# SIMULIA Manatee

Features presentation



Version 1.5 - 7/25/2025

## Table of contents

# MODELLING

## 1.1. Quick e-NVH Simulation Definition

### 1.1.1. Predefined and User-Defined Multiphysics Workflows

**Description**

Manatee offers some default workflows to create multiphysics simulations that automatically combine the modeling levels that are the most adapted to the V-model development cycle stage of a given electrical drive**.** In addition to these standard workflows defined for electrical, mechanical, and NVH engineers, Manatee also allows the creation of user-defined workflows.

Each workflow can be run either for:

- **single-speed simulation** (for instance to simulate network-fed electrical machines, or to make checks at a single operating point before running variable speed simulations)
- **variable-speed simulation** (for instance, to study noise and vibrations along the enveloped torque-speed curve)
- **torque-speed plane simulation** (for instance to study if resonances are maximized at a partial load level).

Predefined simulation workflows have been designed based on the experience of more than +200 consulting projects.

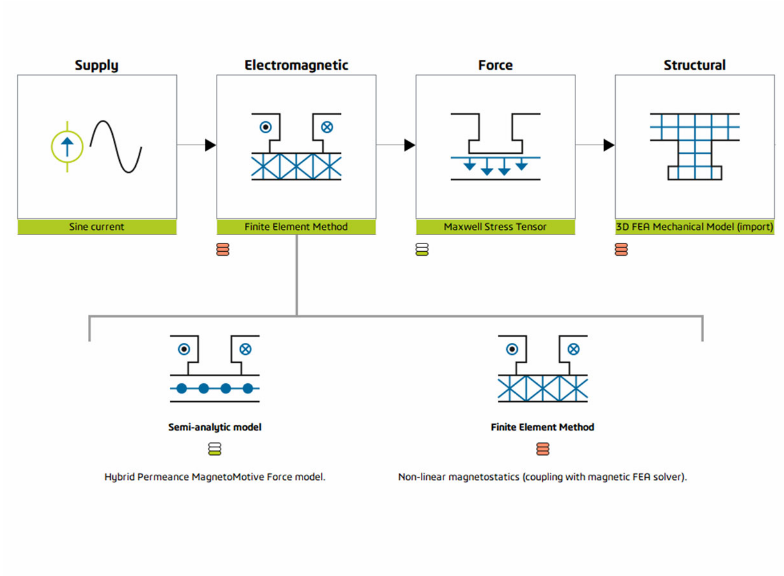
User-defined workflows allow the creation of a workflow by defining every physics (*Supply, Electromagnetic, Force, Structural, Acoustic*) or by removing some physics to reduce computing time.

Each workflow can be automatically combined with Manatee and tools to find the best trade-off whatever the current design phase.

**Application**

Manatee e-NVH simulations can be defined and launched in a few clicks by any engineer, compared to several hours of set-up in general-purpose multiphysics FEA software. The different default workflows are adapted to electrical engineers, mechanical engineers, acoustic engineers and NVH test engineers.

The possibility to create user defined workflows offers more flexibility to adapt Manatee to particular engineering practices**.** These simulation workflows can be executed sequentially or in parallel in the engineering team, allowing to speed-up the development cycle of electrical systems**.**


Supply
Electromagnetic
Force
Structural
Sine current
Finite Element Method
Maxwell Stress Tensor
3D FEA Mechanical Model (import)
Semi-analytic model
Hybrid Permeance MagnetoMotive Force model.
Finite Element Method
Non-linear magnetostatics (coupling with magnetic FEA solver).

### 1.1.2. Fast Electrical Machine Set-Up

**Description**

Manatee enables the fast definition of the following electrical machine types:

- **interior and surface permanent magnet synchronous machines** (IPMSM and SPMSM)
- **wound rotor synchronous machines** (WRSM) also called Externally Excited Synchronous Machines (EESM)
- **induction machines** (SCIM)
- **outer rotor PM machines**

Manatee comes with a complete set of electrical machine templates for quickly defining the magnetic circuit geometry. Predefined slot shapes and magnet shapes allow parameter sweeps on the topology.

The winding pattern is automatically defined using star of slot method, which is widely used by electrical engineers. Special slot or magnet pocket geometries can be defined using slot .dxf import, magnet pocket .dxf import, uneven bore shape .dxf import and radial ventilation .dxf import features.

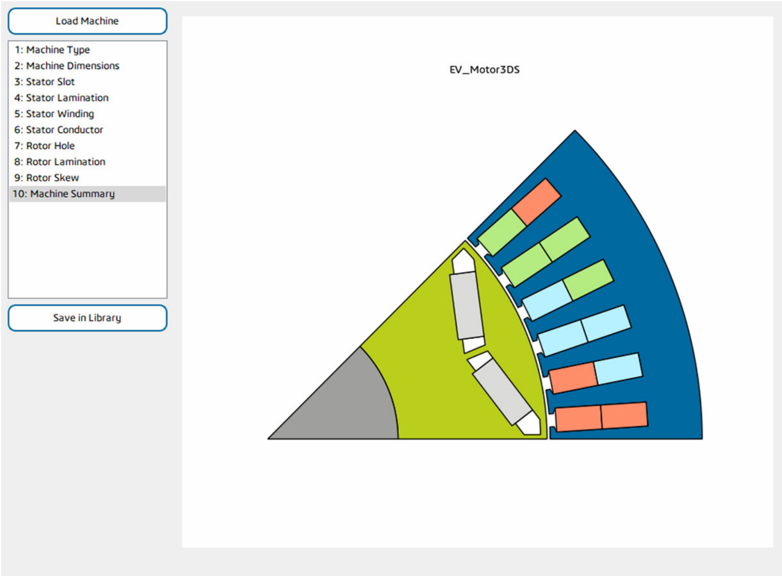
Several topological particularities can also be easily defined:

- different **skew patterns** are available (linear, V-shape, zig-zag or user-defined)
- **uneven pole distribution** can be taken into account (e.g. different North and South poles) for SPMSM and IPMSM
- different sets of **ventilation ducts, notches and keys** (additional magnetic materials in the airgap) can be added to the stator and/or the rotor bores, either in a parametrized shape or using .dxf import

Manatee also comes with a series of electrical machines that have been already defined and used for validation purposes.

**Application**

Manatee software enables a fast electrical machine magnetic circuit set-up by both electrical engineers and mechanical/NVH engineers based on a limited number of input parameters. Electrical machine files are saved as .json files to be easily shared, read and versioned among engineers to ease the collaboration.


Load Machine
1: Machine Type
2: Machine Dimensions
3: Stator Slot
4: Stator Lamination
5: Stator Winding
6: Stator Conductor
7: Rotor Hole
8: Rotor Lamination
9: Rotor Skew
10: Machine Summary
Save in Library
EV_Motor3DS

### 1.1.3. User-Defined Slot Shape Import From .DXF

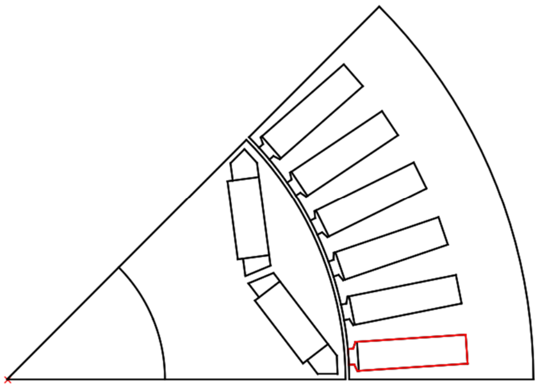
**Description**

In Manatee software, you can define the slot of your electrical machine either with predefined templates or with user-defined slot shape import from .dxf files. Once the .dxf file is imported, you can define your slot & winding with a few clicks by selecting relevant lines and points. Even with a user-defined slot shape, Manatee can change the winding number of layers, the winding pattern and the number of slots of your electrical machine (Manatee includes an automated winding algorithm based on Star of Slot method).

**Application**

This .dxf import feature can be used by all engineers involved in the design of electrical machines, including electrical and mechanical engineers**.** Manatee can model lamination geometries coming from real-life, industrial CAD models.

Demonstration



### 1.1.4. Magnet Shape .DXF Import

**Description**

In Manatee software, the magnetic circuit of electrical machines can be quickly drawn either with predefined templates or with user-defined magnet shape .dxf import. This is particularly useful to include geometric details (air pockets due to rivets, bolts, or cooling ducts) that influence magnetic field distribution.

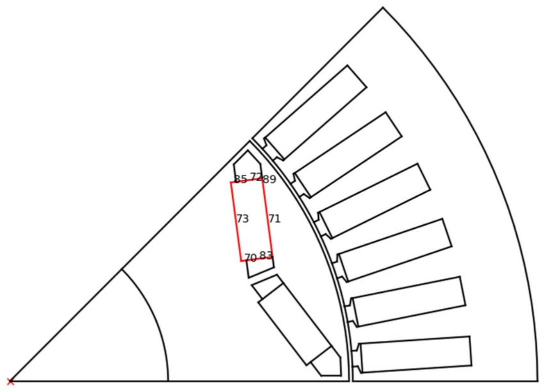
Once the .dxf file has been imported in the machine library, you can apply a scaling factor and define your holes & magnets with a few clicks by selecting lines and points, especially the magnetization direction.

**Application**

The design of rotor lamination has several objectives such as minimizing hoop stress, maximizing cooling efficiency, maximizing torque, minimizing electromagnetic noise etc. This often leads to complex geometries for interior magnet pockets and bridges, which must be taken into account in e-NVH simulations according to consulting experience.

In Manatee software, any engineer can set up a machine geometry with a few clicks using .dxf file import and predefined templates. In the video below, it is shown how to define holes and magnets simply using the .dxf file import feature, with an example based on an IPMSM. This feature is essential to studying real lamination geometries coming from industrial CAD models**.**

[Demonstration]()



# 2. SIMULATION

## 2.1. Fast and Accurate e-NVH Calculations

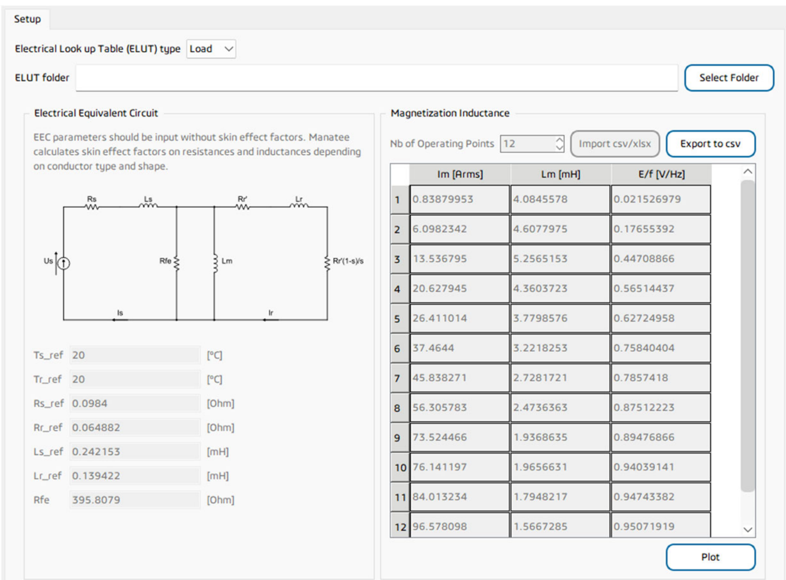
### 2.1.1. Fast Electric Circuit Models

**Description**

Manatee e-NVH software includes fast electrical circuit models to perform voltage-driven electromagnetic simulations. These models can be used to quickly estimate current levels from voltage inputs without transient simulations. They are based on harmonic Equivalent Electrical Circuits (EEC) in steady state, describing the voltage/current transfer functions with equivalent resistances and inductances.

**Application**

Fast EEC models can be used by electrical engineers to directly input the voltage control law. They are especially useful for induction machines (input of slip and phase voltage as a function of operating point) and for the simulation of PWM voltage inverters.



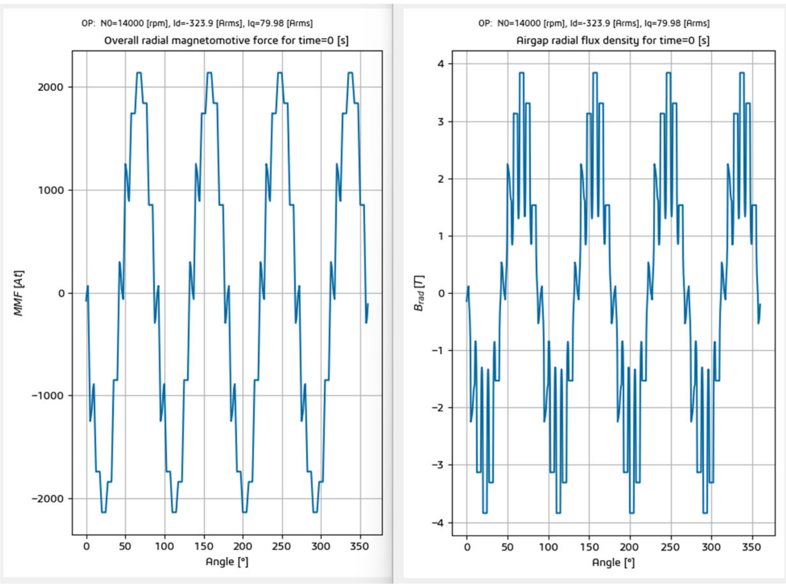
## 2.1.2. Fast Magnetic Models

**Description**

Besides proprietary algorithms to accelerate standard magnetic FEA simulations, Manatee e-NVH software also includes fast hybrid electromagnetic models to be used in the early design phase of electric machines. These hybrid magnetic models predicting the airgap flux distribution rely on the combination of permeance/magnetomotive force models, FEA computations, or magnetic reluctance models (for example to estimate saturation effects better). They can be used in current-driven or voltage-driven simulation workflows to quickly capture the main interactions between magnetic forces and structural modes, complementary to FEA magnetic models used in the intermediate or detailed design phase.

**Application**

These fast magnetic models can be used by electrical engineers when ranking different e-machine topologies at the conceptual design phase (for example, comparing IPMSM to SCIM or different slot/pole combinations). As model parameters (for example, the number of harmonics and discretization) are automatically defined by Manatee, these fast models can also be easily run by mechanical or acoustic engineers to run a "what-if" scenario and get a qualitative idea of the design variables' influence on magnetic forces, vibration, and noise.





SIMULIA DASSAULT SYSTEMES

### 2.1.3. Finite Elements Magnetic Models

**Description**

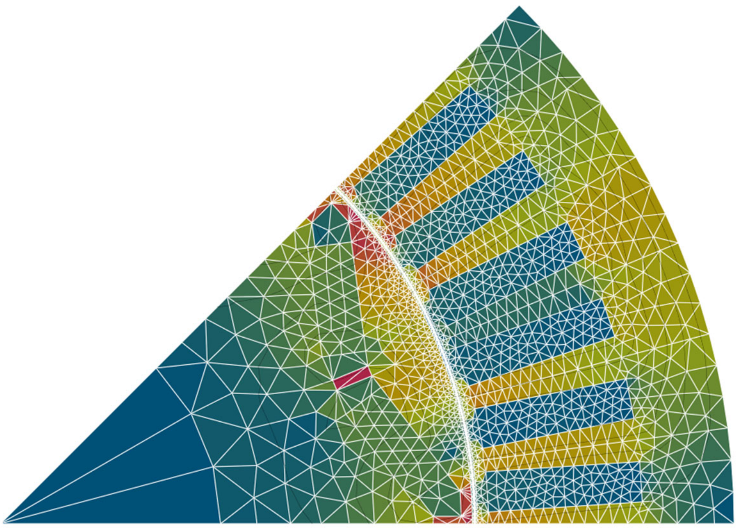
In addition to flux import, Manatee includes a fully automated coupling with a FEA magnetic solver. The coupling includes optimized meshing, symmetries, and parallelization to reduce the computing time of this nonlinear **magnetostatic FEA**.

All magnetic models include proprietary algorithms to speed up the magnetic FEA simulations, which rely on Magnetic Look-up Tables (MLUT) combined with extrapolation/interpolation techniques.

FEA-based MLUT can be used in current-driven or voltage-driven simulation workflows to accurately capture the interactions between magnetic forces and structural modes, complementary to fast magnetic models which can be used in early design phase.

**Application**

These accurate magnetic models can be used by electrical or electromagnetic design engineers when iterating on the magnetic circuit geometry of the electric machine. Once magnetic forces have been characterized at different operating points inside a Magnetic Look-Up Table (MLUT), this MLUT can be loaded by mechanical engineers or NVH engineers to perform variable speed e-NVH calculations. When iterating on the structural design, this MLUT can be reused, accelerating mechanical design iterations for magnetic noise and vibration levels.



## 2.1.4. Beam Element Model

**Description**

Manatee e-NVH software provides a fast structural mechanics model for rapidly evaluating vibration levels under electromagnetic excitations. The model is based on the Beam Element Model of the stator yoke/tooth system. The rotor structure is not modeled, and the stator structure is discretized in beam elements. Stator winding is modeled as an added mass. For external rotor PMSM, the equivalent cylindrical shell model is preferred.

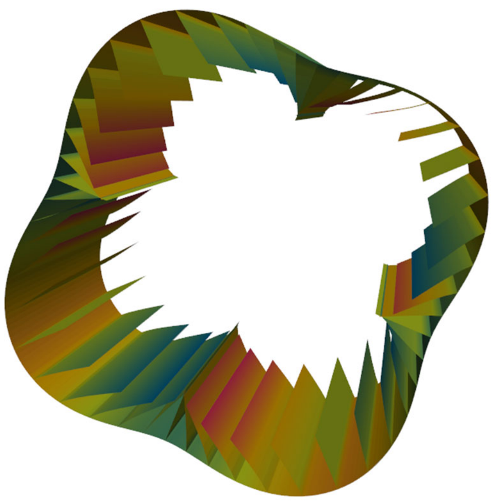
**Application**

During the concept design phase of electric drives, it is important to avoid structural resonances between main lamination modes and magnetic forces. Electrical engineers can use these fast structural models to quickly evaluate stator vibration and noise levels due to magnetic forces and make a first ranking of different electrical machine topologies. Mechanical engineers can rely on the stator BEM model to estimate the natural frequencies of the stator in free-free boundary conditions. Even if natural frequencies shift when the lamination is unified in the final housing, an order of magnitude of the main stator modes, which can be excited by magnetic forces (such as breathing mode and ovalization mode), is particularly useful for early e-NVH risk assessment.

Compared to the equivalent cylindrical shell model, the BEM model represents the stator tooth bending effect and assesses the impact of both radial and circumferential forces (in particular by using the linear contribution plot). It should then be preferred for inner rotor machines.

This fast model is used by electromagnetic design engineers to optimize the magnetic circuit directly concerning stator RMS vibration level in dB or sound power level in dBA instead of working at magnetic stress or force level.

In the detailed design phase, once a detailed CAD model of the e-machine structural environment (e.g., housing, gearbox, etc.) is available, calculations can be refined using the Manatee 3D modal basis import feature.



### 2.1.5. Finite Elements Structural Models

**Description**

The Manatee e-NVH collaborative platform can perform calculations on a 3D FEA mechanical model of the electric drive, which may include rotor and stator, housing and gearbox, driveline and bearings, etc... This detailed modeling allows for more realistic modes (e.g., rotor/housing coupling mode, rotor bending modes) compared to the quick analytic structural model or the Beam Element Model. It is highly recommended when introducing tolerances and faults during e-NVH calculations.

Manatee can import a modal basis from a third-party 3D FEA mechanical software (e.g. SIMULIA Abaqus, ...). During the import, Manatee performs unique pre-processing, which greatly reduces e-NVH computation time. Using the Electromagnetic Vibration Synthesis algorithm, the imported modal basis in Manatee format can then be reused in variable speed simulation or parameter sweep (as long as magnetic circuit modification does not change the modal basis).

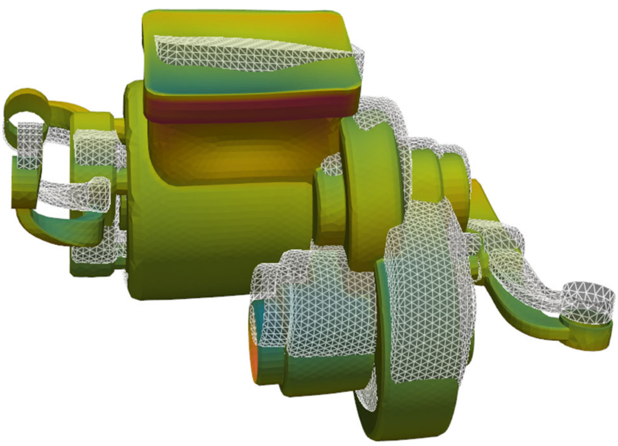
The 3D FEA mechanical model can include sensors to extract vibration levels in specific areas for comparison with accelerometer measurements or to extract nodal vibration in x, y, and z directions for comparison with NVH requirements.

It can also include connection points for the computation of blocked forces in x, y, and z directions for comparison with NVH requirements.

**Application**

Mechanical engineers can carry out the import of a 3D mechanical FEA modal basis. The resulting modal basis in Manatee format can then be used by electrical engineers when iterating on the electromagnetic model or by NVH engineers when checking e-NVH requirements at variable speed.





### 2.1.6. Fast Semi-Analytical Acoustic Models

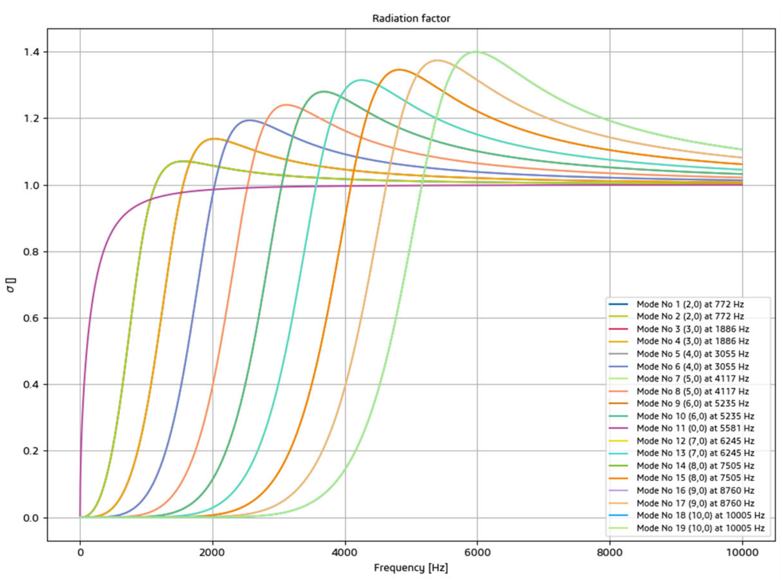
**Description**

Manatee e-NVH software includes fast semi-analytical models of the acoustic radiation of electric machines, which can be used in different design phases.

In the early design phase, when no detailed CAD model is available, some semi-analytic radiation factor models of the external structure (stator or rotor) are proposed based on Equivalent cylinder shell models. In the detailed design phase, when Manatee uses a complex 3D FEA model, a fast way to evaluate the Sound Power Level is the analytic Equivalent Radiated Power (ERP) model.

**Application**

Electrical engineers can use the equivalent cylindrical shell models in the early design phase to estimate the Sound Power Level radiated by the main in-plane flexural modes of the lamination winding assembly (or magnet steel assembly for external rotors). Mechanical and acoustic engineers can use the Equivalent Radiated Power model to estimate the sound level due to magnetic excitations.



## 2.2. Robust Design Including Manufacturing Tolerances

### 2.2.1. 3D Static and Dynamic Eccentricities

**Description**

Manatee software allows the assessment of the effect of 3D static and dynamic eccentricities due to mechanical tolerances on the electromagnetic noise and vibration levels**.** Parallel and inclined static and dynamic eccentricity levels can be specified at the drive and non-drive end, as well as the position of the static eccentricity axis. The effect of the parallel eccentricity direction on the e-NVH level can be studied when importing a 3D FEA mechanical model.

For a quick analysis, Manatee uses a perturbation technique of the airgap flux density to estimate parasitic magnetic forces induced by 3D static and dynamic eccentricities. This method can be applied when using a Magnetic Look Up Table, even when importing the airgap flux from third-party software.

This perturbation technique, also used for uneven airgap, is suitable for low airgap deformation values (max 15% of the magnetic airgap width). It can be used to estimate the effect of eccentricity on "high frequency" magnetic force harmonics that are not strongly related to the saturation level of the electrical machine. When applying the dynamic eccentricity quick model, a component due to the Unbalanced Magnetic Pull at H1 may be introduced in vibration and noise results. This component level might be overestimated due to the missing saturation effect in the perturbation model. It might also be underestimated compared to experiments due to the missing mechanical unbalanced force. Finally, H1 excitation occurs at "low frequency," where acoustic noise might be overestimated using the Equivalent Radiated Power (ERP) model. Therefore, H1 vibroacoustic results under dynamic eccentricity should be interpreted carefully using the quick perturbation model.

**Application**

This feature allows mechanical engineers to calculate the effect of 3D eccentricities on electromagnetic noise and vibrations. Thus, too-conservative mechanical tolerance values can be avoided.

It also allows electrical engineers to perform robust e-NVH ranking of different electrical machines. An electrical machine A may be louder than machine B without eccentricity, while it becomes the opposite with 15% dynamic eccentricity.

It is recommended that eccentricity effects be modelled when introducing a 3D FEA mechanical model in Manatee, including rotor and stator structures. Eccentricity induces parasitic Unbalanced Magnetic Pull, adding structure-borne and air-borne noise.

Demonstration


Set Eccentricity
Setup
Preview
Eccentricity rate along rotor axial position
Eccentricity rate along rotor axial position
Eccentricity rate [%]
Axial position from Non Drive-End to Drive-End [m]
Rotor center position in xy plane at Drive-End
Rotor center variation in xy plane at Drive-End
Rotor center variation along y axis [
Rotor center variation along x axis [%]
Rotor center position in xy plane at Non Drive-End
Rotor center variation in xy plane at Non Drive-End
Rotor center variation along y axis [
Rotor center variation along x axis [%]
Preview
Ok
Cancel

## 2.2.2. Uneven Airgap

**Description**

Manatee software allows the assessment of the effect of uneven bore radius due to mechanical tolerances on electromagnetic noise and vibration levels. A particular pattern (for example, elliptical deformation) and its magnitude in percentage of the airgap width can be chosen.

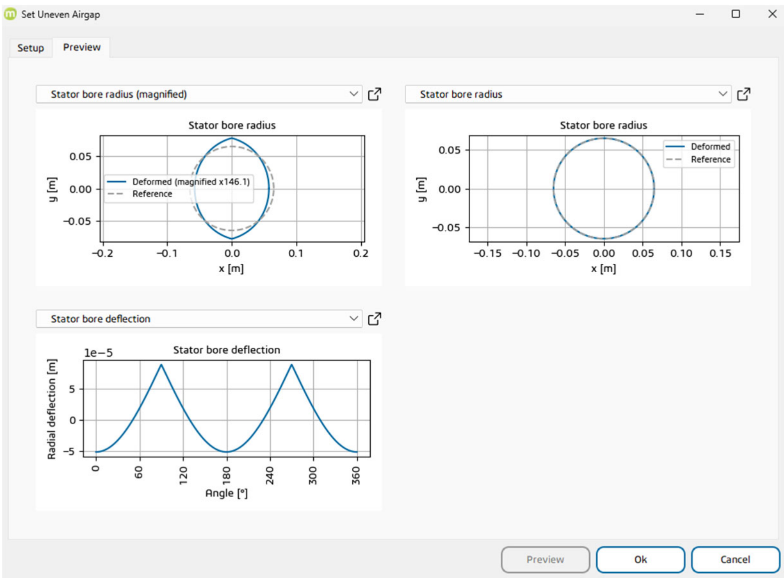
For a quick analysis, Manatee uses a perturbation technique of the airgap flux density to estimate parasitic magnetic forces induced by 3D eccentricities. This method can be applied when using a Magnetic Look-Up Table, even when importing the airgap flux from third-party software.

This perturbation technique, also used for eccentricities, is suitable for low airgap deformation values (max 15% of the magnetic airgap width). It can be used to estimate the effect of eccentricity on “high-frequency” magnetic force harmonics that are not strongly related to the electrical machine's saturation level.

**Application**

This feature allows mechanical engineers to calculate the effect of uneven airgap on electromagnetic noise and vibrations. This way, values of mechanical tolerances that are too conservative can be avoided. Uneven airgap can be induced by the manufacturing process (for example, segmentation, welding, shrink fit) of the electrical machine.

It also allows electrical engineers to perform robust e-NVH ranking of different electrical machines. Electrical machine A may be louder than machine B with a perfectly circular stator, while it becomes the opposite when stator deformation is included.



### 2.2.3. Uneven Magnetization

**Description**

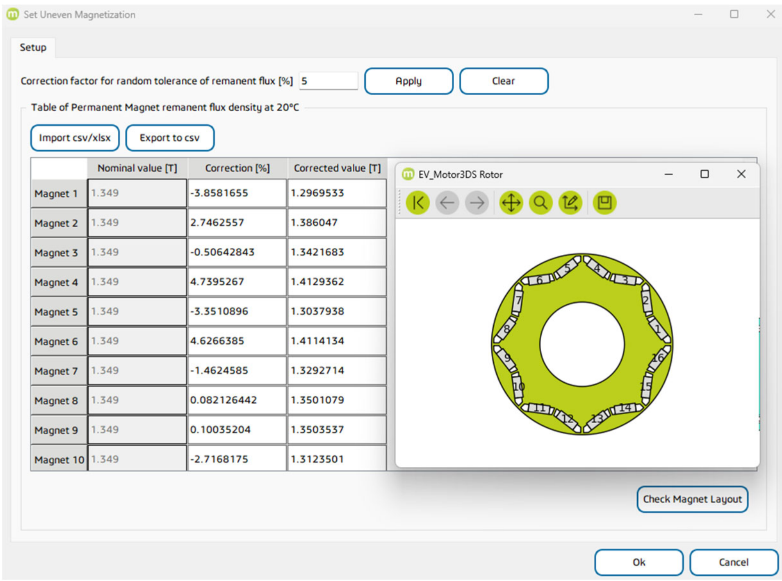
Manatee software allows you to assess the effect of uneven magnetization due to manufacturing or assembly tolerances on electromagnetic noise and vibration levels. A random perturbation can be set for all the magnets, or a user-defined variation can be set separately for each magnet of each pole.

Permanent magnet excitations might be uneven due to manufacturing variations, different operating temperatures, different positions in slots...

**Application**

This feature allows electrical engineers to calculate the effect of uneven magnetization on electromagnetic noise and vibrations. Too conservative values of remanent flux tolerances can be avoided. Uneven magnetization may be specified using some magnetic field measurements outside the Permanent Magnet rotor.

This feature also allows electrical engineers to perform robust e-NVH ranking of different electrical machines. An electrical “machine A” may be louder than “machine B” without uneven magnetization, while it becomes the opposite with 2% of uneven magnetization.



# 3. POST-PROCESSING

## 3.1. Insightful e-NVH Data Exploration

### 3.1.1. Order Tracking Analysis

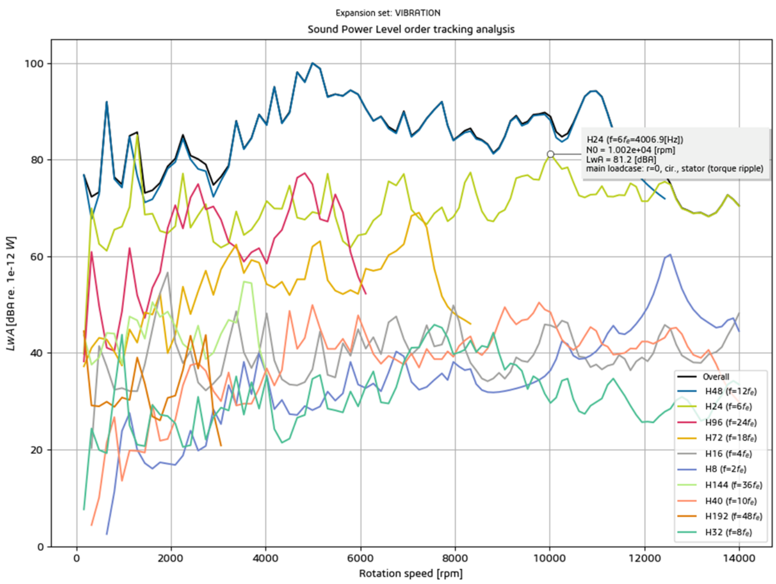
**Description**

Manatee e-NVH software provides a wide range of post-processing at the end of the simulation to analyze your electrical machine's electromagnetic & vibroacoustic behavior. The Order Tracking analysis enables to visualize the contribution of each excitation frequency to vibration and noise levels of the electric machine.

Order Tracking Analysis is available for different quantities such as the Sound Power Level, the Sound Pressure Level or the vibration displacement, velocity, and acceleration. If several sets have been defined in the imported 3D FEA mechanical model, they can be selected to focus on a particular sensor or panel contribution to sound power.

Besides, order levels can be visualized as a function of frequency or speed. The frequency axis allows to capture which orders are resonating with the same structural mode. Natural frequencies and structural modes can be displayed in the same graph to identify the implication of a given mode on a resonance peak.

Demonstration



## 3.1.2. Variable-Speed Spectrogram Analysis

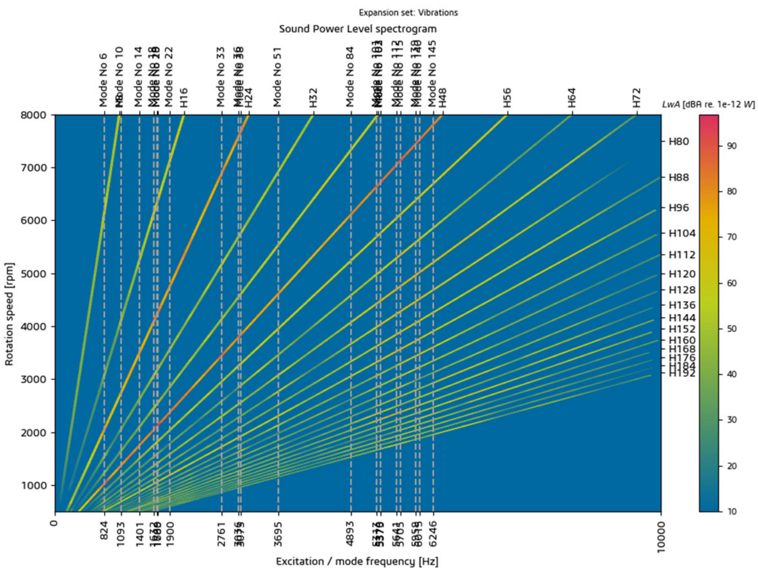
**Description**

In Manatee software, spectrogram visualization can efficiently analyze the vibration and acoustic noise of electric drives induced by e-machine electromagnetic excitations. Spectrograms allow one to visualize how a spectrum (flux, force, vibration or noise) varies along a series of operating points (different speeds or time stamps). Contrary to the Magnetic Frequency Signature Analysis tool, spectrograms contain magnitude information on spectral lines.
The level of each harmonic can be analyzed using Order Tracking analysis. Spectrograms come with different options to ease interpretation, such as Load Case filtering and display of natural frequencies or orders.

**Application**

Spectrograms and automated Order Tracking analysis are key visualization tools available at the end of every e-NVH simulation under Manatee. It can be applied to several multiphysic model outputs (flux, force, vibration, noise). Electrical, mechanical and acoustic engineers can use spectrograms to quickly identify the root cause of resonances in terms of electromagnetic excitation frequency and wavenumber.

[Demonstration]



### 3.1.3. Torque Speed Plane Calculations (Noise Maps)

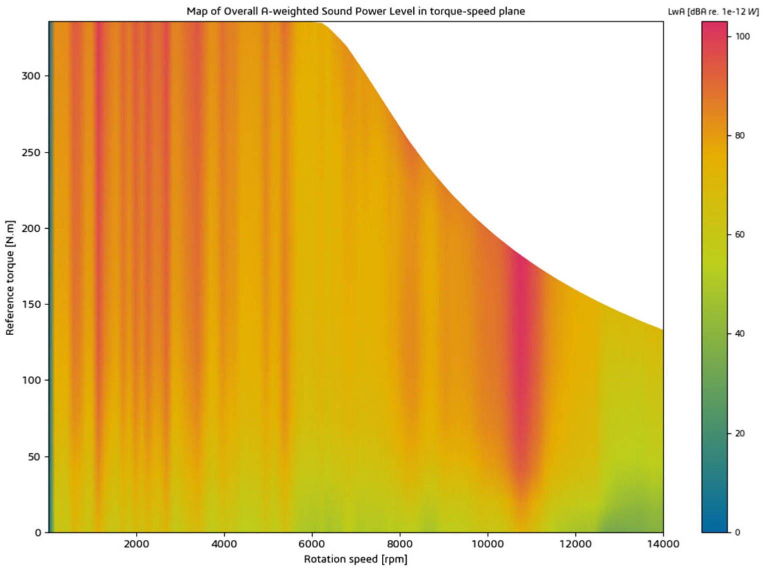
**Description**

Manatee's torque/speed plane feature allows its users to characterize the magnetic noise and vibration levels in the whole torque/speed plane, that is, on the four quadrants (traction / braking / reverse modes) of their electric machine, including noise map plots. Calculations can be quickly carried out using Manatee's Magnetic Look-Up Table feature.

**Application**

Resonances due to electromagnetic excitations may occur at partial load, not necessarily at maximum torque or current levels. Noise due to magnetic forces may also differ in the traction or braking phase. This feature allows electrical and acoustic engineers to calculate acoustic noise and vibrations due to Maxwell forces in electric motors' whole torque/speed plane and synthesize sound levels at different torque levels.

[Demonstration]()



### 3.1.4. Operational Deflection Shape

**Description**

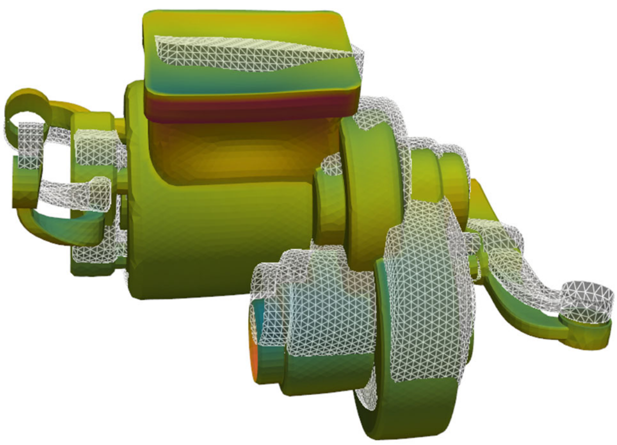
Operation Deflection Shape (ODS) analysis directly visualizes system-level dynamic deflections at a given operating point and frequency. Frequencies can be selected for mechanical orders (multiple of H1, rotor mechanical frequency) or electrical orders (multiple of fundamental electrical frequency). ODS is the analog of the exciting force Operational Force Shape (OFS) for structure deflections.

Both mechanical mesh and operational forces can be overlayed. The scale of the deflection shape can be changed, and the resulting animation can be saved.

**Application**

This features allows electrical, mechanical and NVH engineers to interpret resonances during the virtual prototyping of electrical machines, identifying the modes involved in vibration/noise generation (complementary to Modal Unit Force). Visualization of structural deflections can be done with operational forces. Far below resonance, exciting forces and deflections are in phase. At resonance, exciting forces and deflections are 180° out of phase.

ODS may help mechanical, and NVH engineers identify the most relevant regions to be stiffened.



### 3.1.5. Operational Forces

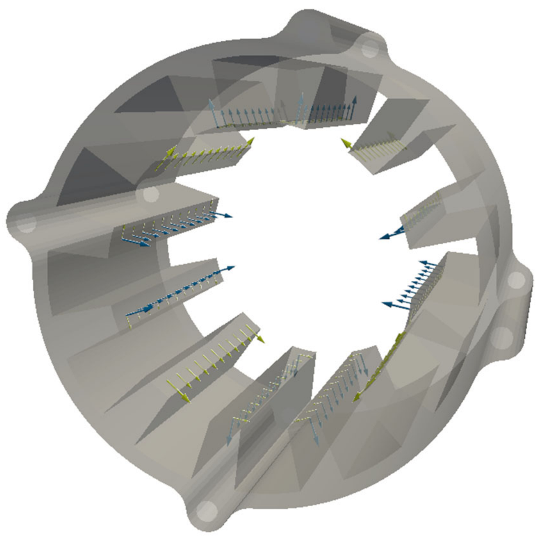
**Description**

Operational Force Shape (OFS) analysis provides a direct visualization of system-level dynamic magnetic forces at a given frequency or for a given Load Case. Frequencies can be selected for mechanical orders (multiple of H1, rotor mechanical frequency) or electrical orders (multiple of fundamental electrical frequency). It is the analog for exciting forces of the excited structure Operational Deflection Shape (ODS).

OFS can be visualized in 3D or in 2D in the plane of a slice (especially useful for skewed electrical machines).

**Application**

This feature allows electrical engineers to visualize the shape of magnetic excitations and mechanical engineers to analyze the root cause of resonance during the virtual prototyping of electrical machines. Tangential and radial forces may act in phase or anti-phase, resulting in constructive or destructive interference at the vibration level.



### 3.1.6. Sound Quality Metrics

**Description**

Manatee e-NVH software can compute the Sound Pressure Level and synthesize the sound of the electrical system, combining magnetic noise produced by the electrical machine with imported non-magnetic noise. The total sound signature can then be analyzed using Sound Quality metrics to accurately quantify the perceived sound attributes beyond the simple Sound Power Level value.

Besides A-weighting, the following psychoacoustic metrics are available at the end of every simulation:

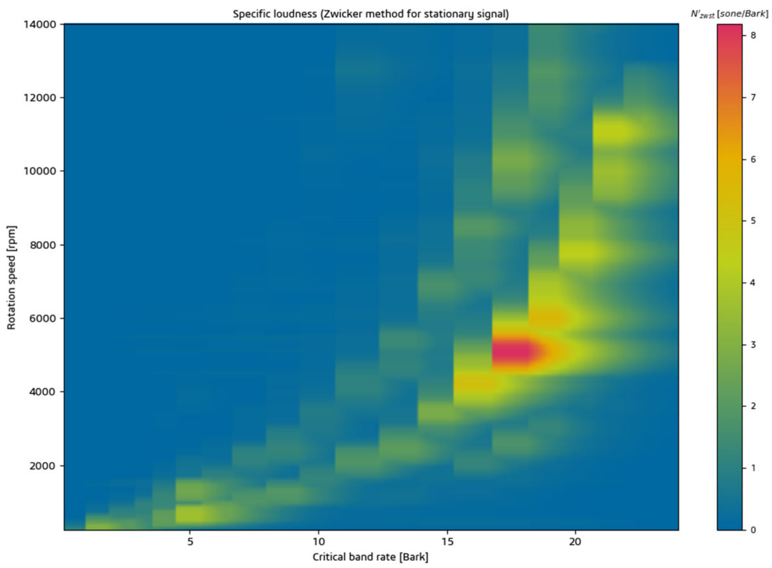
- Loudness and specific loudness (Zwicker method for stationary signals)
- Sharpness (DIN 45692)
- Roughness and specific roughness (Daniel & Weber method)

**Application**

The physical Sound Power level is sometimes insufficient to quantify the acoustic annoyance of an electric drive. In some cases, e-motor prototypes are rejected by a customer just because they sound more unpleasant than the competitor prototype. This can be due to tonalities or modulation effects introduced by eccentricities or Pulse Width Modulation. Electric drives are prone to tonalities as magnetic forces occur at some frequencies.

Some standards, therefore, use psychoacoustic indices to quantify the subjective perception of sound more objectively. For example, tonalities are penalized in wind turbine and railway applications. Sound quality metrics enable acoustic or NVH engineers to quantify and analyze system-level acoustic annoyances.

Demonstration



# 4. ADVANCED ANALYSIS

## 4.1. Advanced e-NVH Root Cause Analysis Tools

### 4.1.1. Interactive Plots

**Description**

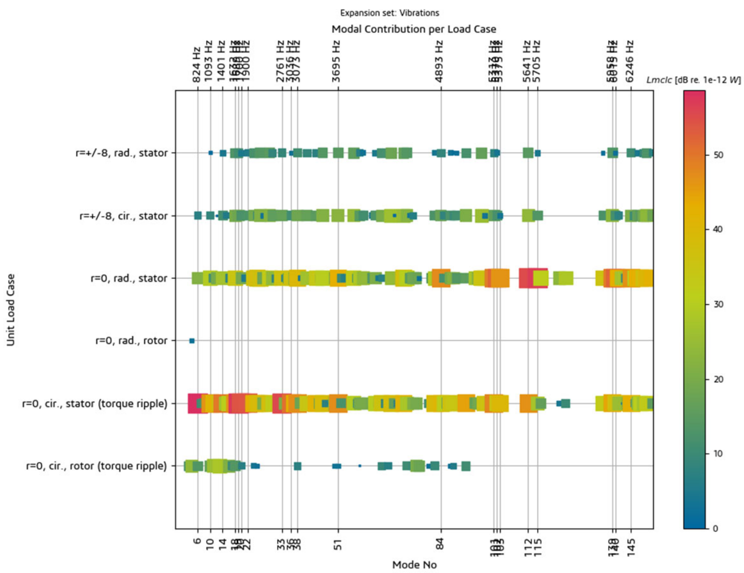
In Manatee software, a selection of relevant plots is automatically generated at the end of the electrical machine simulation. Depending on the chosen workflow, they may include electrical, electromagnetic, structural mechanics or acoustic quantities.

Each plot can be undocked to access further interactive options. The icon banner also offers shortcuts to standard plots (spectrums, spectrograms, order tracking analysis, torque-speed maps). All plots include mathematical post-processing (e.g., Fourier transform in 1D or 2D) and can be animated in time or space. Most can be exported in raw format (e.g., .csv).

**Application**

All engineers involved in the development of electric drives can access insightful visualization tools of the most relevant physics. Post-processing of simulation outputs does not need to be carried out in another environment, making result interpretation faster.

[Demonstration]()



## 4.1.2. Magnetic Force Signature Analysis

**Description**

This key feature of Manatee e-NVH software gives the frequency signature of primary magnetic force harmonics (excitation frequencies and wavenumbers) depending on slot/pole/phase combinations, electrical machine topology (for example induction or synchronous machine, inner or outer rotor), load state (for example no load, full load) and supply (for example sine / PWM). The saturation harmonics for induction machines are also included. Calculating magnetic force harmonics is based on analytic models and gives instantaneous results, making it easy to do what-if scenarios.

Results are presented as a Campbell diagram of magnetic lumped force harmonics function of speed and frequency. The physical origin of a given magnetic Load Case in terms of permeance, magnetomotive force, flux wave combinations, and excitation sources (rotor/stator excitation fields, slotting harmonics, armature winding or magnet space harmonics).

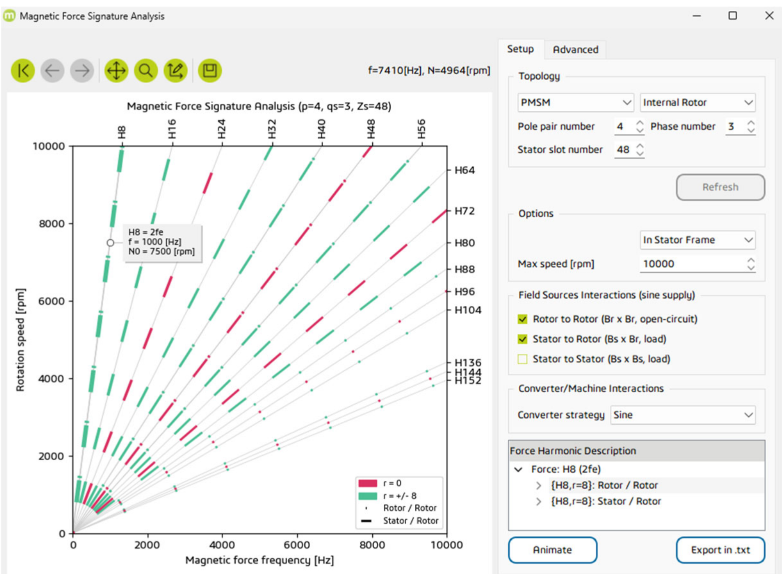
**Application**

Electrical engineers can use the Magnetic Force Signature Analysis (MFSA) tool in the early design phase to quickly compare Maxwell excitations among different topologies. Once a noise issue has been identified, electromagnetic design engineers can also use this feature to discriminate the harmonic origin of the electromagnetic excitation (for example, a combination of 11p and 13p rotor mmf harmonics with a first-order slotting harmonic) to implement electromagnetic design optimization.

Mechanical and acoustic engineers can also use it to first estimate the main resonances between magnetic force harmonics and main lamination modes.

Finally, it can be useful for NVH test engineers to identify the nature of electromagnetic excitations from experimental spectrograms and easily discriminate magnetic noise from other noise sources (e.g., mechanical and aerodynamic noise).

Demonstration



### 4.1.3. Spatiogram (Load Case Contribution)

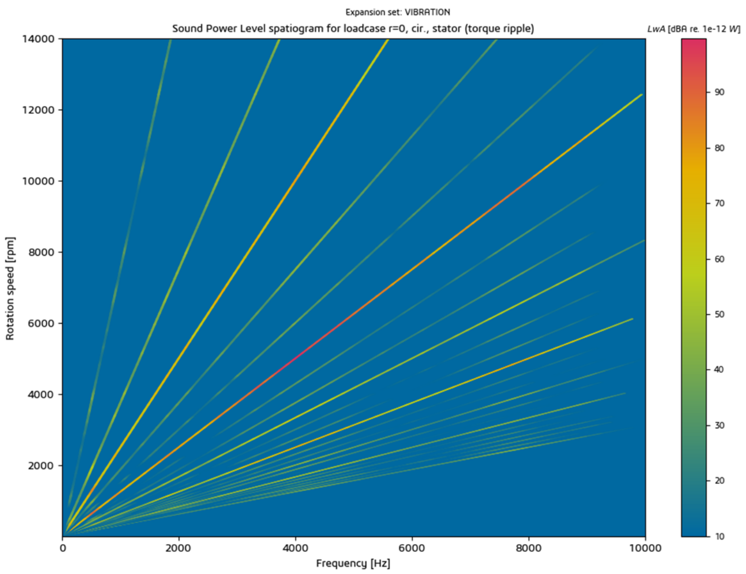
**Description**

Spatiograms is a unique visualization tool of Manatee software that gives variable-speed vibration and noise results (spectrograms) per electromagnetic Load Case. This is one of Manatee's software tools for quickly understanding the nature of electromagnetic excitations responsible for acoustic noise issues.

The Electromagnetic Vibration Synthesis algorithm naturally allows splitting the vibroacoustic contribution of each Load Case. A load case is defined by a magnetic force wavenumber (e.g., r=0 for a pulsating force along the airgap), a direction of application (e.g., radial), and a set of application nodes (e.g., stator tooth tip nodes). Torque ripple observed by the stator and unbalanced magnetic pull observed by the rotor are two examples of load cases.

**Application**

The split of Load Case and structural mode contributions to the overall noise level allows both electrical and mechanical engineers to quickly understand the problem and implement noise mitigation techniques. Contrary to general-purpose FEA software, Manatee results come with powerful post-processing to speed up result interpretations.



## 4.1.4. Linear Contribution Plot

**Description**

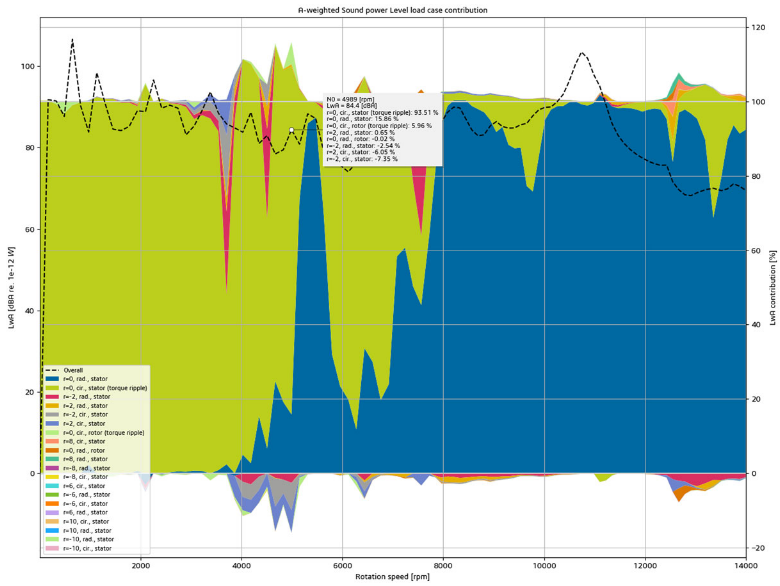
Manatee software offers powerful tools to identify the root cause of e-NVH issues. One of these tools is the Load Case contribution plot which allows to quickly visualize the linear contribution of each load case to the overall noise or vibration and which is expressed in percentage.

Note that in dB/dBA, a 50% linear contribution corresponds to a 3dB contribution.

**Application**

Mechanical and NVH engineers can use the contribution plot to quickly identify the root cause of the e-NVH issue, whether air-borne or structure-borne, radial or circumferential.

An automatic split of internal/external and radial/circumferential load cases is also available through the "Split contributions" button to understand whether the e-NVH issue is air-borne or structure-borne, radial or circumferential along the speed. In particular, the effect of torque ripple and unbalanced magnetic pull on the stator and rotor can be separated.



# 5. OPTIMIZATION

## 5.1. Predefined Noise Control Techniques

### 5.1.1. Skew Pattern Optimization

**Description**

Manatee software allows you to calculate the effect of skewing on electromagnetic noise and vibration levels. You can choose a predefined rotor skew pattern (e.g., V-shape step skew for IPMSM, linear skew) or a user-defined geometry.

Manatee automatically expands electromagnetic and force calculations along the machine axis. Skewing calculations can be quickly performed when using a pre-calculated Magnetic Look-up Table. Skewing is also supported when importing the airgap flux from third-party software.

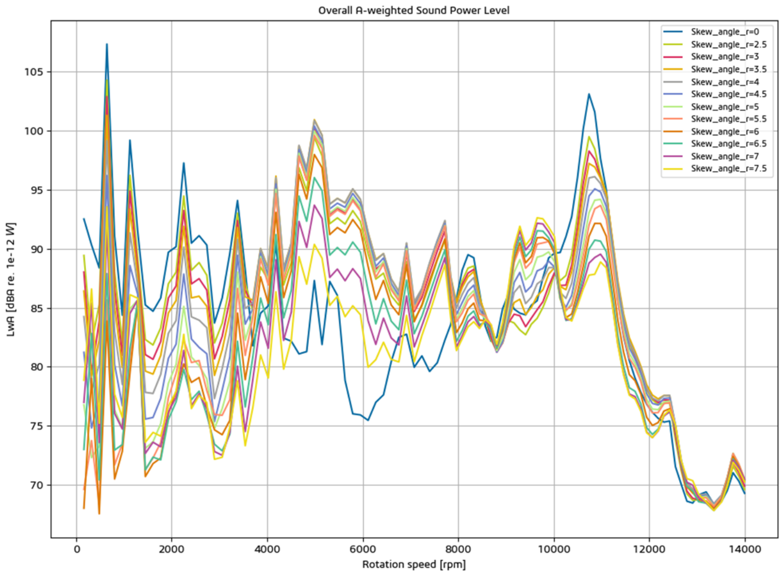
**Application**

This feature allows electrical and mechanical engineers to find the optimal skew pattern, maximizing average torque and minimizing noise along the torque-speed curve while keeping torque ripple and cogging torque to an acceptable level (note: cogging torque and peak-to-peak torque ripple are generally *not correlated to e-NVH*).

The only required input is the skewing type to be investigated starting from a reference design. Manatee automatically defines a parameter sweep on the skew angle and tracks useful information for each design, such as average torque, peak-to-peak torque ripple, maximum sound power level over speed and the amplitude of the main noise and forces harmonics.

Skewing can excite longitudinal modes of the electrical machine structure (for example, mode (2,1) of the stator). It is, therefore, advised that it be used with a realistic 3D FEA mechanical model using the modal basis import feature.

Demonstration


Overall A-weighted Sound Power Level
LwA [dBA re. 1e-12 W]
105
100
95
90
85
80
75
70
0
2000
4000
6000
8000
10000
12000
14000
Rotation speed [rpm]
Skew_angle_r=0
Skew_angle_r=2.5
Skew_angle_r=3
Skew_angle_r=3.5
Skew_angle_r=4
Skew_angle_r=4.5
Skew_angle_r=5
Skew_angle_r=5.5
Skew_angle_r=6
Skew_angle_r=6.5
Skew_angle_r=7
Skew_angle_r=7.5

## 5.1.2. Harmonic Current Injection

**Description**

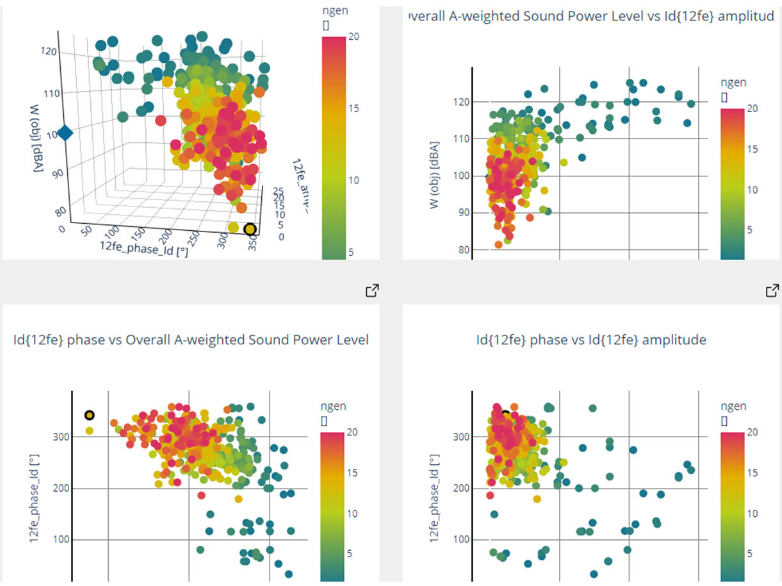
Manatee e-NVH solutions include a Harmonic Current Injection (HCI) environment designed to quickly mitigate magnetic noise and vibration produced by electric machines through optimal harmonic current injection. This environment automatically creates an optimization problem for current harmonic parameters (amplitude and phase, in DQ frame for synchronous machines) on the noisiest operating point of reference simulation to reduce noise and vibrations while maintaining an acceptable efficiency level.

Specific design and response variables are automatically defined depending on the machine and reference results and can be modified if necessary.

**Application**

The Harmonic Current Injection environment is designed to help electrical engineers optimize the control of electrical machines for efficiency and e-NVH. For example, it helps find the optimal amplitude and phase of current and voltage harmonics along DQ-axes at six times the electrical frequency to dampen NVH levels at 6fe induced by torque or radial ripple.

[Demonstration]



## 5.2. Efficient e-NVH Design Exploration

### 5.2.1. Parameter Sweep Definition

**Description**

Manatee software allows parameter sweeps on electrical machine multiphysics simulation inputs. Design variables that can be varied include all geometrical parameters from magnetic circuit templates (e.g., slot shapes, magnet pocket shapes, notch shape, skew rate), winding design parameters (coil pitch), control parameters (e.g., current angle for fixed speed PMSM), fault parameters (e.g., eccentricity level) or magnet temperature.

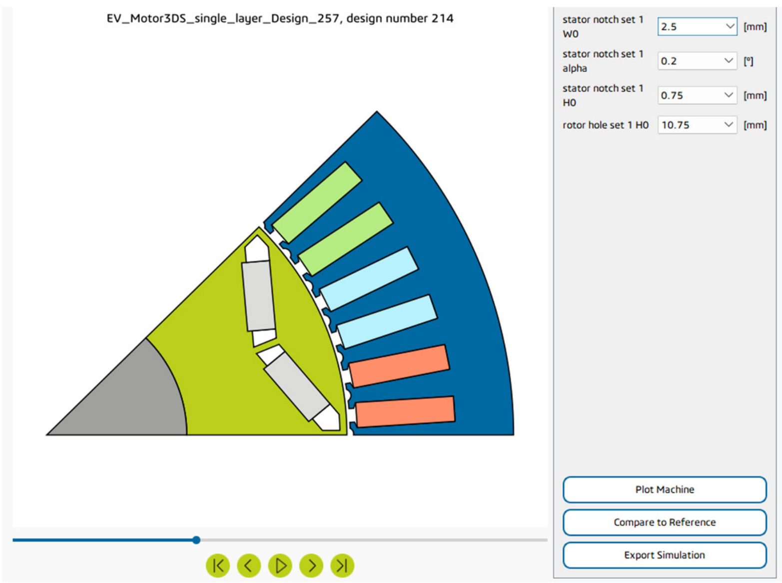
Standard response variables are included in parameter sweeps (for example, torque, maximum noise level along torque/speed curve). Still, advanced output variables can also be user-defined (for example, the level of a specific harmonic in flux/vibration/noise quantities, xyz vibration on a given node, etc.).

Manatee automatically identifies the calculations affected by design variable changes so that Magnetic Look Up Tables and modal basis calculations are only updated when relevant.

**Application**

Before running a detailed optimization study, electrical engineers can identify the most influential design parameters on acoustic noise and vibration levels due to magnetic forces. Mechanical engineers can also run a sensitivity study on static and dynamic eccentricity levels to specify the manufacturing tolerances better.

User-defined outputs allow NVH engineers to set up customized NVH requirements (for example Maxwell pressure levels in N/m^2, force levels in N, vibration levels at some particular points in dB etc).



### 5.2.2. Multi-Objective Optimization

**Description**

Manatee e-NVH software has a multi-objective optimization environment for electric machine magnetic circuit design variables. The default solver is the NSGA-II genetic algorithm. Design variables include geometric parameters from magnetic circuit templates (such as slot shape, notch shape, magnet pocket shape, and skew rate), winding design (e.g., coil pitch), rotor skew (e.g., skew angle), or current harmonics**.**

Overall noise, vibration, force or torque levels, and specific harmonics can be used as objectives to minimize or maximize. These variables can also be used to define constraints or be simply tracked during the simulation.

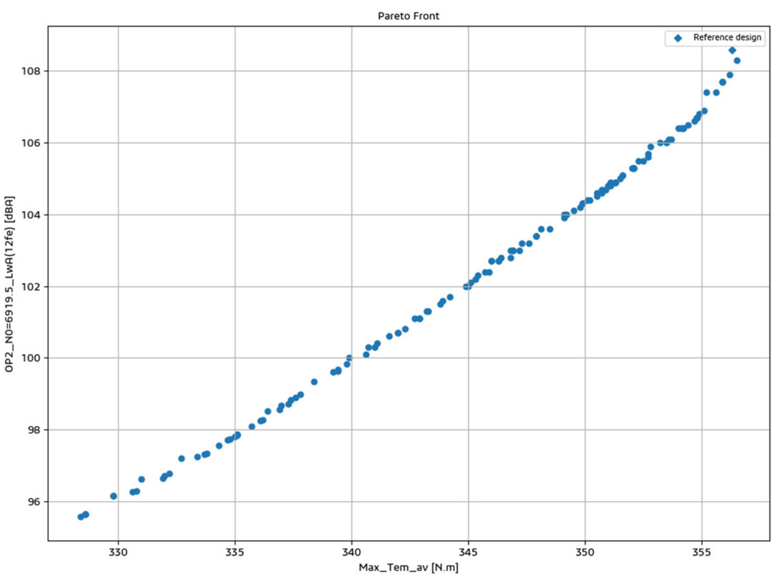
Dedicated post-processings are automatically generated at the end of the optimization to extract the Pareto front, study the algorithm's convergence rate, or explore the final design space. It is also possible to extract a given design and run more detailed simulations on it.

**Application**

The optimization environment is designed to help Electrical and NVH Engineers improve the multi-physic performances of a given design, especially in terms of noise, vibrations and electromagnetic performances.

User-defined outputs allow NVH engineers to define customized requirements. This is particularly helpful in automotive applications, where different OEMs and tier-one suppliers may have different ways of specifying NVH requirements.

[Demonstration]



### 5.2.3. Design Explorer

**Description**

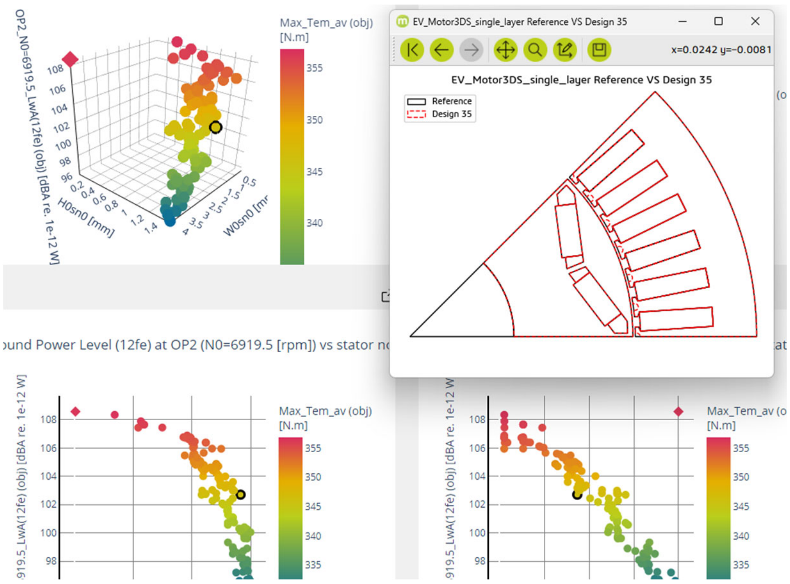
Manatee e-NVH software allows to smoothly perform electrical machine design explorations among optimization or parameter sweep results. Manatee Design Explorer provides a dedicated interface to explore all the simulated designs with 5D visualization (XYZ axes, color and size). The design cloud can be filtered on the response/design variables (for example with additional constraints).

A given electric machine design can be visualized and exported within a new simulation multiphysics workflow for further analysis with a button click. A group of designs can also be selected to compare their characteristics more easily and exported as a .csv file.

**Application**

Running parameter sweeps can create massive data sets with several designs and response variables for each design. This interface enables to conveniently display and filter all the designs to find the best trade-off. This analysis can be carried out by all engineers involved in developing electric drives.

Demonstration



# 6. TOOL INTEGRATION

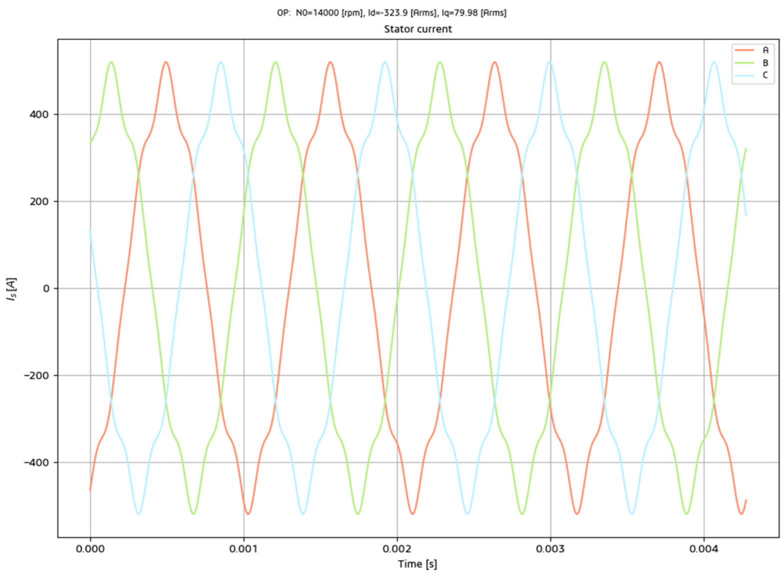
## 6.1. Smooth Integration Into CAE Workflow

### 6.1.1. Current Import

**Description**

When supply currents have already been computed on third-party electromagnetic software or measured, this feature of Manatee software allows to calculate airgap flux density from the sole import of phase current signal along one electrical period. Variable speed current import, skewing and eccentricity are supported.

Currents can be imported at very few operating points, flux density and magnetic forces are then automatically extrapolated or interpolated at variable speed using the MLUT algorithm.




**Application**

This import feature can be used by electrical engineers who want to perform simulations with non-sinusoidal currents. The impact of non-conventional control or current profiling on noise and vibration can be evaluated.

**Documentation**

For more information on how to import currents from third-party software, you can have a review the documentation available in the software.

### 6.1.2. Airgap Flux Import

**Description**

When electromagnetic calculations have already been performed in third-party electromagnetic software, this feature of Manatee software allows Maxwell force calculations from the sole import of airgap flux density distribution along time and angular position in the airgap. A Magnetic Look-up Table is automatically built, supporting variable speed flux import as well as skewing.

Eccentricity can be applied even when importing the flux from a machine without eccentricity when using Manatee uneven airgap perturbation model.

Flux density can be imported at very few operating points. Magnetic forces are then automatically extrapolated or interpolated at variable speed using the MLUT algorithm.

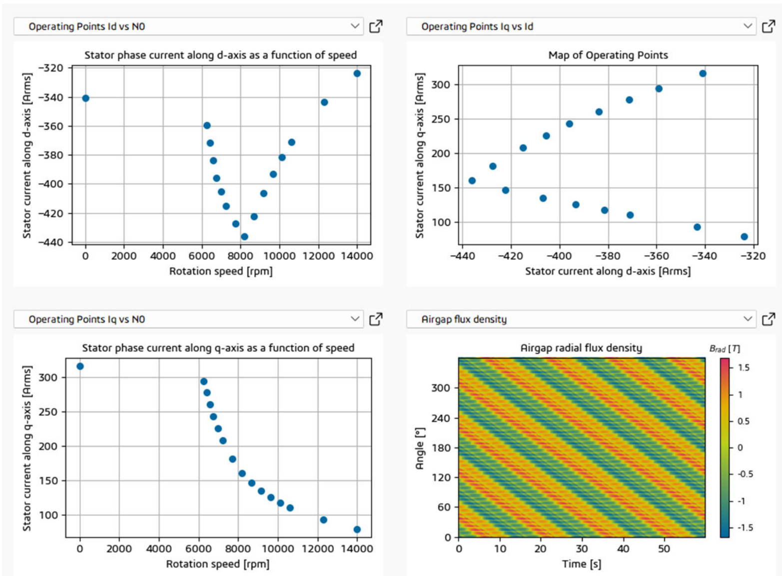
**Application**

Electrical engineers can use this import feature to avoid running electromagnetic calculations again from third-party software.

This import feature can also be used in the detailed design phase to include some strong magnetic-to-electrical circuit coupling effects, which are not included in Manatee electromagnetic calculations.

**Documentation**

The software's guidelines provide more information on how to import an air gap flux density from third-party software.



### 6.1.3. Modal Basis Import

**Description**

Noise and vibration induced by electric motor operation can be calculated with Manatee software through the modal basis import feature of a third-party 3D FEA mechanical model. Contrary to analytic NVH models, a 3D FEA mechanical model allows for an accurate model of the effect of electric machine mechanical integration (for example, rotor housing coupling mode, rotor bending modes, and housing boundary conditions). It is especially useful when introducing tolerances and faults during e-NVH calculations.

**Application**

Contrary to the early design phase during which electrical engineers do not know the mechanical integration of their electrical machine, the first version of the mechanical integration is known in the detailed design phase as a CAD model of the rotor, stator, housing and driveline assembly. At this development stage, the type of lamination interference fit, e-motor cooling and driveline architectures are known. A 3D FEA mechanical model can, therefore, be defined by a mechanical engineer, and electrical machine mechanical properties can be tuned by fitting the model with an Experimental Modal Analysis.

Once the 3D FEA mechanical model is built, it can be represented by its modal basis. The format of the modal basis may depend on the third-party mechanical software used. The modal basis assumes a linear behavior of the mechanical assembly. If necessary, the mechanical assembly is linearized around a particular operating point (e.g., under a certain load, assuming a certain eccentricity level).

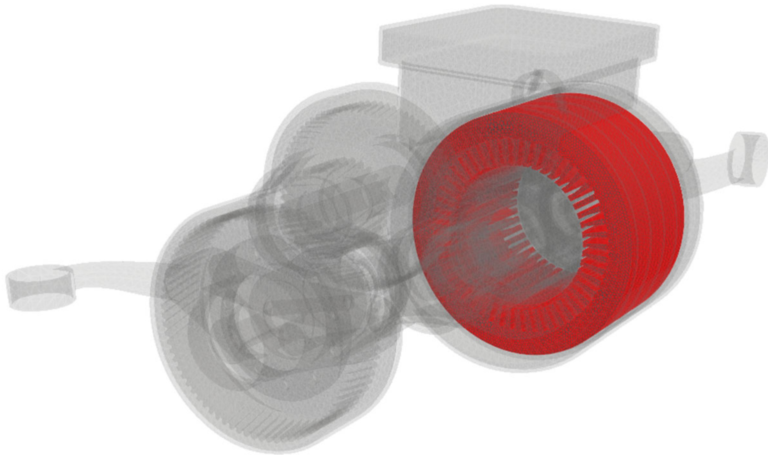
Importing a 3D FEA modal basis in Manatee can be carried out with up to 6 billion degrees of freedom. It can contain complex coupling elements for modeling bearings and gears.

**Documentation**

The guidelines in the software provide more information on how to prepare a 3D FEA mechanical model and modal analysis for use in Manatee e-NVH software.

Available format: .inp/.op2, .fem/op2, .dat/op2 or .rst.

Before running modal analysis in the third-party 3D FEA mechanical model, it is important to identify the nodes where vibration must be calculated by Manatee and the nodes of the surfaces radiating acoustic noise. Several surfaces can be defined to run panel contribution analysis under Manatee.



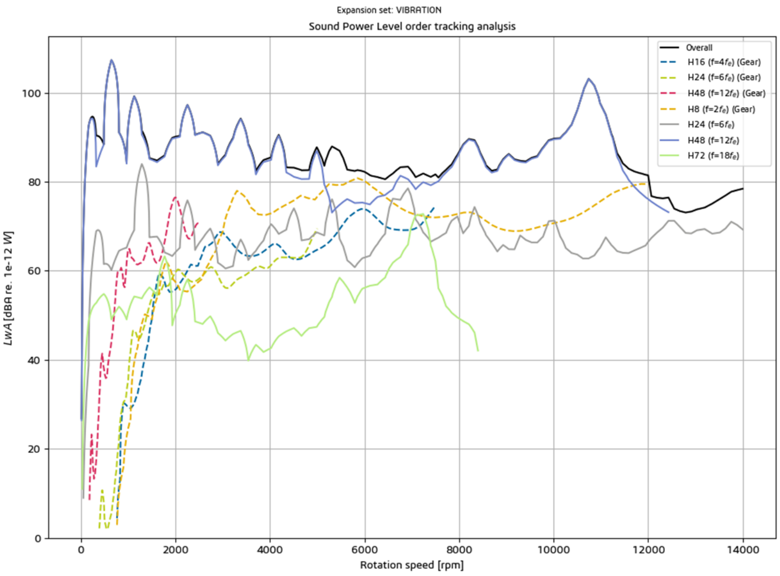
### 6.1.4. External Noise Import

**Description**

External noise sources (for instance, gear noise or aerodynamic noise, which are not produced by electromagnetic forces) can be imported inside Manatee using an Excel sheet format to obtain a full picture of the system's acoustic signature. The resulting overall noise and order tracking analysis can be explored using Manatee postprocessing tools.

**Application**

The import of external noise helps acoustic engineers see when electromagnetic noise dominates other sources of noise at each operating point. In automotive applications, NVH engineers can import gear mechanical noise calculated with third-party software to check NVH targets fulfilment per order and calculate sound quality metrics inside Manatee due to combined e-motor whine and gear whine**.**



### 6.1.5. Force Export

**Description**

Magnetic forces computed by Manatee e-NVH software can be exported in the frequency domain in .json format. Export can be done either in the time or frequency domain. A list of desired operating points can be selected, and the time discretization or maximum frequency can be tuned to get a reasonable output file size.

**Application**

The export of Manatee forces allows electrical engineers to use the user-friendly interface to compute the electromagnetic excitations and then send the output data to the NVH engineers to pursue NVH studies within third-party software. For example, magnetic forces could be exported to calculate structure-borne noise at the vehicle level in Abaqus or to iterate on the acoustic packaging in [Wave6](Wave6).


```json
"excitationData": [
    {
        "operatingPoint": "N0=14000 [rpm], Id=-323.9 [Arms], Iq=79.98 [Arms], Tem_av_ref=132.7 [N.m]",
        "forceData": [
            {
                "frequencies": [
                    0.0,
                    933.3333333333335,
                    1866.666666666667,
                    2800.0000000000005,
                    3733.333333333334,
                    4666.666666666667,
                    5600.000000000001,
                    6533.333333333334,
                    7466.666666666668,
                    8400.000000000002,
                    9333.333333333334
                ],
                "statorExcitation": [
                    {
                        "loadcase number": "NVH load case 0",
                        "loadcase": "r=-8, rad., stator",
                        "forceAmplitudeValues": [
                            0.00391940875655541,
                            0.0,
                            0.01614945532053711,
                            0.0,
                            6.770455969542994,
                            0.0,
                            0.05489958239784314,
                            0.0,
                            0.009303239383922043,
                            0.0,
                            7.281663801075416
                        ],
                        "forcePhaseValues": [
                            0.14235117946037212,
                            0.0,
```

## 6.1.6. Nodal Vibration Export

**Description**

Manatee computes nodal vibrations in the x, y, and z directions using a predefined set of nodes from a 3D FEA mechanical model. This requires importing the model with "Sensor nodes for vibration calculation" use. After simulation, nodal displacement, velocity, and acceleration can be exported as frequency functions. The vibration data for specific mechanical orders or operating points can be saved in .unv or .csv formats.

**Application**

Exporting nodal vibrations enables NVH engineers to compare vibrations at specific structural points with NVH requirements or test data. This data can also be used in third-party acoustic software, like SIMULIA Wave6, to refine acoustic calculations and determine Sound Pressure Levels at particular locations.

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 100 | Node 101 | Node 101 |
| 2 | | V_x | V_x | V_y | V_y | V_z | V_z | V_x | V_x | V_y | V_y | V_z | V_z | V_x | V_x |
| 3 | freq [Hz] | Magnitud | Phase [rad | Magnitud | Phase [rad | Magnitud | Phase [rad | Magnitud | Phase [rad | Magnitud | Phase [rad | Magnitud | Phase [rad | Magnitud | Phase [ra |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 407.6628 | 2.84E-06 | -1.00081 | 2.79E-06 | 2.805959 | 2.79E-06 | 2.805959 | 2.98E-06 | -1.06085 | 2.70E-06 | 2.78841 | 2.70E-06 | 2.78841 | 3.03E-06 | -0.99521 |
| 6 | 815.3257 | 7.09E-06 | -0.0492 | 4.18E-06 | -2.96932 | 4.18E-06 | -2.96932 | 7.10E-06 | -0.07027 | 4.79E-06 | -2.96383 | 4.79E-06 | -2.96383 | 7.48E-06 | -0.05554 |
| 7 | 1222.988 | 3.32E-05 | 1.50081 | 1.92E-05 | 2.337725 | 1.92E-05 | 2.337725 | 2.67E-05 | 1.222418 | 2.10E-05 | 2.3162 | 2.10E-05 | 2.3162 | 2.72E-05 | 1.348399 |
| 8 | 1630.651 | 6.41E-07 | 1.363596 | 1.47E-06 | 1.51489 | 1.47E-06 | 1.51489 | 5.20E-07 | 1.373681 | 1.50E-06 | 1.517645 | 1.50E-06 | 1.517645 | 5.21E-07 | 1.326342 |
| 9 | 2038.314 | 6.33E-07 | 0.109794 | 5.96E-07 | 0.407196 | 5.96E-07 | 0.407196 | 6.68E-07 | 0.317806 | 6.13E-07 | 1.335418 | 6.13E-07 | 1.335418 | 6.80E-07 | 0.397454 |
| 10 | 2445.977 | 0.000165 | 0.667833 | 0.000395 | 2.501876 | 0.000395 | 2.501876 | 0.00022 | 0.272673 | 0.000397 | 2.506449 | 0.000397 | 2.506449 | 0.000186 | 0.53843 |
| 11 | 2853.64 | 1.58E-06 | -2.79658 | 2.48E-06 | -2.80541 | 2.48E-06 | -2.80541 | 1.58E-06 | -2.89919 | 2.50E-06 | -2.82571 | 2.50E-06 | -2.82571 | 1.28E-06 | 2.894642 |
| 12 | 3261.303 | 5.33E-07 | -1.13002 | 2.17E-07 | -0.53601 | 2.17E-07 | -0.53601 | 5.96E-07 | -1.29752 | 2.26E-07 | -0.5371 | 2.26E-07 | -0.5371 | 5.85E-07 | -1.29571 |
| 13 | 3668.965 | 9.90E-06 | 0.838503 | 1.55E-06 | -1.54312 | 1.55E-06 | -1.54312 | 1.07E-05 | 0.762647 | 1.36E-06 | -1.48339 | 1.36E-06 | -1.48339 | 1.00E-05 | 0.829536 |
| 14 | 4076.628 | 1.57E-07 | -1.24945 | 2.80E-08 | -2.50223 | 2.80E-08 | -2.50223 | 1.79E-07 | -1.22923 | 2.83E-08 | -3.0167 | 2.83E-08 | -3.0167 | 1.67E-07 | -1.24466 |
| 15 | 4484.291 | 1.93E-07 | 2.272722 | 3.51E-08 | 0.546541 | 3.51E-08 | 0.546541 | 2.18E-07 | 2.280554 | 2.93E-08 | 0.421915 | 2.93E-08 | 0.421915 | 2.00E-07 | 2.305641 |
| 16 | 4891.954 | 6.74E-05 | 2.204476 | 1.21E-05 | 2.534318 | 1.21E-05 | 2.534318 | 6.89E-05 | 2.121859 | 1.49E-05 | 2.618849 | 1.49E-05 | 2.618849 | 6.69E-05 | 2.155912 |
| 17 | 5299.617 | 2.17E-07 | 2.324911 | 1.43E-07 | 2.547354 | 1.43E-07 | 2.547354 | 2.35E-07 | 2.333817 | 1.48E-07 | 2.461931 | 1.48E-07 | 2.461931 | 2.29E-07 | 2.324973 |
| 18 | 5707.28 | 4.30E-07 | -0.22959 | 6.83E-08 | -1.11821 | 6.83E-08 | -1.11821 | 4.41E-07 | -0.20201 | 7.65E-08 | -1.0234 | 7.65E-08 | -1.0234 | 4.32E-07 | -0.21756 |
| 19 | 6114.942 | 4.90E-06 | 0.975781 | 1.30E-06 | 1.513646 | 1.30E-06 | 1.513646 | 4.90E-06 | 0.965808 | 1.32E-06 | 1.477927 | 1.32E-06 | 1.477927 | 4.95E-06 | 0.959159 |
| 20 | 6522.605 | 2.95E-07 | 0.525851 | 1.83E-07 | 2.008945 | 1.83E-07 | 2.008945 | 2.82E-07 | 0.520866 | 1.73E-07 | 2.15861 | 1.73E-07 | 2.15861 | 2.86E-07 | 0.531822 |
| 21 | 6930.268 | 6.49E-07 | 2.514169 | 2.46E-07 | 1.167842 | 2.46E-07 | 1.167842 | 6.60E-07 | 2.505271 | 2.85E-07 | 1.671707 | 2.85E-07 | 1.671707 | 6.44E-07 | 2.528122 |
| 22 | 7337.931 | 1.83E-05 | 2.472289 | 1.55E-06 | -1.78232 | 1.55E-06 | -1.78232 | 1.78E-05 | 2.452078 | 5.30E-07 | -3.0959 | 5.30E-07 | -3.0959 | 1.83E-05 | 2.447341 |
| 23 | 7745.594 | 1.00E-06 | -2.67335 | 7.65E-07 | 0.907394 | 7.65E-07 | 0.907394 | 9.54E-07 | -2.63549 | 8.33E-07 | 0.877194 | 8.33E-07 | 0.877194 | 9.43E-07 | -2.64803 |
| 24 | 8153.257 | 1.07E-06 | -1.67969 | 7.49E-08 | -2.51528 | 7.49E-08 | -2.51528 | 1.07E-06 | -1.69444 | 6.88E-08 | -2.20353 | 6.88E-08 | -2.20353 | 1.07E-06 | -1.68024 |
| 25 | 8560.919 | 4.40E-05 | 0.571265 | 2.59E-06 | 0.886714 | 2.59E-06 | 0.886714 | 4.44E-05 | 0.561622 | 2.25E-06 | 1.405031 | 2.25E-06 | 1.405031 | 4.38E-05 | 0.584886 |
| 26 | 8968.582 | 8.60E-06 | -1.12258 | 7.21E-07 | 2.770066 | 7.21E-07 | 2.770066 | 8.37E-06 | -1.14011 | 3.89E-07 | 2.940887 | 3.89E-07 | 2.940887 | 8.62E-06 | -1.1323 |
| 27 | 9376.245 | 1.96E-06 | 0.476094 | 8.29E-08 | -2.37993 | 8.29E-08 | -2.37993 | 1.92E-06 | 0.478978 | 3.76E-08 | -1.88844 | 3.76E-08 | -1.88844 | 1.96E-06 | 0.477799 |
| 28 | 9783.908 | 7.21E-06 | -0.40183 | 2.65E-07 | 3.024744 | 2.65E-07 | 3.024744 | 7.10E-06 | -0.3951 | 1.27E-07 | -2.92092 | 1.27E-07 | -2.92092 | 7.19E-06 | -0.39841 |

## 6.1.7. Advanced Output Tracking

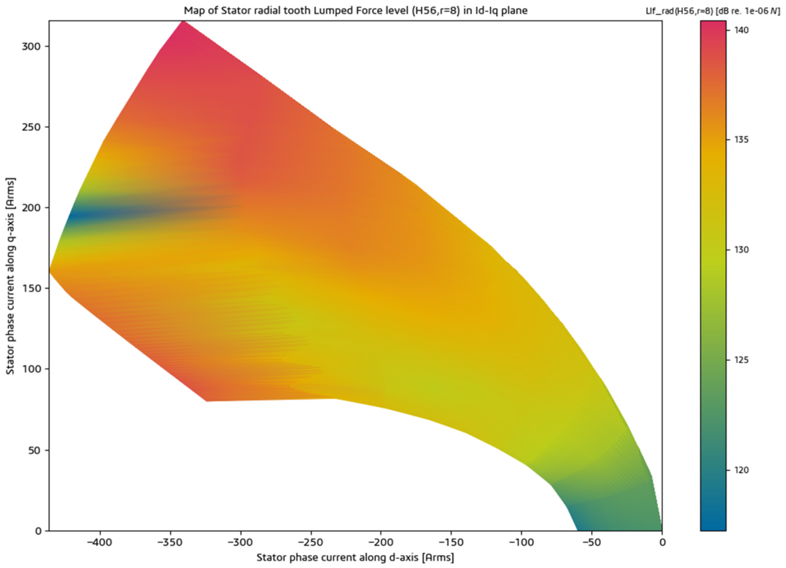
**Description**

Manatee e-NVH software offers the possibility to track user-defined physical simulation output. Standard outputs, such as the overall sound power level, vibration level or average torque, are automatically tracked. The user can also add trackers on very specific data, such as a given force harmonic at a selected Operating Point, the maximum nodal vibration level in the x-direction, etc.

These specific trackers can be defined for any kind of simulation (fixed speed, variable speed or torque-speed), and can be used as objectives or constraints in an optimization problem. All tracked outputs can be exported in a CSV file at the end of the simulation.

**Application**

The advanced output tracking is designed to help Electrical and NVH Engineers meet e-NVH requirements and improve the multiphysics performances of a given design, especially in terms of noise, vibrations and electromagnetics. Flexibility in output definition allows adapting NVH requirements to every electrical machine integrator.



### 6.1.8. Batch Mode

**Description**

Manatee software can be run using batch commands. Predefined multiphysics workflows can then be called from third-party scripts (e.g., optimization loops).
These batch commands allow editing/running a simulation predefined in the Graphical User Interface. It is also possible to import the airgap flux density and the 3D FEA mechanical model from third-party software using the corresponding batch mode commands.

That makes Manatee highly interoperable software that can be seamlessly integrated with other applications.

**Application**

This feature allows CAE engineers to appropriately include Manatee software inside a customized virtual prototyping toolchain for the multiphysic design optimization of electrical systems.