j11.88} + \frac{E_2}{569.8} = 20.53\angle -80.4° \text{ A}$$

$$I_1 = I_2^{'} + I_{parallel} = 59.41\angle -19.9° \text{ A}$$

$$V_1 = E_2 + I_1(0.0881 + j0.4865) = 263.2\angle 13.4° \text{ V}$$

$$P_{in/phase} = |V_1||I_1| pf = 263.2 \times 59.41 \times 0.836 = 13.07 \text{ kW}$$

Input Power Factor

$$pf = \cos(13.4 - (-19.9)) = 0.836 \text{ lagging}$$

$$P_{in} = 3P_{in/phasse} = 3 \times 13.07 = 39.21 \text{ kW}$$

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Summary of the example

- The calculations tell us how the input voltage (stated as line voltage) compared with stated specifications (455.9V vs 460V three phase).
- To find the starting current for the motor, we need to have s = 1 (rotor stationery) i.e the 'shaft' resistance is a dead short (0 ohms).
- We need find the input impedance of the entire circuit.

$$Z_{in} = (0.0881 + j0.4865) + \left(569.8 \| j11.88 \| (0.0767 + j0.6829)\right)$$
$$= 1.1434\angle 82.1^\circ\ \Omega$$

$$I_{start} = \frac{V_1}{Z_{in}} = \frac{263.2}{1.1434\angle 82.1^\circ} = 230.2\angle -82.1^\circ\ \text{A}$$ Ignoring phase angle of V_1

$$pf_{start} = \cos(-82.1) = 0.137\ \text{lagging}$$

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Starting Current

- From the example, the starting current is 4 times the full-load running current

$$I_{start} = \frac{V_1}{Z_{in}} = \frac{263.2}{1.1434\angle 82.1^\circ} = 230.2\angle -82.1^\circ\ \text{A}$$

$$I_1 = I_2' + I_{parallel} = 59.41\angle -19.9^\circ\ \text{A}$$

- This means the supply voltage will drop until the motor starts rotating.
- Reducing this starting current by reducing the line voltage can temporarily avoid circuit breaker tripping.

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Choosing a Motor

- Motor name plate
- How speed and torque are related
- Sizing a new motor

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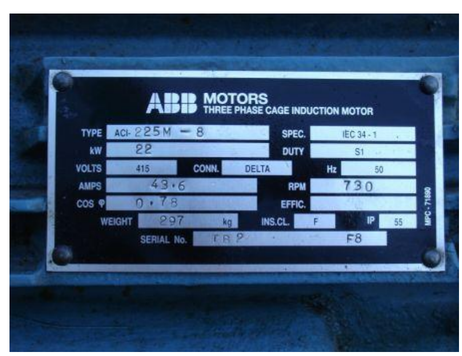
Name Plate

Source: EECA

AS/NZS1359.5:2004 section 1.5 requires motor rating plates to be marked in accordance with Section 9 of AS/NZS 1359.101:

- manufacturer's name or mark,
- Manufacturer's serial number, or identification mark,
- rated output(s),
- rated voltage(s) range of voltages,
- rated speed(s) range of rated speeds,
- IP code,
- number of phases,
- class(es) of rating of the machine if designed for other than rating for continuous running duty S1
- rated frequency or range of rated frequency.

For a full list of marking requirements see the standards.



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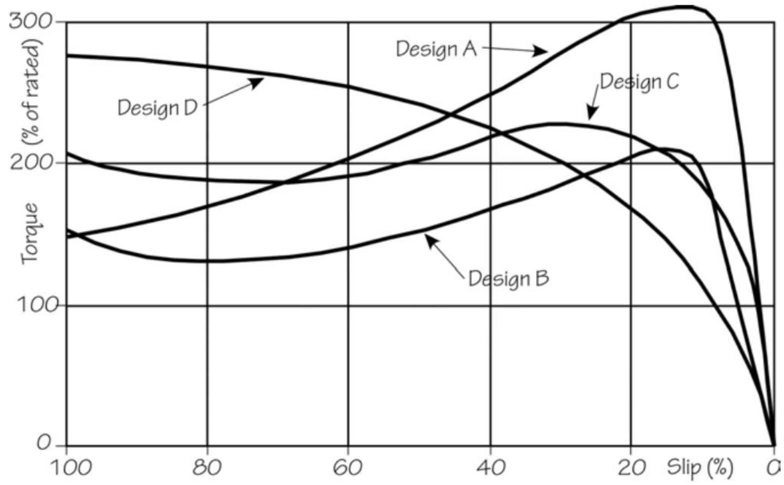
Torque vs Speed

- NEMA induction motor torque curves
- Design B is most common motor
- 100% is zero speed
- 200% torque is breakdown torque for design B – high torque, speed drops rapidly
- Valley is pull-up torque
- So why different curves?
- Design A has the highest breakdown torque – Speed doesn't vary as much as B.



$$T_{out} = \frac{P_{out}}{\omega_s}$$

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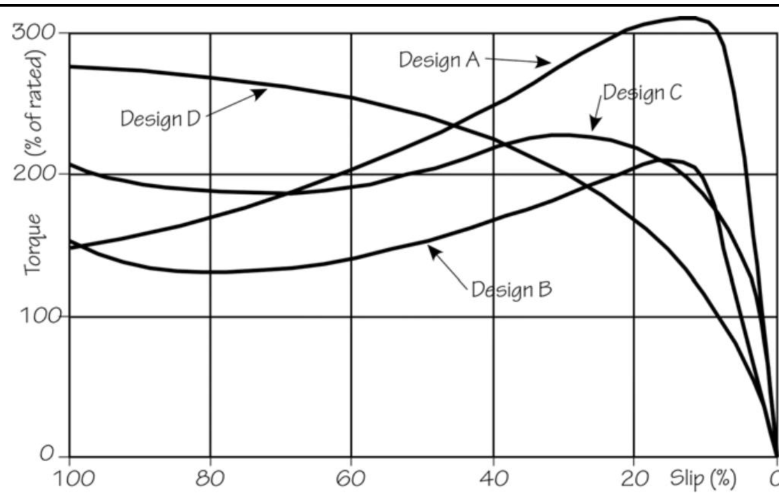
Torque vs Speed

- Design B has modest starting current and can be started with powerline voltage
- Design C and D have high starting torque
- Design B and C have moderate starting current
- Design D doesn't require high starting current.



$$T_{out} = \frac{P_{out}}{\omega_s}$$

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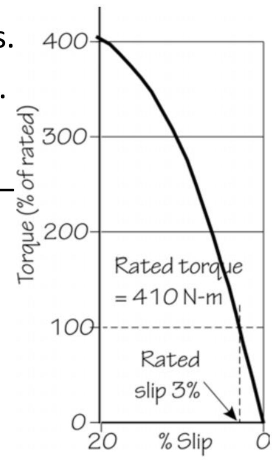
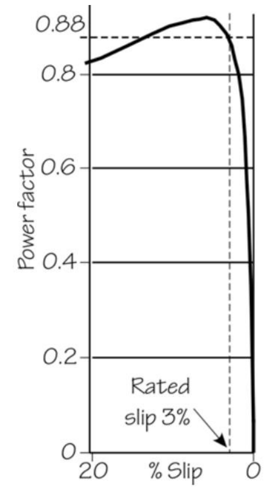
Over motoring – Overdesigning (Not good)

- Lets look at some scenarios and curves.
- All curves deliver full load at slip of 3%.
- Full load rated torque of 410 N-m
- Suppose we want to drive at 275 N-m – will run at 2% slip
- Not stressing motor right?
- But look at PF curve
- PF decreases as slip drops
- So over motoring is not good!
- We are paying extra to get us poor power factor!





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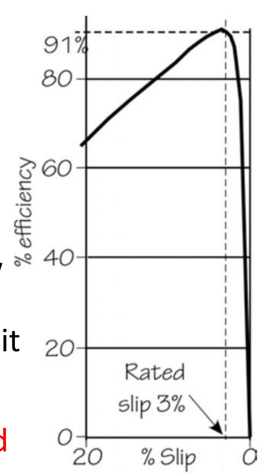
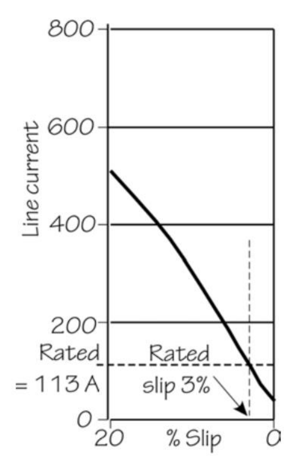
Over motoring – Efficiency vs Line Current

- Peak Efficiency achieved at full rated slip.
- If we run 'light' at 2% slip, efficiency drops to 85%
- So over motoring drives the efficiency down – more money for same job.
- Over sized motor doesn't draw rated line current because its running below capacity.
- While the current is lower than rated, it hasn't decreased much (not as much 2/3rd)
- So it takes extra power for a given load to drive with oversized motor.





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So what do we do?

- When we select a motor for a given load, we should select a motor that matches that load while using the motor at its full rating.
- If a load requires 500 N-m of torque, select a motor that is designed to deliver 500 N-m as its full load.
- But what if I can't find such a motor? Should I go high or low?
- Many motors have a service factor of 1.15, so a motor that can deliver at full load 440 N-m won't be overloaded by a load of 500 N-m ($440 \times 1.15 = 506$).
- So the proper choice would be a 440 N-m motor.

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Motor Selection based on matching Load

- To select a motor – choose a motor whose rated torque equals load torque
- Or whose HP rating is equal to load's HP
- Not that easy and leads to wrong decision
- Our example: centrifugal fan that requires a torque of 70 N-m at 1,800 rpm and 100 N-m at start.
- We are to select a motor to properly drive this load. The only other thing we know about the fan is that the power required is proportional to the cube of the shaft speed.
- Our solution – finding the HP required by the fan and pick some from catalogue – Lets do it tomorrow!

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