REDUCTION OF ACOUSTIC NOISE AND VIBRATIONS DUE TO MAGNETIC FORCES IN SYNCHRONOUS MACHINES

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Summary

I. Magnetic noise generation process
   a) Magnetic forces
   b) Resonance phenomenon
   c) Tangential Vs radial forces

II. Analytical characterization of force harmonics
    a) Principle
    b) General case
    c) Particular cases

III. Review of calculation methods
     a) Analytical methods
     b) Semi-analytical methods
     c) Numerical and hybrid methods

IV. Low-noise design guidelines
    a) Machine design
    b) Control design

V. Experimental characterization
   a) EMA, ODS, OMA
   b) Examples

VI. Application case: reduction of vibration in a PMSM with the use of MANATEE® software
**Effect of radial force harmonics**

Order $m$ : radial deflections of order $m$

**Effect of tangential force harmonics**

Order $m=0$ : torsional deflections

Order $m>1$ : radial deflections of order $m$
\[ B_r(\theta, t) = B_r^r(\theta, t) + B_r^s(\theta, t) = \lambda(\theta, t) \left[ f_{nm}^r(\theta, t) + f_{nm}^s(\theta, t) \right] \]

Permeance «slotting» harmonics:
- \( m = k_s Z_s, f = 0 \) for stator slotting (Ps)
- \( m = k_r 2p, f = k_r 2pf_r \) for rotor inset magnets (Pr)
- \( m = k_s Z_s \pm k_r 2p, f = \pm k_r 2pf_r \) for rotor / stator slotting interactions (Psr)

Magnet mmf harmonics:
- \( m = (2km+1)p, f = (2km+1)f_s \) (Fm)

Armature winding harmonics:
- \( m = p, f = f_s \) for fundamental
- higher time harmonics due to PWM
- space subharmonics for non-overlapping concentrated winding (ex \( m = 2, f = f_s \)) (Fa)

- Radial and tangential flux density have same harmonic contents
- The combination of high spatial order harmonics of flux density can create low order of radial force
- The largest noise and vibration come from low spatial order forces (<6)
• Application with MANATEE® software on a SPMSM:
  - no load variable speed spectrogram
  - full load variable speed spectrogram including PWM
  - study of the optimum pole arc to pole pitch ratio