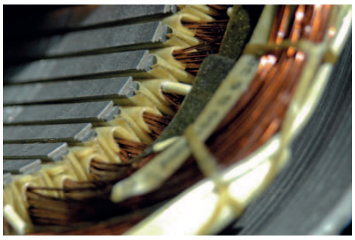
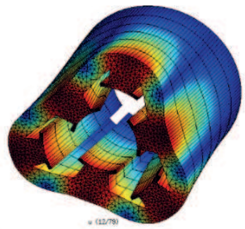
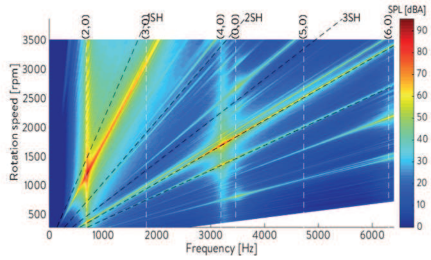
ENGINEERING CONSULTING RESEARCH

ACOUSTIC NOISE AND VIBRATIONS DUE TO MAGNETIC FORCES IN ROTATING ELECTRICAL MACHINES







1 OBJECTIVES

The objectives of the technical training are the followings:

- understand the phenomenon of audible noise and vibrations due to magnetic forces in main types of rotating electrical machines (e.g. PMSM, SRM, IM)
- identify the root cause (e.g. winding, saturation, slotting, eccentricity, PWM) of a given vibration or acoustic noise harmonic based on experimental data interpretation, analytical calculations or simulations
- find some mechanical and electrical re-design solutions to mitigate a given harmonic once it has been identified
- know the advantages and drawbacks of main simulation methodologies for the assessment of audible electromagnetic noise and vibrations
- adapt a given electrical machine design workflow to include e-NVH performance
- design a NVH test campaign to characterize the vibro-acoustic behaviour of an electrical machine / understand the root cause of acoustic noise and vibration / improve its numerical simulation design process

The training is illustrated with examples coming from scientific literature, EOMYS experimental data and simulations using the MANATEE® software dedicated to the fast electromagnetic and vibroacoustic design of electrical machines.

2 PUBLIC

Profile: Electrical Engineers, Mechanical Engineers, NVH Test Engineers
Number: max 15 persons to ease interactions between the trainer and the attendees

3 ORGANIZATION

3.1 Location

The training can be delivered directly at your office upon request. Alternatively, a remote training session can be organized based on a video conference tool.

3.2 Language

The training is done in English or French – all written documents are in English.

3.3 Duration

The full training lasts 18 hours (6 sessions of 3 hours) during 3 days. The duration and content of the training can be adapted to your specific needs.

3.4 Deliverables

The technical training is based on a detailed PowerPoint presentation (~500 slides). Due to large number of slides, a full paper copy of the presentation is not delivered by EOMYS to each attendee (only summarizing slides in each part). The slides used during the training are delivered as a .pdf file.
The presentation includes some extended bibliographic references, audio files and animation files.

3.5 Cost

The training cost depends on the type and location (for a face to face training or distant training), the number of attendees and training options (e.g. application of the training on a specific case provided by the customer). For a detailed quotation, please contact us at contact@eomys.com.

4 CONTENT

Note that the training content can be customized to fit with your specific application.
As an option, a special electrical machine topology or some particular experimental data provided by the customer can be analysed during the technical training.

Introduction

1. Importance of acoustic noise & vibrations
2. Acoustic noise sources in electrical machines
3. Interactions between electromagnetic and NVH design
4. Basic working principles of electrical machines (option)
5. Main topologies used in automotive applications (option)

A. Sound and vibrations: generalities and application to electric machines

Objective: recall the fundamentals of noise and vibrations that will be used all along the training, but make the link between general notions and the field of electrical machines.

- A1. Vibrations
  - A1a. Case of the linear resonator: stiffness, mass, damping, quality factor
  - A1b. Generalization to N d.o.f.
  - A1c. Structural modes
  - A1d. Modal superposition principle
  - A1e. Measurements (hardware)
  - A1f. Standards
  - A1g. General mitigation solutions
- A2. Sound

- A2a. Pressure, velocity
- A2b. Power, intensity
- A2c. Additivity & masking effects
- A2d. Distance & reflection effects
- A2e. Directivity
- A2f. Third octave analysis, dBA
- A2g. Psychoacoustics
- A2h. Radiation efficiency
- A2i. Measurements (hardware)
- A2j. Standards
- A2k. General mitigation solutions

A3. Noise sources in electrical machines
- A3a. Aerodynamic sources
- A3b. Mechanical sources
- A3c. Magnetic sources
- A3d. Contributions

B. Generation process of magnetic noise and vibrations

Objective: detail how the different magnetic force types can excite some of the electrical machine structural modes and radiate acoustic noise.

B1. Magnetic forces in electrical machines
- B1a. Maxwell forces and Laplace forces
- B1b. Magnetostriction
- B1c. Expression and meaning of Maxwell radial and tangential forces
- B1d. Rotating Vs standing force waves
- B1e. Axial magnetic forces

B2. Static effect of magnetic forces
- B2a. Radial and tangential force on outer stator
- B2b. Radial and tangential force on inner rotor
- B2c. Outer rotor case
- B2d. End-winding case

B3. Structural modes of electrical machines
- B3a. Stator lamination and frame assembly modes
- B3b. Rotor modes
- B3c. End-windings modes
- B3d. Damping
- B3e. Effect of temperature

B4. Dynamic effects of magnetic forces
- B4a. Principle of resonance
- B4b. Application to stator / rotor modes

B5. From vibration to acoustic noise: transfer path analysis

C. Analytical characterization of magnetic force harmonics

Objective: detail what are the different types of magnetic force harmonics in terms of frequencies and spatial orders, and relate them to the design parameters.

C1. Principle of harmonic decomposition
- C1a. Fourier transform
- C1b. Calculation rules

C2. Stator mmf harmonics

C3. Rotor mmf harmonics

C4. Permeance harmonics

C5. Flux density harmonics

C6. Main magnetic force harmonics in normal operation
- C6a. Effect of slotting
- C6b. Effect of saturation

C6c. Effect of winding
C6d. Effect of PWM
C7. Case studies
C8. Effect of outer rotor
C9. Effect of PWM
C10. Force harmonics in degraded operation
C10a. Dynamic and static eccentricities
C10b. Uneven airgap
C10c. Inter-turn short-circuit
C10d. Broken bar and demagnetization

D. Calculation techniques of magnetic noise and vibrations

Objective: detail what are the different methods to calculate noise & vibration due to magnetic forces, with their advantages and drawbacks in terms of accuracy, speed, robustness.

D1. Modelling approaches
D1a. Generalities
D1b. Numerical approach
D1c. Analytical approach
D1d. Hybrid methods
D2. Electromagnetic calculations
D2a. Analytical (e.g. permeance / mmf) or semi-analytical methods (e.g. subdomain models)
D2b. Finite element methods
D3. Structural calculation
D3a. Analytical methods
D3b. Finite element methods
D4. Electromagnetic to structural coupling methods
D4a. Maxwell stress method
D4b. Virtual work method
D4c. Equivalent forces
D5. Acoustic calculations
D5a. Analytical methods
D5b. Numerical methods
D5c. Others
D6. Acoustic and vibration synthesis methods
D7. Numerical challenges
D8. Analysis of current numerical software solutions

E. Reduction techniques of magnetic noise and vibrations

Objective: detail all the design rules allowing to reduce noise & vibrations due to magnetic forces, with their advantages and drawbacks.

E1. General techniques
E2. Analytical scaling laws
E3. Electromagnetic design
E3a. Topolopy
E3b. Slot / pole / phase numbers
E3c. Assymetries
E3d. Winding design
E3e. Rotor and stator continuous or stepped skewing
E3f. Pole shape / position
E3g. Magnetization
E3h. Slot and tooth shape / position
E3i. Notches
E3j. Wedges
E3k. Airgap increase
E3l. Others

E4. Control design
  E4a. Generalities
  E4b. Current angle
  E4c. Harmonic current injection
  E4d. PWM strategy
  E4e. Others
E5. Structural design
  E5a. Yoke shape
  E5b. Frame to lamination contact

F. Experimental characterization of magnetic noise and vibrations

Objective: detail how to fully characterize the electrical machine vibro-acoustic behaviour and how to interpret the experimental data in order to redesign a machine.

F1. Introduction
F2. Experimental modal analysis
F3. Operational modal analysis
F4. Operational deflection shapes
F5. Hardware and software setup
F6. Run-ups, order analysis and spatiograms
F7. Vibro-acoustic type tests
F8. Interpretation of experimental data
F9. Source discrimination methodology

G. Application with MANATEE® software

Objective: detail how to analyse the vibroacoustic behaviour of an electric machine using MANATEE, and how to redesign the machine to reduce noise and vibration levels

G1. Overview of MANATEE electrical, electromagnetic, structural and acoustic models
G2. Definition of machine & simulation projects
G3. Check of geometry & winding
G4. Open circuit / no load vibroacoustic simulation
G5. Partial load vibroacoustic simulation
G6. Multi simulation environment: sensitivity studies and optimization
G7. Root cause analysis using MANATEE tools
G8. Application of common reduction techniques (skewing, current injection, magnet shaping)
G9. Review of all post processings of MANATEE
G10. Case study based on Customer input data