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, 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.

3 PUBLIC

Profile: Electrical Engineers, NVH Test Engineers, CAE NVH Engineers, Mechanical Engineers
Number: max 14 people
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:

<table>
<thead>
<tr>
<th>Session</th>
<th>Date</th>
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<tbody>
<tr>
<td>1st</td>
<td>12th May 2020</td>
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<tr>
<td>2nd</td>
<td>13th May 2020</td>
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<tr>
<td>3rd</td>
<td>14th May 2020</td>
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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

<table>
<thead>
<tr>
<th>12 May 2020</th>
<th>Introduction to electrical machines and vibro-acoustics</th>
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<tr>
<th>13 May 2020</th>
<th>e-NVH generation process – physics, maths and numerical simulation</th>
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<tr>
<th>14 May 2020</th>
<th>e-NVH mitigation techniques and experimental characterization</th>
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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. The presentation includes some extended bibliographic references, audio files and animation files.
4.5 Training cost

<table>
<thead>
<tr>
<th>Formula</th>
<th>Cost (EUR excl. VAT) per person</th>
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<tbody>
<tr>
<td>3-day</td>
<td>2000</td>
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<tr>
<td>2-day</td>
<td>1500</td>
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<tr>
<td>1-day</td>
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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.

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 May 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
2. Acoustic noise sources in electrical machines
3. Interactions between electromagnetic and NVH design

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

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
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. 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

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
   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