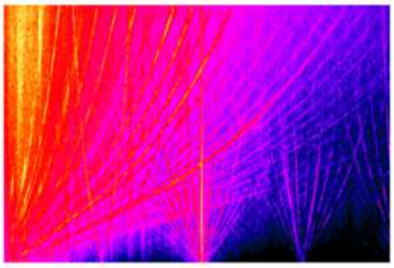
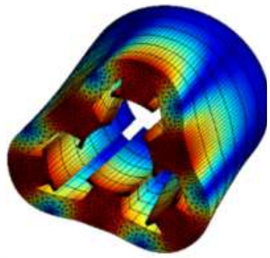
E-NVH: ACOUSTIC NOISE AND VIBRATIONS DUE TO ELECTROMAGNETIC FORCES IN ELECTRICAL MACHINES





1 PEDAGOGICAL OBJECTIVES

The objectives of the full technical training (3 days) 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 (EV / HEV NVH), 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 the following means:

- scientific literature with detailed references
- small experiments designed by EOMYS to introduce the physics of e-NVH
- experimental tests run on HEV/EV (Renault Zoe/Twizzy, Nissan Leaf, Smart Fortwo, Opel Ampera, Toyota Prius, Volkswagen e-up, Tesla model X, BWM i3, Hyundai Ioniq/Kona)
- NVH simulations from MANATEE® software, dedicated to fast and accurate e-NVH design of electrical machines

3 PUBLIC

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

4 ORGANIZATION

4.1 Date, duration and language

The training on electromagnetic Noise, Vibration Harshness (**e-NVH**) phenomenon is organized in **3 sessions of 6 hours** at the following dates:

e-NVH training: 15th, 16th and 17th of September2020

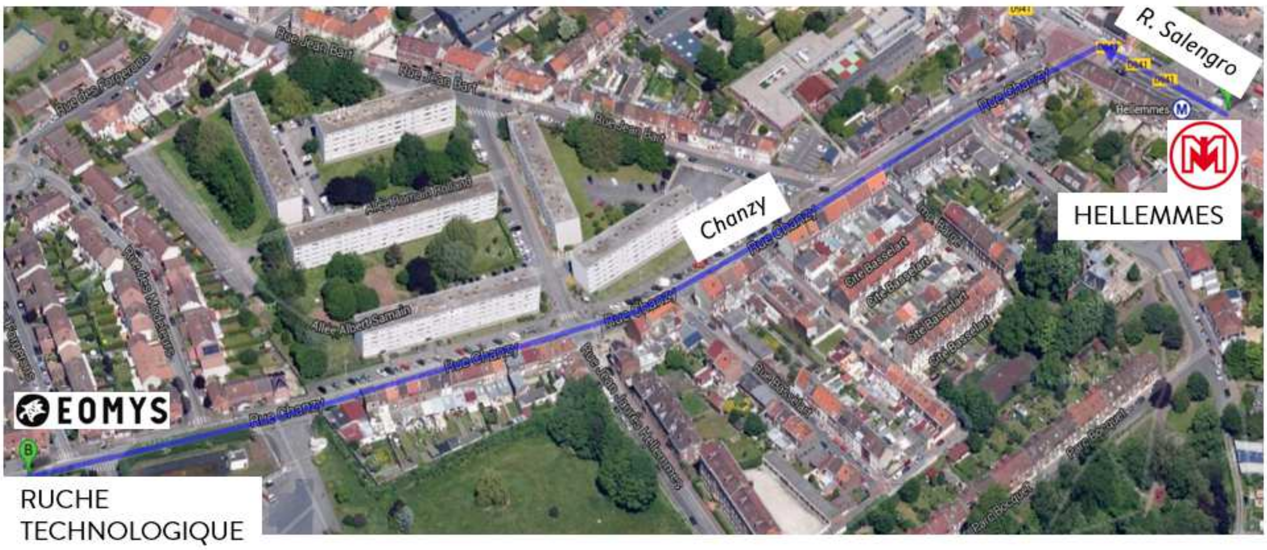
Training language is in English (slides + oral presentation) – for French-speaking trainees, some individual explanations can be delivered in French for better understanding.

4.2 Location

The training is organized at EOMYS office in Lille, FRANCE (1 hour from Paris, 1 hour 30 mn from London, 30 mn from Brussels with high speed train) at the following address:

EOMYS
Ruche d'Entreprises de Lille Hellemmes
121 rue de Chanzy
59260 Hellemmes Lille

Subway: Mairie d'Hellemmes (yellow line n° 1)
(15 mn of subway + walk from Gare Lille Flandres or Gare Lille Europe train stations)



4.3 Agenda of the e-NVH training

	15 Sept 2020		Introduction to electrical machines and vibro-acoustics
	Start	End	Description
AM	8:30	9:00	*Welcome of trainees and registration*
	9:00	9:30	Presentation of EOMYS and trainees Introduction
	9:30	10:30	(A1) Working Principles of electrical machines - focus on EV/HEV traction topologies
	10:30	10:55	*Break*
	10:55	12:25	(A1) Working Principles of electrical machines - focus on EV/HEV traction topologies
PM	12:25	13:30	*Lunch break*
	13:30	15:00	(A2) Sound and vibration fundamentals – application to electrical machines
	15:00	15:25	*Break*
	15:25	16:55	(A2) Sound and vibration fundamentals – application to electrical machines
	16:55	17:15	*Open questions*
	19:30		*(option) Dinner at estaminet "Chez la vieille" 60 Rue de Gand, 59000 Lille*

	16 Sept 2020		e-NVH generation process – part 1
	Start	End	Description
AM	9:00	10:30	(B) Magnetic noise and vibration generation process
	10:30	10:55	*Break*
	10:55	12:25	(B) Magnetic noise and vibration generation process
PM	12:25	13:30	*Lunch break*
	13:30	15:00	(C) Analytic characterization of magnetic force harmonics
	15:00	15:25	*Break*
	15:25	16:55	(C) Analytic characterization of magnetic force harmonics (E) Calculation techniques of magnetic noise and vibrations
	16:55	17:15	*Open questions*

	17 Sept 2020		e-NVH generation process – part 2
	Start	End	Description
AM	9:00	10:30	(E) Calculation techniques of magnetic noise and vibrations (D) Reduction techniques of magnetic noise and vibrations
	10:30	10:55	Pause
	10:55	12:25	(D) Reduction techniques of magnetic noise and vibrations
PM	12:25	13:30	Lunch break
	13:30	15:00	(G) Experimental characterization of magnetic noise and vibrations
	15:00	15:25	*Break*
	15:25	16:55	(G) Experimental characterization of magnetic noise and vibrations
	16:55	17:15	*Open questions*

4.4 Deliverables of the e-NVH training

The technical training is based on a detailed PowerPoint presentation. The slides used during the training are delivered as a .pdf file including bibliographic references.

4.5 Training cost

Formula	Cost (EUR excl. VAT) per person
3-day	2000
2-day	1500
1-day	850

It is possible to only attend to one, two or three e-NVH training days.

The training cost includes coffee breaks, lunches and social dinner. The training cost does not include breakfasts, accommodation and transportation.

Note for French companies:
EOMYS ENGINEERING est référencé DataDoc comme organisme de formation sous le numéro 3259 09376 59. Cette formation peut donc faire l'objet d'un financement partiel par votre OPCA. Pour les étudiants en thèse de doctorat, une validation de la formation en termes d'ECTS est possible, renseignez-vous auprès de votre école doctorale.

4.6 Contact and registration

Registration must be performed before 2nd September 2020 online at the following link:
www.eomys-registration.com

For all information please contact Anne TRUMMER at +33 (0)7 62 41 59 12 or at the email address training(at)e-nvh.com

5 DETAILED PROGRAM

Introduction

1. Importance of acoustic noise & vibrations in electric motor design
2. Noise sources in electrical machines (aerodynamic, mechanical, magnetic)
3. Interactions between electromagnetic and NVH design

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

Objective: see the fundamentals of electrical machines that will be used all along the training, but make the link between general notions and NVH.

- A1. Working principle of electrical machines
- A2. Electrical machine manufacturing principles
- A3. Control of electrical machines
- A4. Principle of PWM
- A5. Main EV/HEV architectures and topologies used in automotive application

A2. 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

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 of magnetic noise and vibrations
- B6. Advanced effects
  - B6a. Boundary conditions
  - B6b. Temperature
  - B6c. Gearbox / e-motor interactions

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. Case studies using MANATEE software before general theory
- C2. Principle of harmonic decomposition
  - C2a. Fourier transform
  - C2b. Calculation rules
- C3. Stator mmf harmonics
- C4. Rotor mmf harmonics
- C5. Permeance harmonics
- C6. Flux density harmonics
- C7. Main magnetic force harmonics in normal operation
  - C7a. Effect of slotting
  - C7b. Effect of saturation
  - C7c. Effect of winding harmonics
- C8. Additional case studies
- C9. Effect of outer rotor
- C10. Effect of PWM
- C11. Sound quality considerations of e-NVH
- C12. Force harmonics in degraded operation
  - C12a. Dynamic and static eccentricities
  - C12b. Uneven airgap
  - C12c. Demagnetization
  - C12d. 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 methods (e.g. permeance / mmf)
- E2b. Semi-analytical methods (e.g. subdomain models)
- E2c. 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 (not included in EOMYS regular e-NVH training, only available as a customized training)

Objective: detail FEA methodology adapted to electrical machines

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, application to e-machines

G5. Operational Modal Analysis, application to e-machines

G6. Operational Deflection Shapes, application to e-machines

G7. Transfer Path Analysis, application to e-machines
G8. NVH acquisition software set-up
G9. Run-ups, order analysis
G10. Spatiograms, tooth FRF and Operational Force Shape analysis
G11. Vibro-acoustic type tests
G12. Interpretation of experimental spectrograms, focus on EV/HEV
G13. Source discrimination methodology at e-motor or vehicle levels

I. e-NVH testing – practical application with OROS® NVH acquisition software (not included in EOMYS regular e-NVH training, only available as a customized training)

Objective: run an e-NVH test campaign on a small electric motor provided by EOMYS or by customer using OROS dynamic acquisition system and NVGate software EV/HEV NVH module developed by EOMYS