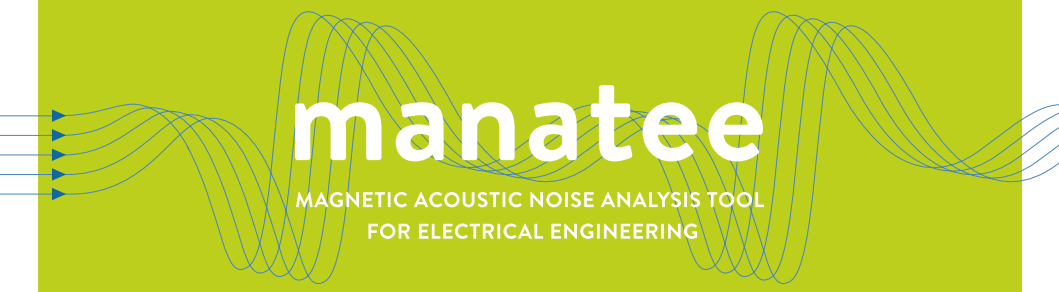

manatee

MAGNETIC ACOUSTIC NOISE ANALYSIS TOOL
FOR ELECTRICAL ENGINEERING

AVAILABLE MODULES
OCTOBER 2019

EOMYS

	MODULE NAME	FUNCTION	DETAILED DESCRIPTION
E-NVH SIMULATION WORKFLOWS	**WF.BS**	E-NVH basic multiphysic simulation workflow with single speed post processing	MANATEE **basic simulation workflow and post processings for the vibroacoustic calculation of electrical machines at a single speed.** For MANATEE built-in fast electromagnetic models, electrical machines must be defined using available geometrical overlays. Contains more than **120 pre-defined plots** (permeance, flux, force, vibration and noise) including FFT in 1D or 2D spaces, and all vibro-acoustic post processing at single speed **(A-weighting, third octave analysis, sound power /pressure spectrum and overall levels).**
	WF.DV	E-NVH pre-defined simulation workflows along e-machine development cycle	MANATEE **pre-defined simulation workflows** combining the modelling level options most adapted to electrical machine topology and different stages of **V-model electrical machine development cycle,** from **early design phase** to **detailed design phase.** Examples of workflows include: cogging torque, torque ripple, bemf, flux linkage maps, e-NVH along torque speed curve using semi analytic electromagnetic & vibroacoustic models in open circuit/full load with sine current/PWM, e-NVH along torque speed curve using Load Interpolation Algorithm coupled to FEMM, e-NVH along torque speed curve refined with Electromagnetic Vibration Synthesis calling third party FEA structural model, e-NVH along torque speed curve refined with Electromagnetic Noise Synthesis calling third party acoustic model, etc.
E-NVH VARIABLE SPEED SOLUTIONS *Solutions to easily define variable-speed e-NVH calculations including advanced post-processing tools*	**VAR.QS**	Quasi Static Variable Speed	Calls **several MANATEE fixed-speed steady state simulations** with varying supply based on control strategy (e.g. constant flux, torque/speed curve, import of current etc.), possibility to model non-linear run-ups. All NVH post processing of ENVH module are extended to variable speed (overall SPL/SWL as a function of speed, noise and vibration **waterfalls, order tracking analysis, variable speed modal participation** factors, force / vibration / noise **spatiograms,** operational deflection shape).
	VAR.TR	Transient Variable Speed	Calls MANATEE models in **full transient mode, without separating NVH calculation at several speeds.** Currents and rotor angle are therefore specified as time waveforms. All variable speed post processing of LAB.VS are then available, performing STFT instead of FFT. Especially useful when coupling MANATEE to a Simulink control block (CT2.PWM).
	VAR.MAP	Acoustic noise calculation over full torque / speed range (noise maps)	Calls several MANATEE simulations based on input Id/Iq maps to characterize the e-motor **NVH behaviour in torque/speed plane** on four quadrants (traction / braking / reverse modes), including noise map plots and detailed post processings. Can be combined with ALG.LEA, ALG.LIA and ALG.EVS, ALG.ENS to speed up calculations (using semi analytic NVH models, full map can be obtained in less than one minute of calculation).
E-NVH ALGORITHMS *A series of unique algorithms to speed-up e-NVH calculations and give more physical insights to electrical machine designers*	**ALG.LEA**	Load Extrapolation Algorithm to speed up variable speed calculation of operational magnetic loads in early design phase	Fast variable speed NVH calculation based on **accurate magnetic force extrapolation algorithms at variable speed** (neglecting the change of saturation at variable speed). The waterfall synthesis accounts for specified control law (e.g. Id/Iq function of speed). All post processing of ENVH are extended to variable speed (noise and vibration waterfalls, order tracking analysis, modal participation factors). To account for saturation effects more accurately at variable speed, use of ALG.LIA is recommended.
	ALG.LIA	Load Interpolation Algorithm to speed up variable speed calculation of operational magnetic loads in detailed design phase	Calculation of **air-gap Flux density Look Up Table** at different excitation (Id,Iq) or as a function of speed. Most relevant when coupling MANATEE with FEMM using EM3 modules. The flux density look up table allows to quickly calculate magnetic forces and torque ripple including saturation effects, which can be reused in SOL.SKEW for skew optimization or ALG.EVS for spectrogram synthesis or VAR.QS for variable speed NVH calculations. MANATEE built-in projection algorithm allows to reliably convert airgap Maxwell stress to stator tooth magnetic forces.
	ALG.EVS	Electromagnetic Vibration Synthesis to speed up variable-speed FEA-based vibration calculations, or optimization of electromagnetic excitations with respect to vibration	**Speeds up magnetic vibration calculations** while giving more physical insights by applying **elementary electromagnetic loads** in radial & tangential directions (wavenumbers identified automatically by MANATEE) on the structural model, calculating the **Frequency Response Functions** of the structures (rotor or stator) and synthesizing the overall vibration response under operational loads. Can be used with any type of structural model provided in SM (analytic or FEA such as Hypermesh/ Optistruct, Ansys, Nastran). The structural FEA model can exist (defined by the user) or be automatically built by MANATEE with SM.NUM option. EVS is particularly useful when a high number of operational loads have to be calculated, for instance in variable speed calculations (e.g. NVH maps on torque speed plane) or in optimization mode (e.g. pole shaping).

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	ALG.ENS	Electromagnetic Noise Synthesis to speed up variable-speed FEA-based acoustic calculations, or optimization of electromagnetic excitations with respect to noise	Equivalent of ALG.EVS for acoustic noise. **Speeds up magnetic noise calculations** while giving more physical insights by applying **elementary electromagnetic loads** in radial & tangential directions on the vibroacoustic model, calculating the **Frequency Response Functions** of the structures (rotor or stator) and synthesizing the overall acoustic response under operational loads. The vibroacoustic FEA model must exist under Actran. ENS is particularly useful when a high number of operational loads have to be calculated, for instance in variable speed calculations (e.g. NVH maps on torque speed plane) or in optimization mode (e.g. pole shaping).
E-NVH ROOT CAUSE ANALYSIS *Solutions to carry early stage e-NVH analysis or identify noise and vibration root cause with advanced post processing*	**RCA. HARM**	Harmonic analysis for e-NVH troubleshooting in early design stage	Identifies all **main magnetic force harmonics (frequencies and wavenumbers)** based on slot/pole/phase combinations, electrical machine topology (PMSM, WRSM, SCIM, SRM) and load state using theoretical analytic work (instantaneous calculations). Provides the physical origin of a given force harmonic in terms of **permeance, magnetomotive force, flux waves combinations** as well as in terms of excitation sources **(rotor/stator mmf, PWM time harmonics, eccentricities, saturation, winding or magnetization** space harmonics).
	RCA.PLOT	Dedicated e-NVH post processing to quantify magnetic force contribution to noise & vibration	Performs a series of advanced graphical post processing at fixed or variable speed to quickly perform NVH root cause analysis, including **spectrograms** (displayed with natural frequencies and magnetic excitations orders), vibration and noise **spatiograms** (spectrograms **per radial/ tangential force wavenumbers applied on stator/rotor), Order Tracking** analysis (vibration and noise level for each magnetic force wave, per wavenumber and frequency), **modal participation** factor (noise and vibration level per structural mode), numerical Transfer Path Analysis, **Operational Deflection Shape** analysis (visualization of how the structure vibrates at a given speed and frequency).
	RCA.FILT	Filter any group of wavenumbers or frequencies in force, flux, permeance or force	**Allows to cancel a specified group of harmonics** in radial/ tangential Maxwell stress, radial/tangential flux density, rotor/stator magnetomotive force, rotor/stator permeance to check their impact on e-NVH. Includes a fully **automated harmonic analysis** using default harmonic sources (PWM time harmonics, stator/rotor field space harmonics, stator/ rotor slotting harmonics).
E-NVH MITIGATION SOLUTIONS *A series of dedicated noise control environments for the design optimization of control, magnetic or structural-based e-NVH mitigation techniques*	**SOL.SKEW**	Skew pattern optimization	Design environment to study the **impact of PMSM skew pattern on acoustic noise and vibrations, average torque and torque ripple** based on flux distribution look-up tables (FLUT format). The vibroacoustic model can be of any type depending on MANATEE inputs (semi-analytic, numerical, or with imported FRF). A sensitivity study on a linear continuous or stepped skew angle can be run to find the best tradeoffs between noise & torque ripple minization. A full **multiobjective optimization** can be run on the stepped-skew pattern (v1.08).
	SOL. NOTCH	Stator or rotor notching	Applies **notches to stator and/or rotor lamination** with predefined shapes (polar, rectangular), number of notches, and spatial distribution. Includes possibility to apply notching on IPMSM rotor along D or Q axis. Effect of notches is included on FEMM, PMMF and SDM electromagnetic models (SDM model only accounts for polar notches).
	SOL.CINJ	Harmonic current injection module	Allows to inject **id or iq harmonic currents** in DQH or ABC frame to study their impact on NVH performance of the electric motor.
	SOL.YOKE	Lamination shape ratio	Automatically performs a **sensitivity study on stator structure geometry** (outer yoke increase, bore radius decrease) to lower magnetic noise and vibrations. Give the relative dB change for each structural mode.
E-NVH ROBUST DESIGN SOLUTIONS *Solutions to carry robust e-NVH design of electric motors*	**ROB. FAULT**	Mechanical and Electromagnetic Fault Simulation	Handles **manufacturing tolerances and fault simulation** when calculating magnetic loads such as **static and dynamic eccentricities, uneven airgap, PMSM demagnetization, SPMSM pole displacement,** stator short circuit, SCIM broken bar to study the NVH effect of asymmetries both at design stage (to specify tolerances) or after manufacturing (to troubleshoot noise issues). Part of **faults can be applied even when importing flux density** with IO.FLUX (e.g. outer structure ovalization, and eccentricities), without the need to carry electromagnetic calculations without symmetry.
	ROB. NFREQ	Automated sensitivity study on natural frequencies to obtain dispersion of NVH levels	Calls all MANATEE vibro-acoustic models while including a **variation on the structural natural frequencies** to make **robust NVH design** of electrical machines.

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E-NVH IMPORT EXPORT SOLUTIONS *Solutions to ease MANATEE integration within existing design workflow, including use of MANATEE post processing on experimental data*	**IO.ELEC**	Import of measured or simulated current/ voltage waveforms	**Imports a user-defined voltage or current waveform** to be used in quasi static (resp. transient) variable speed analysis, without (resp. with) rotor angle waveform. The rotor position is adjusted to achieve user-defined operating point in steady state. The imported waveform is filtered according to user-defined parameters. The **NVH effect of unbalanced currents or parasitic current harmonics** including in measurements can be studied.
	IO.FLUX	Import of airgap magnetic field distribution	**Imports the airgap flux density distribution** calculated with third party electromagnetic software at single speed or variable speed, or using MANATEE **Flux Look Up Table (FLUT)** format, and projects the airgap Maxwell stress on the inner and outer structures to calculate magnetic forces and resulting NVH behaviour. Includes harmonic filters to **remove parasitic harmonics** coming from meshing issues.
	IO.FMAG	Import of FEMAG magnetic model	Imports **FEMAG** electromagnetic software output files (e.g. PLT0 and BCH) to run MANATEE vibration and acoustic calculations without having to redefine completely the electrical machine in MANATEE. Cannot import FEMAG model generated with .dxf.
	IO.MT	Import of user-defined magnetic stress waves	Imports **user-defined radial and tangential airgap Maxwell stress waves** in terms of magnitude, frequency, wavenumber and phase. Allows to simplify magnetic loadings to separate the influence of different magnetic force harmonics.
	IO.MF	Export of magnetic forces calculated by MANATEE	**Exports calculated harmonic magnetic forces** per tooth tip (lumped load vector) or per node **in .unv format.**
	IO. MODAL	Import of measured or calculated modal basis	**Import of structural modal basis** (.OP3) and calculation of modal forces to perform modal expansion, including modal participation factors.
	IO.FRF	Import of measured or calculated Frequency Response Functions	Imports a **measured or calculated Frequency Response Function** from tooth tip radial force to outer yoke vibration.
	IO.EXCEL	Export of MANATEE results in Excel sheet	Exports **any variable of MANATEE simulation or user-defined post-processing inside an Excel sheet** with value, description, and unit - possibility to append the values to easily compare different simulation inputs and outputs.
	IO.WAV	Export of calculated noise as .wav file	**Exports calculated sound pressure level as a .wav file** in steady (sine supply, PWM) or quasi static variable speed mode (sine supply) for further analysis in third party sound quality software and calculation of psychoacoustic metrics.
E-NVH LABORATORY *Solutions to carry parameter sweep, multiobjective optimization and simulation comparison*	**LAB. COMP**	Comparison of simulation projects or electrical machines	**Automatically runs and compares several simulation projects** or several electrical machines with pre-defined post processing to quickly compare the e-NVH behaviour of different projects.
	LAB.SA	Sensitivity Analysis and parameter sweep	Calculates the **sensitivity of a response variable** with respect to design variables (e.g. to study the effet of +/- 5% pole width or slot numbers on noise) and quantify the correlation factors, using different sampling strategy of the design space to be explored.
	LAB.CMO	Constrained Multiobjective Optimization	Couples MANATEE with a global optimization tool (NSGA-II) for **constrained multiobjective mixed variable optimization,** or with local optimizer (SQP) for local single objective optimization. Multidimensional optimization results can be visualized conveniently with the Mult Sim Viewer Graphical interface under Matlab.
	LAB.MDE	Multidimensional Design Explorer	Multidimensional optimization or sensitivity results can be visualized conveniently with the Mult Sim Viewer Graphical interface under Matlab, combining 5D visualization of Pareto fronts or sensitivity studies (3 axis + color + shape). Filters can be applied on design variables, response variables or constraints and designs can be marked along the different projection windows to ease **multidimensional design space exploration.**

EOMYS offers several licensing options. A dedicated MANATEE customer support which delivers high-quality consulting services is included in every licensing option. Please contact us for any information and price list.

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E-NVH CONTROL MODELS *Built-in control models to quickly find variable speed operating points of electrical machines and generate suitable supply waveforms*	**WG1.PWM**	Generation of non-sinusoidal voltage waveforms	Generates 3-phase non sinusoidal **voltage supply waveforms** (possibilty to define different commutation strategies at different speeds). PWM voltage waveforms can be generated analytically, numerically or based on a Simulink model (built-in MANATEE Simulink model or **user-defined Simulink model). Analytic voltage** waveforms include SPWM. **Numerical voltage** waveforms include **SPWM, SVPWM, DPWM0/1/2/3/min/max, GDPWM, RSPWM,** calculated angles. **Simulink pre-defined three-phase inverter** includes SPWM and RPWM (randomization of the carrier frequency). Resulting voltage waveform must be input to an Electrical Equivalent Circuit (EEC) model to obtain resulting current waveform.
	WG2.PWM	Generation of non-sinusoidal current waveforms	Generates 3-phase non sinusoidal **current supply waveforms.** Current waveforms can be generated analytically or numerically. **Analytic current** harmonics include **SPWM** and **ideal square wave supply (BLDC). Numerical current waveforms include ideal square wave supply suitable for BLDC or SRM.**
	CT.SCIM	Control module for squirrel cage induction machines	Calculates the slip and voltage to achieve specified torque characteristics based on the equivalent circuit parameters.
	CT.DFIM	Control module for doubly fed induction machines	Calculates the slip and voltage to achieve specified torque characteristics based on the equivalent circuit parameters.
	CT.SM	Control module for synchronous machines	Calculate the current angle to achieve specified torque based on the equivalent circuit parameters according to MTPA strategy.
E-NVH ELECTRICAL MODELS *Built-in electrical models to quickly calculate current distribution including PWM effects*	**EL.SCIM**	Electrical model for inner rotor squirrel cage induction machines	Calculates the **harmonic stator and rotor currents** based on input phase voltage waveform by calculating the equivalent circuit parameters, including **skin effect and saturation effects.** Some parameters (leakage and magnetizing inductance) can be evaluated with finite element (coupling with FEMM) if the module EM3 is activated. Possibility to enforce user-defined lumped parameters.
	EL.DFIM	Electrical model for inner rotor doubly fed induction machines	Calculates the stator and rotor currents based on input phase voltage waveform by calculating the equivalent circuit parameters, including skin effect and saturation effects. Some parameters (leakage and magnetizing inductance) can be evaluated with finite element (coupling with FEMM) if the module EM3 is activated. Possibility to enforce user-defined lumped parameters.
	EL.PMSM	Electrical model for surface, inset and buried permanent synchronous machines	Calculates the stator currents based on input phase voltage waveform by calculating the equivalent circuit parameters (inductances Ld, Lq, PM flux linkage E), including skin effect. Some parameters (leakage and magnetizing inductances) can be evaluated with finite element (coupling with FEMM) if the module EM3 is activated. Possibility to enforce user-defined lumped parameters.
E-NVH ELECTRO-MAGNETIC MODELS *Electromagnetic models for magnetic field calculation in both early and detailed design phase for all electrical machine topologies*	**EM1**	Fast electromagnetic analytical module based on permeance / mmf and winding functions for IPMSM, SCIM, WRSM, PMSM, DFIM	Calculates the airgap **rotor and stator radial flux density** time and space distribution based on **permeance / mmf model.** Includes rotor and stator skewing (any skew shape), any winding type. Hybridation with FEMM to calculate rotor mmf of IPMSM. Possibility to account for saturation with saturated permeance wave.
	EM2.SCIM	Fast electromagnetic semi-analytical module for inner rotor squirrel cage induction machine	Calculates the airgap rotor and stator radial and tangential flux density time and space distribution based on **subdomain models.** Includes armature field with any winding type and skewing effect. Assumes semi opened slots with polar geometry and infinite permeability of magnetic materials.
	EM2. SPMSM	Fast electromagnetic semi-analytical module for surface or surface inset permanent magnet synchronous machines	Calculates the airgap rotor and stator radial and tangential flux density time and space distribution based on **subdomain models.** Includes armature field with any winding type and skewing effect. Assumes semi opened slots with polar geometry for stator, but any shape of surface magnet, and infinite permeability of magnetic materials.
	EM2. IPMSM	Fast electromagnetic semi-analytical module for inner rotor interior permanent magnet synchronous machines	Calculates the airgap rotor and stator radial and tangential flux density time and space distribution based on **subdomain models.** Includes armature field with any winding type and skewing effect. Assumes polar geometries with semi opened slots on stator, and magnet pocket shape according to provided overlays, and infinite permability of the stator (IPMSM saturation is included using a coupling with FEMM to calculate the equivalent rotor magnetization, but rotor saturation is not affected by armature field).

	MODULE NAME	FUNCTION	DETAILED DESCRIPTION
	EM2.SRM	Fast electromagnetic semi-analytical module for switched reluctance machines	Calculates the airgap rotor and stator radial and tangential flux density time and space distribution based on subdomain models. Includes armature field with any winding type and skewing effect. Assumes polar slot opening on both rotor and stator.
	EM3.SM	Electromagnetic finite element module for surface, inset or interior permanent magnet synchronous machines, wound rotor synchronous machines or synchronous reluctances machines	Couples MANATEE with open-source electromagnetic software FEMM for **non linear magnetostatics** problem (automatic drawing, meshing and post processings). Calculates the airgap radial and tangential flux density time and space distribution, as well as torque, and flux linkages. Includes skewing and any winding type, inner and outer rotor. Can be used to calculate the flux density look up tables of ALG.FLUT.
	EM3.IM	Electromagnetic finite element module for inner rotor squirrel cage induction machines at no-load or doubly fed induction machines at partial load	Couples MANATEE with open-source electromagnetic software FEMM for **non linear magnetostatics** problem (automatic drawing, meshing and post processings). Calculates the airgap radial and tangential flux density time and space distribution, as well as torque, and flux linkages. Includes skewing and any winding type, inner rotor.
	EM3.SRM	Electromagnetic finite element module for inner rotor switched reluctance machine	Couples MANATEE with open-source electromagnetic software FEMM for **non linear magnetostatics** problem (automatic drawing, meshing and post processings). Calculates the airgap radial and tangential flux density time and space distribution, as well as torque, and flux linkages. Includes skewing and any winding type, inner rotor.
E-NVH MAGNETIC FORCE MODELS *Validated magnetic force calculations methods to be adapted to every e-machine topology*	**MF.MLV**	Electromagnetic force calculation using lumped Magnetic Load Vector	Calculates the **lumped electromagnetic load vector** (radial, circumferential, moment) at tooth tips from the airgap flux density distribution including tooth sampling effects. Calculates the magnetic forces experienced by SPMSM poles.
	MF.LOC	Local electromagnetic force calculation	Calculates the electromagnetic nodal Maxwell forces on a 2D FEMM mesh using **Virtual Work Principle** method (volume forces) or Maxwell tensor (surface forces). Cannot be used yet with SM models.
E-NVH STRUCTURAL MODELS *Structural models for vibration calculation in both early and detailed design phase*	**SM.ANL**	Structural Mechanics semi-analytical module	Calculates the natural frequencies of the outer structure (rotor or stator) based on an **equivalent cylinder.** Calculates dynamic radial deflections of the outer structure under magnetic forces with an equivalent 2D ring model. Possibility to enforce modal parameters.
	SM.NUM1	Structural Mechanics finite element module based on FRF calculations	Automatically **couples MANATEE to a third party structural FEA software (Altair Optistruct, Ansys Mechanical, MSC Actran)** to apply unit-magnitude rotating loads for ALG.EVS. Possibility to generate automatically a **"concept stator/ rotor"** (3D external stator structure including winding or external rotor including magnet weight) for Optistruct/ Ansys from MANATEE. **Dynamic vibrations** are solved by third party FEA software using **modal superposition** and results of FEA software are automatically read by MANATEE for further post processing.
	SM.NUM2	Structural Mechanics finite element module based on modal expansion	Performs **modal expansion techniques** based on **imported numerical modal basis** to calculate **dynamic vibrations** of radiating enveloppe or specific user-defined nodes. Can be used when performing ALG.EVS under unit-magnitude stress waves, or using an operational magnetic force loading.
E-NVH ACOUSTIC MODELS *Acoustic models for noise calculation in both early and detailed design phase*	**AC.ANL**	Acoustics semi-analytical model	Calculates analytically the **sound power level** and **sound pressure level** radiated by the machine based on **microphone average position** and **room reverberation constant,** either using **Equivalent Radiated Power** (ERP) (unit radiation factor, suitable for SM.NUM), or **semi analytic models of cylindrical shells** (e.g. infinite cylinder, pulsating sphere) depending on outer structure dimensions.
	AC.NUM	Acoustic numerical model	Calculates the **sound pressure field** and resulting **sound power level** by exporting the velocity field calculated by SM.NUM1 or SM.NUM2 model in a third party FEA acoustic software (Actran).