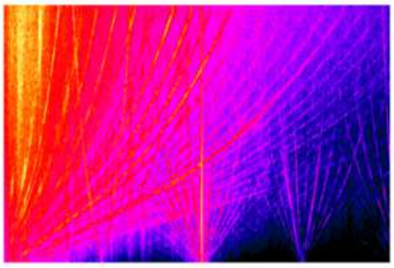
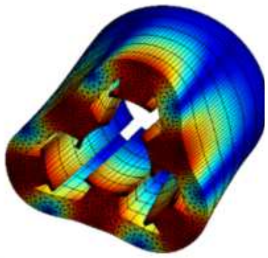
E-NVH: ACOUSTIC NOISE AND VIBRATIONS DUE TO ELECTROMAGNETIC FORCES IN ELECTRICAL MACHINES





1 PEDAGOGICAL OBJECTIVES

The objectives of the technical training are the followings:

- understand the phenomenon of audible noise and vibrations due to magnetic forces in electric motors, mainly Permanent Magnet Synchronous Machines used in automotive applications, including its impact on sound quality;
- identify the root cause (e.g. winding, slotting, PWM) of a given vibration or acoustic noise harmonic based on experimental data interpretation and / or numerical simulation;
- find some mechanical and electrical solutions to mitigate noisy electromagnetic force harmonic;
- know the main numerical simulation challenges of e-NVH, and how to include noise due to electromagnetic forces in its current CAE workflow;
- design an NVH test campaign to characterize the vibro-acoustic behavior of an electric motor under magnetic forces, and troubleshoot electromagnetic noise and vibration issues.

2 MEANS

The technical training is illustrated with small experiments, scientific literature examples, experimental data measured by EOMYS, or electromagnetic and vibroacoustic simulations run with MANATEE® software.
Some small exercises are also provided along the training.

3 PUBLIC

Profile: Electrical Engineers, NVH Test Engineers, CAE NVH Engineers, Mechanical Engineers
Number: max 15 persons

4 ORGANIZATION

4.1 Date, duration and language

The training is split in three sessions to be adapted to engineers with different background.

First, an **introductory session of 3 hours** is organized where the trainees are split in two groups, one group of Electrical Engineers to teach **Sound and Vibration fundamentals**, and one group of NVH Test Engineers / Mechanical Engineers to teach **Electrical Machines fundamentals**. Some links between e-NVH and vibro-acoustic / electrical engineering courses are regularly made during the training.
This introductory session is organized at the following date:

12th March 2019 PM: introductory session

The next days, **two sessions of 6 hours** on e-NVH intended for every profile (both electrical and mechanical / acoustic background) are organized at the following dates:

13th and 14th of March 2019: e-NVH training

Training language is in English (slides + oral presentation).

4.2 Location

The training is organized at The Waterfront in Bristol, UNITED KINGDOM (2 hours from London by train) at the following address (15mn walk from Temple Meads station):

The Waterfront
Welsh Back
BS1
Bristol
UK

4.3

4.4 Agenda

	12th March 2019		Introduction to vibro-acoustics for electrical engineers
	Start	End	Description
PM	13:00	13:30	*Welcome of trainees*
	13:30	14:00	Introduction
	14:00	15:00	(A1) Sound and vibration fundamentals for electrical engineers
	15:00	15:25	*Coffee break*
	15:25	16:55	(A1) Sound and vibration fundamentals for electrical engineers
	16:55	17:15	*Open questions*

	12th March 2019		Introduction to electrical engineering for NVH / mechanical engineers
	Start	End	Description
PM	13:00	13:30	*Welcome of trainees*
	13:30	14:00	Introduction
	14:00	15:00	(A2) Electrical Machine fundamentals for NVH engineers
	15:00	15:25	*Coffee break*
	15:25	16:55	(A2) Electrical Machine fundamentals for NVH engineers
	16:55	17:15	*Open questions*

	13th March 2019		e-NVH generation process – physics, maths and numerical simulation
	Start	End	Description
AM	8:30	10:00	(B) Magnetic noise and vibration generation process
	10:00	10:25	*Coffee break*
	10:25	11:55	(B) Magnetic noise and vibration generation process
PM	11:55	13:00	*Lunch break*
	13:00	14:30	(C) Analytic characterization of magnetic force harmonics
	14:30	14:55	*Coffee break*
	14:55	16:25	(E) Calculation techniques of magnetic noise and vibrations
	16:25	16:45	*Open questions*

	14th March 2019		e-NVH mitigation techniques and experimental characterization
	Start	End	Description
AM	8:30	10:00	(D) Reduction techniques of magnetic noise and vibrations
	10:00	10:25	Pause
	10:25	11:55	(D) Reduction techniques of magnetic noise and vibrations
PM	11:55	13:00	Lunch break
	13:00	14:30	(G) Experimental characterization of magnetic noise and vibrations
	14:30	14:55	*Coffee break*
	14:55	16:25	(G) Experimental characterization of magnetic noise and vibrations
	16:25	16:45	*Open questions*

4.5 Deliverables

The technical training is based on a detailed PowerPoint presentation (~300 slides). Due to large number of slides, a full paper copy of the presentation is not delivered by EOMYS to each attendee (only the "key ideas" 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. Exercises including solutions are provided as a separate document.

4.6 Cost

The training cost is 1400 GPB excl. VAT per person for the two and half days, including coffee breaks (for the two and half days) and lunches (for the two full days). It is possible to only attend to two days (1200 GPB excl. VAT) or one day (700 GPB excl. VAT).

	Cost per person (GBP)
Introductory session + e-NVH training (2.5 days)	1400
e-NVH training (2 day)	1200
e-NVH training (1 day)	700

The training cost does not include breakfasts, accommodation and transportation.

4.7 Contact and registration

Registration must be performed before 1st March 2019 online at the following link:
https://eomys.com/services/article/e-nvh-technical-training-march-2019

For all information please contact Jean LE BESNERAIS at +33 (0)7 70 18 97 61 or at the email address training(at)e-nvh.com

4.8 Payment conditions

The registration is only completed once the bank transfer is effective or once an official Purchase Order Request is received (payment terms: 30 days end of month). The payment should be done to the following bank:

CIC Villeneuve d'Ascq
199 rue du Transit
59650 Villeneuve d'Ascq
FRANCE
International Bank Account Number (IBAN): FR76 3002 7171 0700 0208 1500 112
Bank Identification Code (BIC)- Code swift: CMCIFRPP

All the costs of international bank transfer or currency change should be supported by the Customer.

5 DETAILED PROGRAM

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. Sound and vibrations: fundamentals for electrical engineers

Objective: see 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
- 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

A2. Electrical machines: fundamentals for mechanical / NVH engineers

Objective: see the fundamentals of electrical machines that will be used all along the training, while making a link when possible to NVH.

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

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. 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

Objective: 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
  - 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 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

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 re design a machine.

- G1. Introduction
- G2. Vibration measurement: sensors and standards
- G3. Acoustic measurement: sensors and standards
- 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