Motor Slot Fill and Design for Manufacturability

WINDINGS
Slot Fill Topics

- What is Slot Fill Factor?
- How to Calculate Total Slot Fill
- Slot Fill and Manufacturability
- Design for Manufacturing Solutions
What is Slot Fill Factor?

- What is the Slot Fill (SF) Factor:
  - The slot fill factor is ratio of the cross-sectional area of the amount of material inside of a stator slot compared to the amount of total available space of a bare slot
  - Copper slot fill vs Total slot fill

- Why is Slot Fill Important?
  - Copper slot fill is useful during the design of the motor
    - High slot fill designs can allow for increased conductor area or decreased slot area to reduce losses
  - Total slot fill is more useful during manufacturing
    - The slot fill factor will affect the difficulty of being able to insert the wire and other materials into the slots
How to Calculate Total Slot Fill

- Total slot fill includes the cross-sectional area of all materials going into the slot
  - Wire, liners, wedges, etc.

- Determine the following:
  - Total cross-sectional area of bare slot: $A_{Slot}$
  - Total cross-sectional area of all insulating materials: $A_{Materials}$
  - Total area of magnet wire: $A_{Total\ Wire}$

- Total Slot Fill
  - $S_{F_{Total}} = \frac{A_{Total\ Wire} + A_{Materials}}{A_{Slot}}$
How to Calculate Total Slot Fill

- Total cross-sectional area of bare slot: $A_{Slot}$
  - Use geometry or CAD file to estimate bare slot area

- Total cross-sectional area of all insulating materials
  - Width and thickness of liners, wedges, phase separators, etc.
  - $A_{Materials} = A_{liner} + A_{wedge} + \cdots$
How to Calculate Total Slot Fill

- **Total area of magnet wire**
  - Calculate area of one wire, including insulation
    - \( A_{\text{wire}} = (\pi r_{\text{wire}}^2) \)
  - Multiply the wire area by the number of wires in parallel and the number of turns per coil to get the total coil area
    - \( A_{\text{coil}} = A_{\text{wire}} \times N_{\text{parallel}} \times TPC \)
  - Convert total coil area to a diameter
    - \( D_{\text{coil}} = 2 \times \sqrt{\frac{A_{\text{coil}}}{\pi}} \)
  - Square the diameter to get estimated coil area
    - \( A_{\text{Est}} = D_{\text{coil}}^2 \)
  - Multiply the estimated coil area by the total number of coils per slot
    - \( A_{\text{Total wire}} = A_{\text{Est}} \times \#_{\text{coils/slot}} \)
Slot Fill and Manufacturability

- Typical Slot Fill Factors vs Difficulty:
  - Very Difficult: 80+%%
  - Difficult: 70-80%
  - Normal: 60-70%
  - Typically apply at the inserting operation

- The ranges of each difficulty will vary depending on other design factors
  - Stack length to diameter aspect ratio
  - Slot opening
  - Coil bundle size
  - Magnet wire size
Slot Fill and Manufacturability

- Additional factors that affect the manufacturability
  - Slot shape
  - Lamination variation
  - Lay of the wires in the slot
  - Winding: random vs precision
  - Type of slot insulation

- Application specific validation techniques
  - 3D printed stacks
  - Steel EDM stacks
Design for Manufacturing Solutions

- **Slot opening**
  - Minimum of 2x the wire diameter, typical 3-4x the wire diameter
  - Use protective wire guides

- **Slot Shape**
  - Round vs square bottom

- **Large coil size**
  - Double back: 1/2 turns, 2x the coil per set
  - 2 Coils Make 1: 1/2 turns, 2x the coil sets

- **Magnet wire size**
  - Typical sizes range from: 22AWG – 28 AWG

- **Manufacturing Techniques**