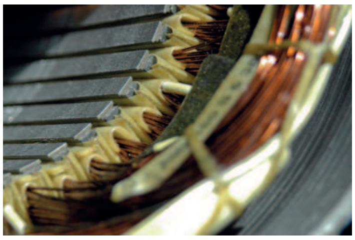
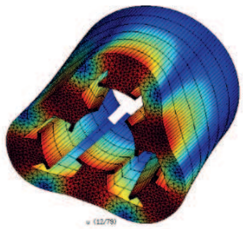
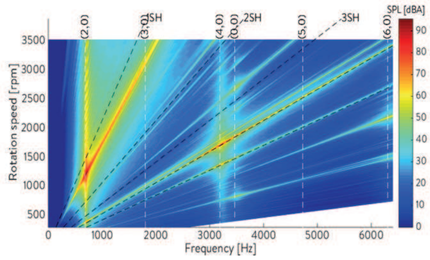
ACOUSTIC NOISE AND VIBRATIONS DUE TO MAGNETIC FORCES IN ROTATING ELECTRICAL MACHINES







1 OBJECTIVES

The objectives of the full technical training including all option modules are the followings:

- understand the phenomenon of acoustic noise and vibrations due to magnetic forces in main types of rotating electrical machines (e.g. PMSM, SCIM);
- 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 an 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;
- use MANATEE® simulation software to include e-NVH criterion in both early and detailed design phase of electric motors, troubleshoot e-NVH issues and implement adapted noise reduction techniques;
- use OROS® NVH measurement system to characterize the NVH and sound quality of electric motors, troubleshoot e-NVH issues.

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, CAE 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 5 days when including 2 application days with MANATEE® e-NVH simulation software and OROS® NVH measurement system. 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. Parts A1 / A2 can be done splitting the training session in two parallel sessions, one for electrical engineers and one for NVH/mechanical engineers.

Introduction

1. Importance of acoustic noise & vibrations in electric motor design
2. Noise sources in electrical machines
3. Interactions between electromagnetic and NVH design

A1. Electrical machines and drives: fundamentals for mechanical / NVH engineers (option)

Objective: recall the fundamentals of electrical machines that will be used all along the training

- A1. Working principle of electrical machines
- A2. Control of electrical machines
- A3. Principle of PWM
- A4. Main topologies used in automotive application

A2. Sound and vibrations: fundamentals for electrical engineers (option)

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. 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. 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

<u>Objective</u>: 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. Illustration with tuning fork and rotating magnet
    - B1d. Notion of wavenumber – rotating and pulsating forces
    - B1e. Quadratic nature of magnetic forces
- B2. Static effect of magnetic forces
    - B2a. Radial, circumferential, axial forces
    - B2b. Radial and tangential forces on outer stator
    - B2c. Radial and tangential forces on inner rotor
- 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
    - B4c. Generalization
- B5. Transfer paths analysis of magnetic noise

C. Analytical characterization of magnetic force harmonics

<u>Objective</u>: detail what are the different types of magnetic force harmonics in terms of frequencies and wavenumbers 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. Sound quality considerations of e-NVH
- C11. Force harmonics in degraded operation
  - C11a. Dynamic and static eccentricities
  - C11b. Uneven airgap
  - C11c. Demagnetization
  - C11d. Short circuit

D. 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.

- D1. General techniques
- D2. Analytical scaling laws
- D3. Electromagnetic design
  - D3a. Topology – ranking of main topologies in EV/HEV
  - D3b. Slot / pole / phase numbers
  - D3c. Asymmetries
  - D3d. Winding design
  - D3e. Rotor and stator continuous or stepped skewing
  - D3f. Pole shape / position
  - D3g. Magnetization
  - D3h. Slot and tooth shape / position
  - D3i. Notches
  - D3j. Wedges
  - D3k. Airgap increase
  - D3l. Others
- D4. Control & commutation design
  - D4a. Generalities
  - D4b. Current angle
  - D4c. Harmonic current injection
  - D4d. PWM strategy
  - D4e. Others
- D5. Structural design
  - D5a. Yoke shape
  - D5b. Frame to lamination contact
- D6. Conclusions on main low-noise design rules

E. 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. Help the trainees to integrate e-NVH in their current simulation workflow.

- E1. Modelling approaches
  - E1a. Generalities

    - E1b. Numerical approach
    - E1c. Analytical approach
    - E1d. Hybrid methods
- E2. Electromagnetic calculations
    - E2a. Analytical (e.g. permeance / mmf) or semi-analytical methods (e.g. subdomain models)
    - E2b. Finite element methods
- E3. Structural calculation
    - E3a. Analytical methods
    - E3b. Finite element methods
- E4. Electromagnetic to structural coupling methods
    - E4a. Maxwell stress method
    - E4b. Virtual work method
    - E4c. Equivalent forces
- E5. Acoustic calculations
    - E5a. Analytical methods
    - E5b. Numerical methods
    - E5c. Others
- E6. Acoustic and vibration synthesis methods
- E7. Numerical challenges of e-NVH simulation
- E8. Analysis of current numerical software solutions

F. FEA structural modelling of electrical machines (option)

Objective: detail FEA methodology adapted to electrical machines

Available in June 2019

G. 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.

- G1. Introduction
- G2. Vibration measurement: sensors and standards (option)
- G3. Acoustic measurement: sensors and standards (option)
- G4. Experimental modal analysis
- G5. Operational modal analysis
- G6. Operational deflection shapes
- G7. NVH acquisition software set-up
- G8. Run-ups, order analysis and spatiograms
- G9. Vibro-acoustic type tests
- G10. Interpretation of experimental spectrograms
- G11. Source discrimination methodology

H. Application with MANATEE® e-NVH simulation software (option)

Objective: detail how to simulate e-NVH in early and detailed design phase using MANATEE software, and how to redesign the machine to reduce noise and vibration levels. Trial licenses can be provided to trainees.

- H1. Overview of MANATEE electrical, electromagnetic, structural and acoustic models
- H2. Definition of machine & simulation projects
- H3. Check of geometry & winding
- H4. Open circuit / no load vibroacoustic simulation
- H5. Partial load vibroacoustic simulation
- H6. Multi simulation environment: sensitivity studies and optimization
- H7. Root cause analysis using MANATEE tools
- H8. Application of common reduction techniques (skewing, current injection, magnet shaping)

H9. Review of all post processings of MANATEE
H10. Case study based on Customer input data

I. Application with OROS® NVH acquisition software (option)

<u>Objective</u>: run an NVH test campaign on a small electric motor provided by EOMYS using OROS acquisition software tools: vibro-acoustic and Sound Quality characterization, noise source discrimination and root-cause analysis, coupling with MANATEE to improve the simulation-driven NVH design of electric powertrains.

Available in June 2019