1 PEDAGOGICAL OBJECTIVES

The objectives of the full technical training (4 days including training on MANATEE® software) 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;
• learn how to use MANATEE® e-NVH simulation software to analyze the NVH behavior of electrical machines both at early and detailed design stages, and implement adapted noise control techniques.

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 on e-NVH phenomenon is organized in 3 sessions of 6 hours at the following dates:

| 2nd, 3rd and 4th of April 2019 |

The optional training on MANATEE e-NVH simulation software is organized on next day:

| 5th of April 2019 |

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)
### Agenda

#### 2nd April 2019

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Description</th>
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<tbody>
<tr>
<td>AM</td>
<td></td>
<td><strong>Welcome of trainees and registration</strong></td>
</tr>
<tr>
<td>8:30</td>
<td>9:00</td>
<td></td>
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<tr>
<td>9:00</td>
<td>9:30</td>
<td><strong>Presentation of EOMYS and trainees Introduction</strong></td>
</tr>
<tr>
<td>9:30</td>
<td>10:00</td>
<td>(A1) <strong>Working Principles of electrical machines - focus on EV/HEV traction topologies</strong></td>
</tr>
<tr>
<td>10:30</td>
<td>10:55</td>
<td><strong>Coffee break</strong></td>
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<tr>
<td>10:55</td>
<td>12:25</td>
<td>(A1) <strong>Working Principles of electrical machines - focus on EV/HEV traction topologies</strong></td>
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<tr>
<td>PM</td>
<td>12:25</td>
<td><strong>Lunch break</strong></td>
</tr>
<tr>
<td>13:00</td>
<td>15:00</td>
<td>(A2) <strong>Sound and vibration fundamentals – application to electrical machines</strong></td>
</tr>
<tr>
<td>15:00</td>
<td>15:25</td>
<td><strong>Coffee break</strong></td>
</tr>
<tr>
<td>15:25</td>
<td>16:55</td>
<td>(A2) <strong>Sound and vibration fundamentals – application to electrical machines</strong></td>
</tr>
<tr>
<td>16:55</td>
<td>17:15</td>
<td><strong>Open questions</strong></td>
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<tr>
<td>19:30</td>
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<td><em>(option) Dinner at estaminet “Chez la vieille” 60 Rue de Gand, 59000 Lille</em></td>
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#### 3rd April 2019

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<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>AM</td>
<td>9:00</td>
<td><strong>Magnetic noise and vibration generation process</strong></td>
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<tr>
<td>10:30</td>
<td>10:55</td>
<td><strong>Coffee break</strong></td>
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<td>10:45</td>
<td>12:25</td>
<td>(B) <strong>Magnetic noise and vibration generation process</strong></td>
</tr>
<tr>
<td>PM</td>
<td>12:25</td>
<td><strong>Lunch break</strong></td>
</tr>
<tr>
<td>13:00</td>
<td>15:00</td>
<td>(C) <strong>Analytic characterization of magnetic force harmonics</strong></td>
</tr>
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<td>15:00</td>
<td>15:25</td>
<td><strong>Coffee break</strong></td>
</tr>
<tr>
<td>15:25</td>
<td>16:55</td>
<td>(E) <strong>Calculation techniques of magnetic noise and vibrations</strong></td>
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<td><strong>Open questions</strong></td>
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#### 4th April 2019

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<tr>
<td>AM</td>
<td>9:00</td>
<td><strong>Reduction techniques of magnetic noise and vibrations</strong></td>
</tr>
<tr>
<td>10:30</td>
<td>10:55</td>
<td><strong>Pause</strong></td>
</tr>
<tr>
<td>10:55</td>
<td>12:25</td>
<td>(D) <strong>Reduction techniques of magnetic noise and vibrations</strong></td>
</tr>
<tr>
<td>PM</td>
<td>12:25</td>
<td><strong>Lunch break</strong></td>
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<tr>
<td>13:00</td>
<td>15:00</td>
<td>(G) <strong>Experimental characterization of magnetic noise and vibrations</strong></td>
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<td>15:00</td>
<td>15:25</td>
<td><strong>Coffee break</strong></td>
</tr>
<tr>
<td>15:25</td>
<td>16:55</td>
<td>(G) <strong>Experimental characterization of magnetic noise and vibrations</strong></td>
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<tr>
<td>16:55</td>
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<td><strong>Open questions</strong></td>
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#### 5th April 2019

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<tr>
<td>AM</td>
<td>9:00</td>
<td><strong>Presentation of MANATEE software modules</strong></td>
</tr>
<tr>
<td>10:30</td>
<td>10:55</td>
<td><strong>Pause</strong></td>
</tr>
<tr>
<td>10:55</td>
<td>12:25</td>
<td>(H) <strong>Implementation of an IPMSM topology</strong></td>
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#### Description

**Introduction to electrical machines and vibro-acoustics**

- **2nd April 2019**
  - AM: Welcome of trainees and registration
  - AM: Presentation of EOMYS and trainees introduction
  - AM: Working Principles of electrical machines - focus on EV/HEV traction topologies
  - PM: Lunch break
  - PM: Sound and vibration fundamentals – application to electrical machines

**e-NVH generation process – physics, maths and numerical simulation**

- **3rd April 2019**
  - AM: Magnetic noise and vibration generation process
  - AM: Coffee break
  - PM: Lunch break
  - PM: Analytic characterization of magnetic force harmonics

**e-NVH mitigation techniques and experimental characterization**

- **4th April 2019**
  - AM: Reduction techniques of magnetic noise and vibrations
  - AM: Pause
  - PM: Lunch break
  - PM: Experimental characterization of magnetic noise and vibrations

**e-NVH simulation using MANATEE® software**

- **5th April 2019**
  - AM: Presentation of MANATEE software modules
  - AM: Pause
  - AM: Implementation of an IPMSM topology
### 4.4 Deliverables

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. Exercises including solutions are provided as a separate document.

### 4.5 Cost

<table>
<thead>
<tr>
<th>Formula</th>
<th>Cost (EUR excl. VAT) per person</th>
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<tbody>
<tr>
<td>4-day</td>
<td>2500</td>
</tr>
<tr>
<td>3-day</td>
<td>2000</td>
</tr>
<tr>
<td>2-day</td>
<td>1500</td>
</tr>
<tr>
<td>1-day</td>
<td>850</td>
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</tbody>
</table>

The training cost includes coffee breaks, lunches and social dinner. It is possible to only attend to one, two or three training days. 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 15th March 2019 online at the following link:  

Registration is only valid once bank transfer is effective or POR has been received.  
For all information please contact Jean LE BESNERAIS at +33 (0)770189761 or at the email address training(at)e-nvh.com

### 4.1 Payment conditions

The registration is only completed once the bank transfer is effective or 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
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

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
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 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
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