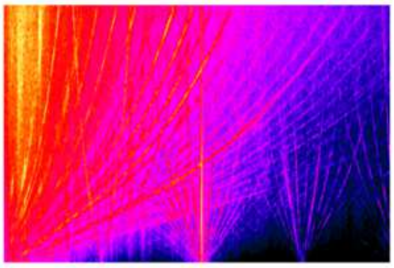
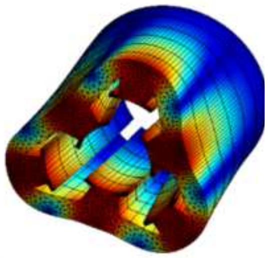
e-NVH: ACOUSTIC NOISE AND VIBRATIONS DUE TO ELECTROMAGNETIC FORCES IN ELECTRICAL MACHINES





1 PEDAGOGICAL OBJECTIVES

The objectives of this technical training organized over 3 days by teleconference (Central European Time) 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 20 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: 12th, 13th and 14th of May 2020

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

4.2 Location

Training is only accessible by teleconference, a Webex link is provided to registrants to access to trainer's live webcam.

4.3 Deliverables

The technical training is based on a detailed PowerPoint presentation. The .pdf slides are provided at least one week before the training. A library of sound files is also provided for use during the training.

4.4 Trainers

Trainers are PhD Engineers working as consultants at EOMYS.

EOMYS ENGINEERING is a team of multidisciplinary R&D Engineers providing qualified consulting, training and software services. EOMYS has developed a strong expertise in **solving e-NVH (NVH due to electromagnetic forces)** issues both at design stage and after manufacturing. With more than **100 customers** world-wide, EOMYS has analyzed more than **100 electric motor noise issues**, implementing both structural and electrical noise mitigation actions leading up to **40 dB reduction**. Its experience covers all types of electric motors (e.g. radial/axial flux, SRM, PMSM, SCIM, WRSM, inner/outer rotor), nominal speeds (5 rpm to 150 krpm) and size (1 cm to 10 m diameter).
In the automotive sector, EOMYS worked on electric drives motors and generators, ancillary e-motors (e.g. pumps, e-clutches, turbochargers), and passive components.

4.5 Agenda of the e-NVH training

	12 May 2020		Introduction to electrical machines and vibro-acoustics
	Start	End	Description
AM	9:00	9:30	Presentation of trainees and EOMYS Introduction
	9:30	10:30	(A1) Working Principles of electrical machines - focus on EV/HEV electric powertrain topologies
	10:30	11:00	*Break*
	11:00	12:30	(A1) Working Principles of electrical machines - focus on EV/HEV electric powertrain topologies
PM	13:30	15:00	(A2) Sound and vibration fundamentals – application to electrical machines
	15:00	15:30	*Break*
	15:30	16:45	(A2) Sound and vibration fundamentals – application to electrical machines
	16:45	17:00	*Review of remaining open questions*

	13 May 2020		e-NVH generation process – part 1
	Start	End	Description
AM	9:00	10:30	(B) Magnetic noise and vibration generation process
	10:30	11:00	*Break*
	11:00	12:30	(B) Magnetic noise and vibration generation process
PM	13:30	15:00	(G) Experimental characterization of magnetic noise and vibrations
	15:00	15:30	*Break*
	15:30	16:45	(H) Industrial application cases – focus on EV HEV NVH
	16:45	17:00	*Review of remaining open questions*

	14 May 2020		e-NVH generation process – part 2
	Start	End	Description
AM	9:00	10:30	(C) Analytic characterization of magnetic force harmonics
	10:30	11:00	*Break*
	11:00	12:30	(D) Reduction techniques of magnetic noise and vibrations
PM	13:30	15:00	(D) Reduction techniques of magnetic noise and vibrations
	15:00	15:30	*Break*
	15:30	16:45	(E) Calculation techniques of magnetic noise and vibrations
	16:45	17:00	*Review of remaining open questions*

4.6 Training cost

Formula	Cost (EUR excl. VAT) per person
3-day	1600
2-day	1200
1-day	650

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

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.

4.7 Contact and registration

Registration must be performed before 2nd May 2020 online at the following link:

www.eomys-registration.com

Online registration to the distant training assumes a single trainee connected to the Webex link. For several participants, please contact Anne TRUMMER at +33 (0)7 62 41 59 12 or at the email address training(at)e-nvh.com to obtain a special quote.

5 DETAILED TRAINING 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
  - A1a. Torque production
  - A1b. DC / AC machine principle
  - A1c. Synchronous Vs reluctance torque
- A2. Magnetic materials
- A3. Electrical machine manufacturing principles
- A4. Torque control with DQ frame
- A5. Speed control with PWM
- A6. Main e-motor topologies used in EV HEV applications
- A7. Main e-drive architecture used in EV HEV applications

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. Linear resonator case: stiffness & mass, damping, forced & resonance regimes
  - A1b. Generalization to N d.o.f.
  - A1c. Structural modes
  - A1d. Modal superposition principle
- A2. Sound
  - A2a. Pressure, velocity
  - A2b. Power, intensity
  - A2c. Log scale
  - A2d. Additivity & masking effects
  - A2e. Third octave analysis, dBA
  - A2f. Directivity
  - A2g. Radiation efficiency
  - A2h. Fluid/structure interaction
  - A2i. Sound source types
  - A2j. Distance & reflection effects
  - A2k. Psychoacoustics

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. Lumped tooth forces
  - B1f. Modulation effect
  - B1g. Global forces – torque, UMP, moments
- B2. Static effect of magnetic forces
  - B2a. Radial and tangential forces on outer stator
  - B2b. 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 with modal force
- 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

<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. Slotting harmonics - case studies using MANATEE software on a PMSM
  - C1a. Fundamental force
  - C1b. Pulsating forces
  - C1c. Lowest wavenumber forces
  - C1d. Generalization
- C2. Switching harmonics
- C3. Effect of faults and tolerances
  - C3a. Dynamic and static eccentricities
  - C3b. Uneven airgap
  - C3c. Demagnetization
- C4. Harmonic characterization
  - C4a. Field sources
  - C4b. Stator mmf harmonics
  - C4c. Rotor mmf harmonics
  - C4d. Permeance harmonics
  - C4e. Flux density harmonics
- C5. Effect of outer rotor

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. Noise control strategies
- 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
  - D5c. Damping
  - D5d. Transfer paths – airborne Vs structure-borne
- D6. Synthesis of low noise electric motor design parameters

E. Numerical simulation 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. Magnetic force calculation
  - E3a. Maxwell stress method
  - E3b. Virtual work method
  - E3c. Equivalent forces
- E4. Structural calculation
  - E4a. Analytical methods
  - E4b. Finite element methods
- E5. Electromagnetic to structural coupling methods
- E6. Acoustic calculations

E6a. Analytical methods
E6b. Numerical methods
E7. Numerical challenges of e-NVH simulation
E8. Load calculation algorithms
E8a. Load extrapolation
E8b. Load interpolation
E9. Vibro-acoustic synthesis algorithm
E9a. Vibration synthesis
E9b. Acoustic synthesis
E10. Current numerical software solutions

G. Experimental characterization of magnetic noise and vibrations

Objective: detail how to fully characterize the electrical machine vibro-acoustic behaviour and how to interpret experimental data to identify e-NVH root cause

G1. Introduction
G2. Vibration measurement: sensors and standards
G3. Acoustic measurement: sensors and standards
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, spectrograms, order tracking analysis
G10. Spatiograms, tooth FRF and Operational Force Shape analysis
G11. Vibro-acoustic type tests
G12. Source discrimination methodology at e-motor or vehicle levels

H. Industrial application case studies (focus on EV HEV NVH)

Objective: review experimental acoustic spectrograms obtained on different industrial applications and more especially EV/HEV automotive applications (ex: Renault Zoe/Twizzy, Hyundai Ioniq/Kona, Nissan Leaf, Toyota Prius, BMW i3, Smart4Two, OpelAmpera, VW e-up)