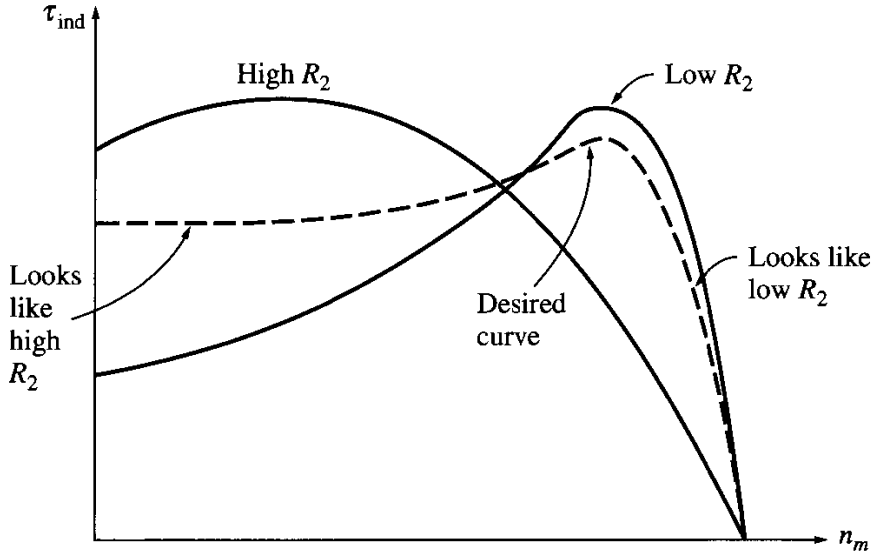
7.6 Variations in Induction Motor Torque-Speed Charateristics

Based on τ_{ind} equation (7-48), we found some dilemmas:

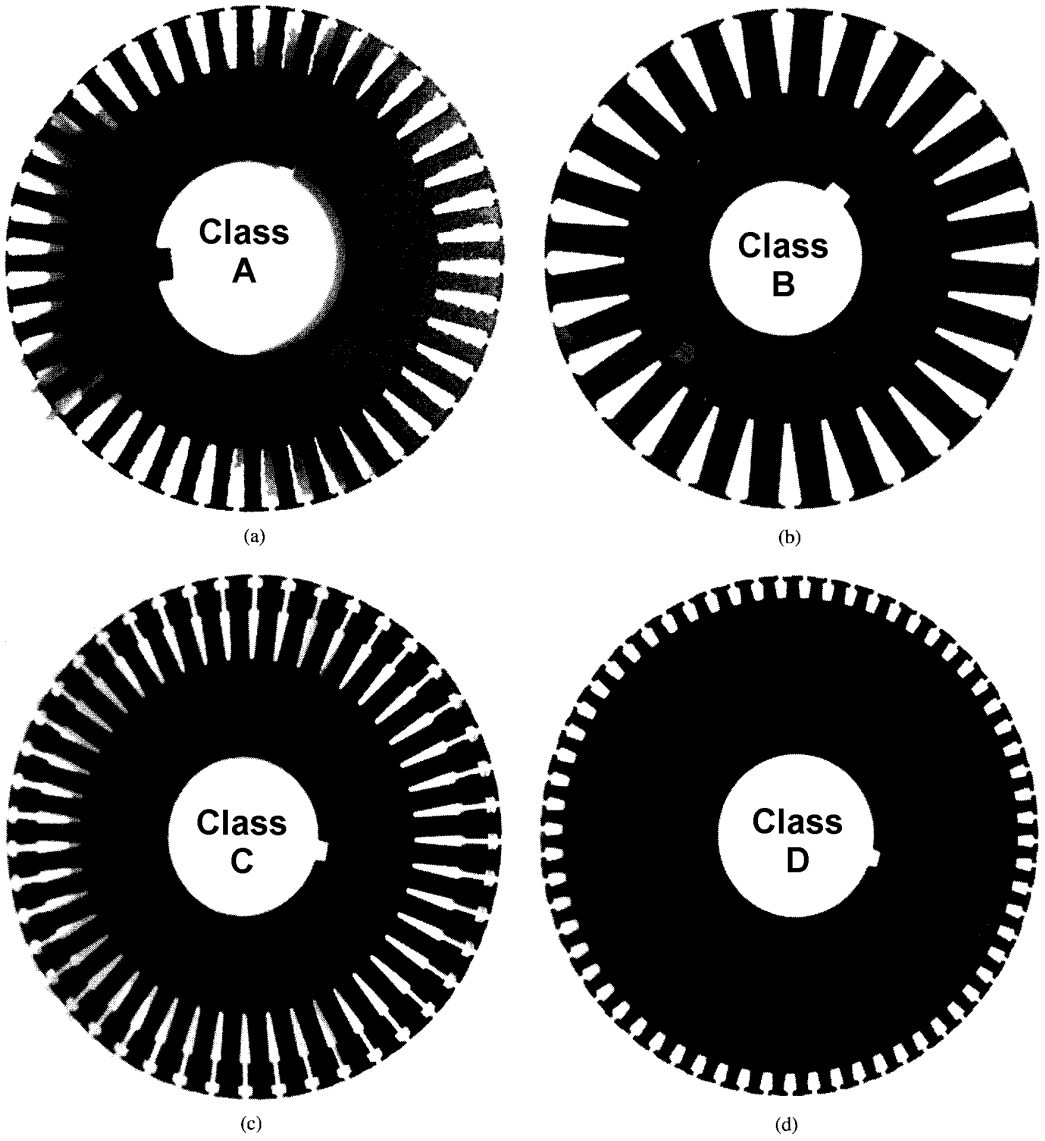
- Increasing τ_{start} at $s = 1$ with a fixed V_{TH} requires increasing s_{max} (decreases n_{max}) and increasing R_2 (and hence R_R) which leads to poor motor efficiency at steady-state. Also, $P_{conv} = (1 - s)P_{AG}$. So, a lower s_{max} means a smaller P_{conv}.
- Conversely, lowering R_2 (and hence R_R) with a fixed V_{TH} leads to better motor efficiency at steady-state and P_{conv}, but the motor has a decreased τ_{start} and increased starting current (could trip breakers).
- These contrasting approaches are illustrated in Figure 7-22 along with a compromise design.
- We want to avoid wound rotor induction motors, where it is easy to change R_R (and R_2), due to cost, efficiency, and maintenance concerns.

Figure 7-22 | A torque–speed characteristic curve combining high-resistance effects at low speeds (high slip) with low-resistance effects at high speed (low slip).



- It is possible with induction motors with cage rotors to vary R_2 and X_2 by changing the cross-section of the rotor bars. Some examples are shown in Figure 7-23 for different National Electric Manufacturers Association (NEMA) design classes.

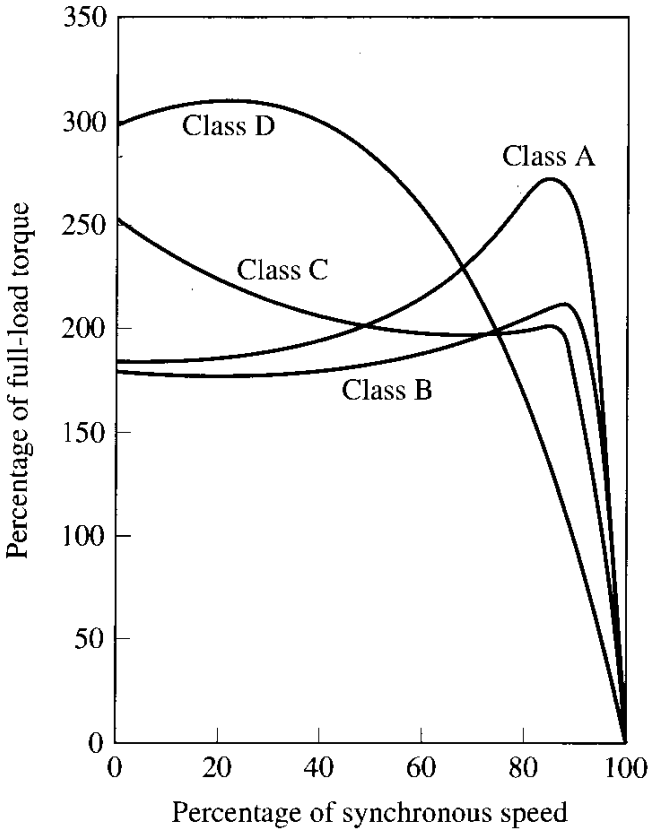
Figure 7–23 | Laminations from typical squirrel-cage induction motor rotors, showing the cross section of the rotor bars: (a) NEMA design class A—large bars near the surface. (b) NEMA design class B—large, deep rotor bars. (c) NEMA design class C—double-cage rotor design. (d) NEMA design class D—small bars near the surface. *(Courtesy of MagneTek, Inc.)*



- The <u>class A</u> rotor bars are thick and near the surface which leads to **low R_2** and low X_2 (less flux leakage) $\Rightarrow$ lower s_{max}/higher n_{max} and lower τ_{start} with high starting current.
- The <u>class D</u> rotor bars are thin and near the surface which leads to **high R_2** and low X_2 (less flux leakage) $\Rightarrow$ higher s_{max}/lower n_{max} and increased τ_{start} and lower starting current.
- The <u>class B</u> rotor bars are thick and go deeper into the rotor which leads to **low R_2** but higher X_2 (more flux leakage) in comparison at high slip $\Rightarrow$ a compromise design that gives increased τ_{start} and lower starting current.

- The class C rotor bars are thinner and go deeper into the rotor which leads to **higher R_2** nad higher X_2 (more flux leakage) $\Rightarrow$ a compromise design that gives increased τ_{start} and lower starting current, but lower τ_{max}.
- Sample torque versus speed curves are shown in Figure 7-24.

Figure 7–24 | Typical torque–speed curves for different rotor designs.



Design Class A- 'standard' induction motor. At full-load τ_{FL} the slip is <5%. τ_{max} is 2-3 times τ_{FL} and $s_{max} < 20\%$. $\tau_{start} > \tau_{FL}$ and starting current is 500-800% of the full-load current.

Design Class B- 'improved' induction motor. At full-load τ_{FL} the slip is <5%. τ_{max} is at least 2 times τ_{FL} and $s_{max} < 20\%$. $\tau_{start} > \tau_{FL}$, but starting current is significantly reduced (~25% less than of class A).

Design Class C- Higher τ_{start} with lower starting current, but lower τ_{max}. Cost more to build. Good for applications needing higher τ_{start}.

Design Class D- Much higher τ_{start} with lower starting current, but high slip at τ_{max}. Good for applications needing high τ_{start}.