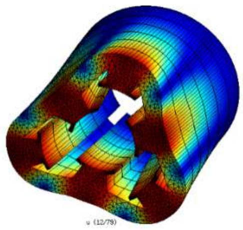
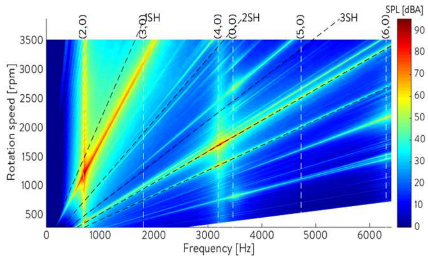
ACOUSTIC NOISE AND VIBRATIONS DUE TO ELECTROMAGNETIC FORCES IN ROTATING ELECTRICAL MACHINES





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 an NVH dynamic acquisition system to characterize the NVH and sound quality of electric motors, and troubleshoot e-NVH issues (application on a small electric motor or an electric car).

2 MEANS

The complete training material a powerpoint presentation of more than **600 slides in English, including sounds, videos, animations and bibliographic references**.

The training is illustrated with examples coming from **scientific literature**, EOMYS **experimental data** and **simulations using MANATEE®** software dedicated to the fast electromagnetic and vibroacoustic design of electrical machines. The e-NVH measurement part can be demonstrated on a **small e-motor testbench** provided by EOMYS or on a **real electric car**.

3 PUBLIC

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

4 ORGANIZATION

4.1 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.

4.2 Language

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

4.3 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.

4.4 Deliverables

The technical training is based on a detailed PowerPoint presentation (~600 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.

4.5 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.

5 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: understand the fundamental working principles of electrical machines that will be used all along the training, making the link with vibroacoustics (mostly for engineers with a mechanical / NVH background)

- 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)

<u>Objective</u>: understand the fundamentals of noise and vibrations that will be used all along the training, making the link with electrical machines (<u>mostly for engineers with a electrical engineering background</u>)

- 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 Sept2020

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 an NVH acquisition software (option)

Objective: run an NVH test campaign on a small electric motor provided by EOMYS or provided by Customer (e.g. electric car) using a dynamic acquisition system including relevant post processing

Demonstration is run using OROS NVH acquisition system and software tools, including the e-NVH module developed by EOMYS to speed up the diagnosis of noise & vibration issues in electric motors (markers, spatiograms). The measurement campaign is designed, run and interpreted with the Customer and all measured data is delivered at the end of the training.