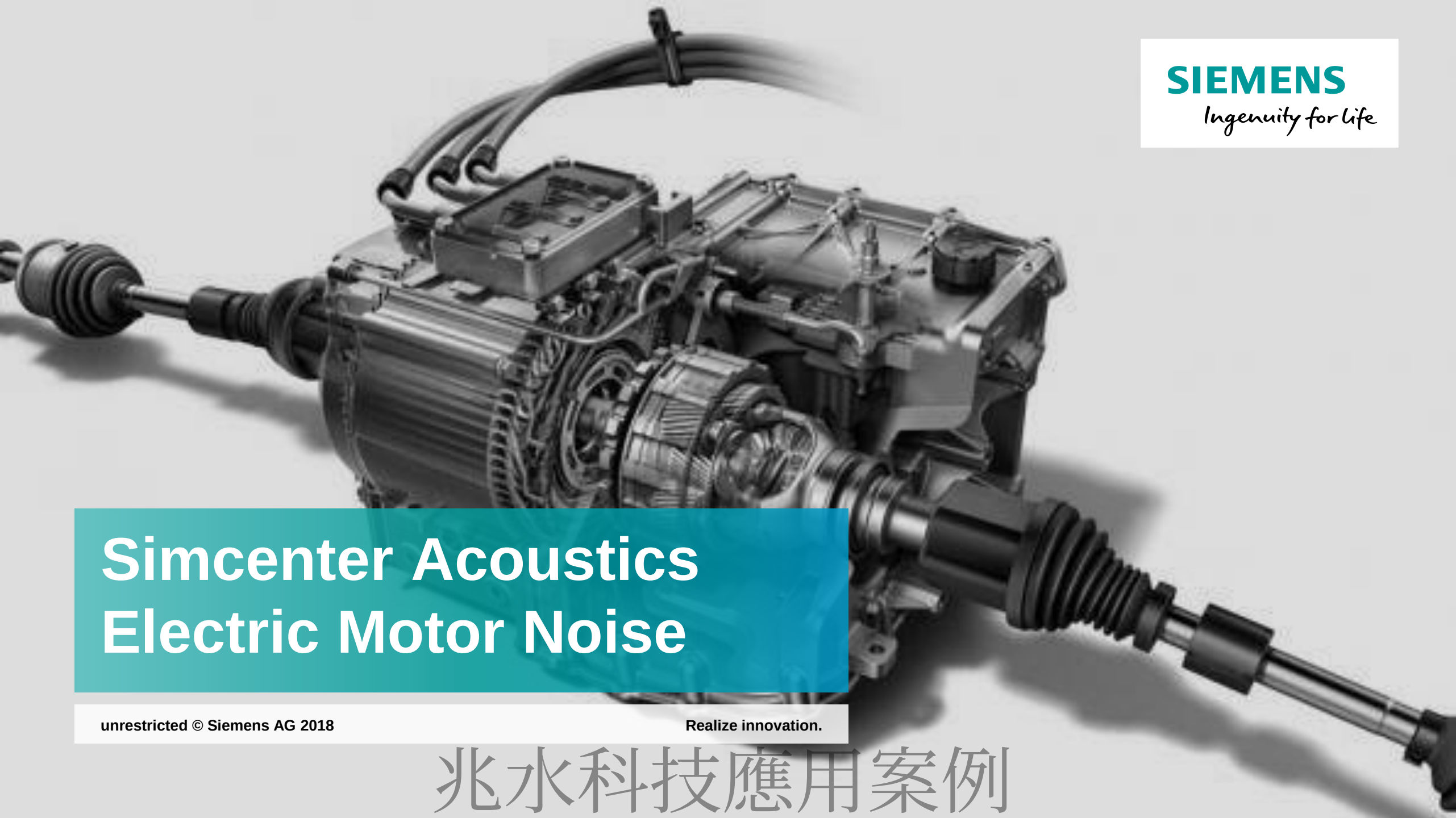


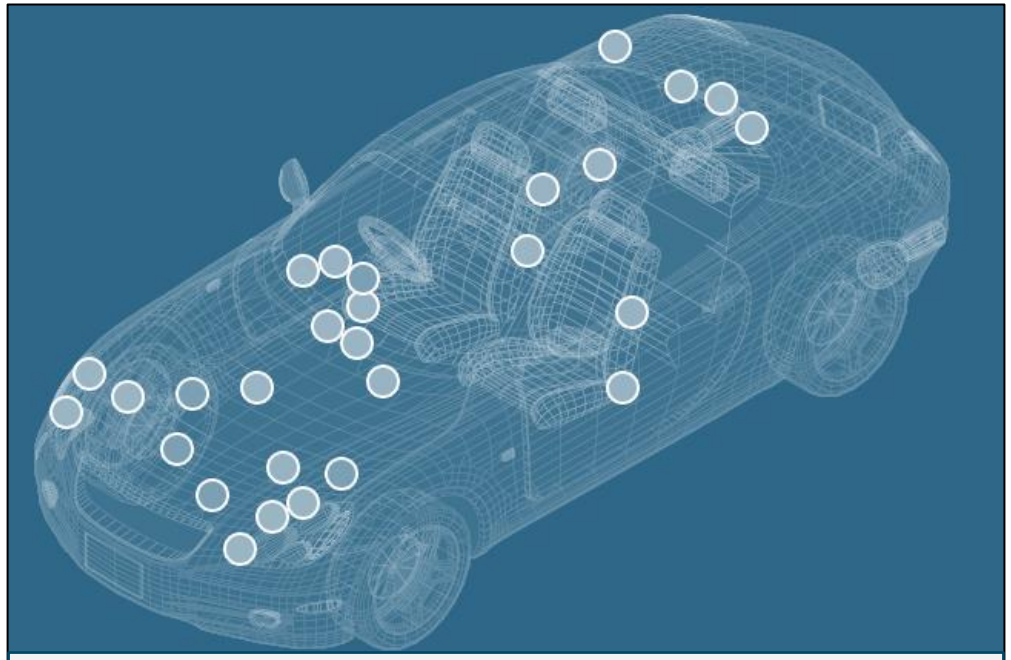
SIEMENS
Ingenuity for life

Simcenter Acoustics
Electric Motor Noise

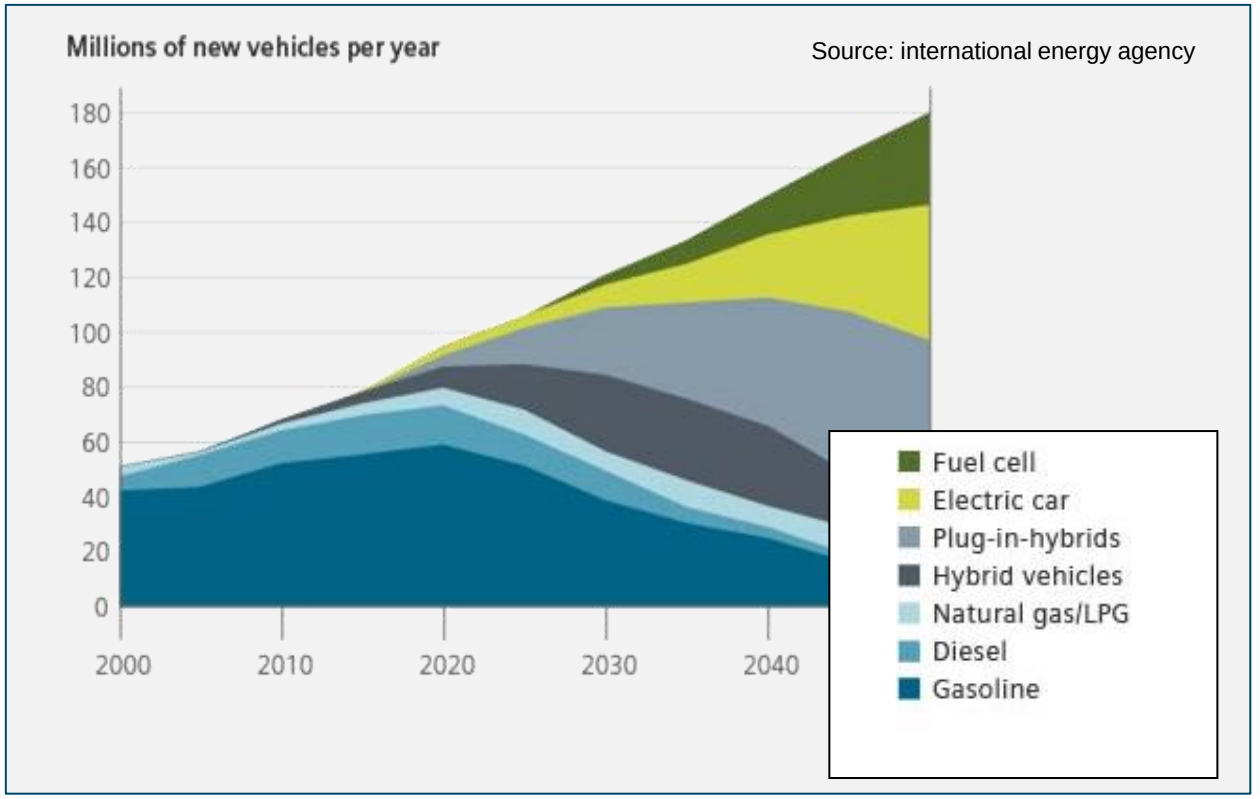
Realize innovation.

兆水科技應用案例

Market Trends
Electrification is growing substantially



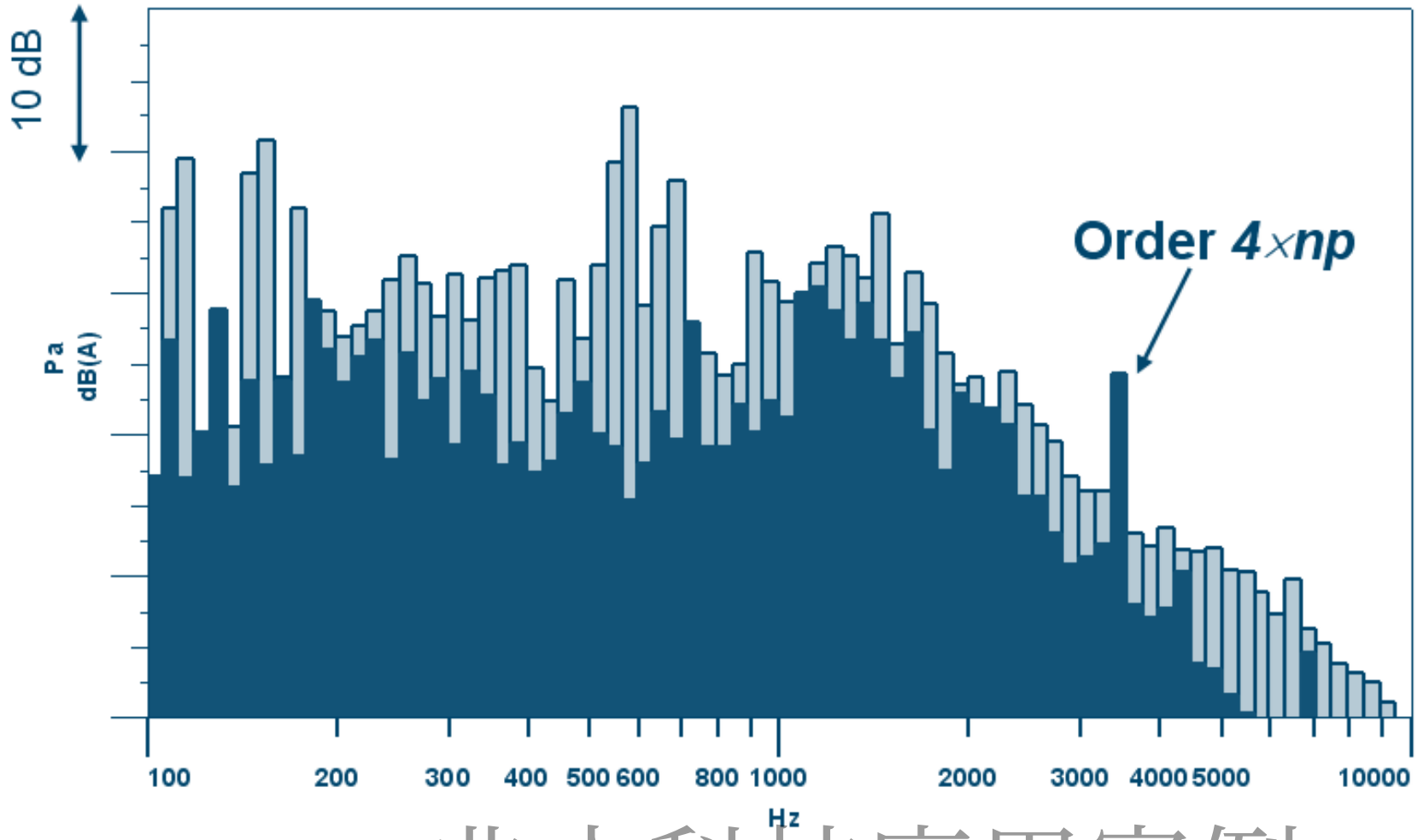
Over 100 electric motors in a standard car



兆水科技應用案例

Electric Motors
Lower absolute noise YET higher ANNOYANCE

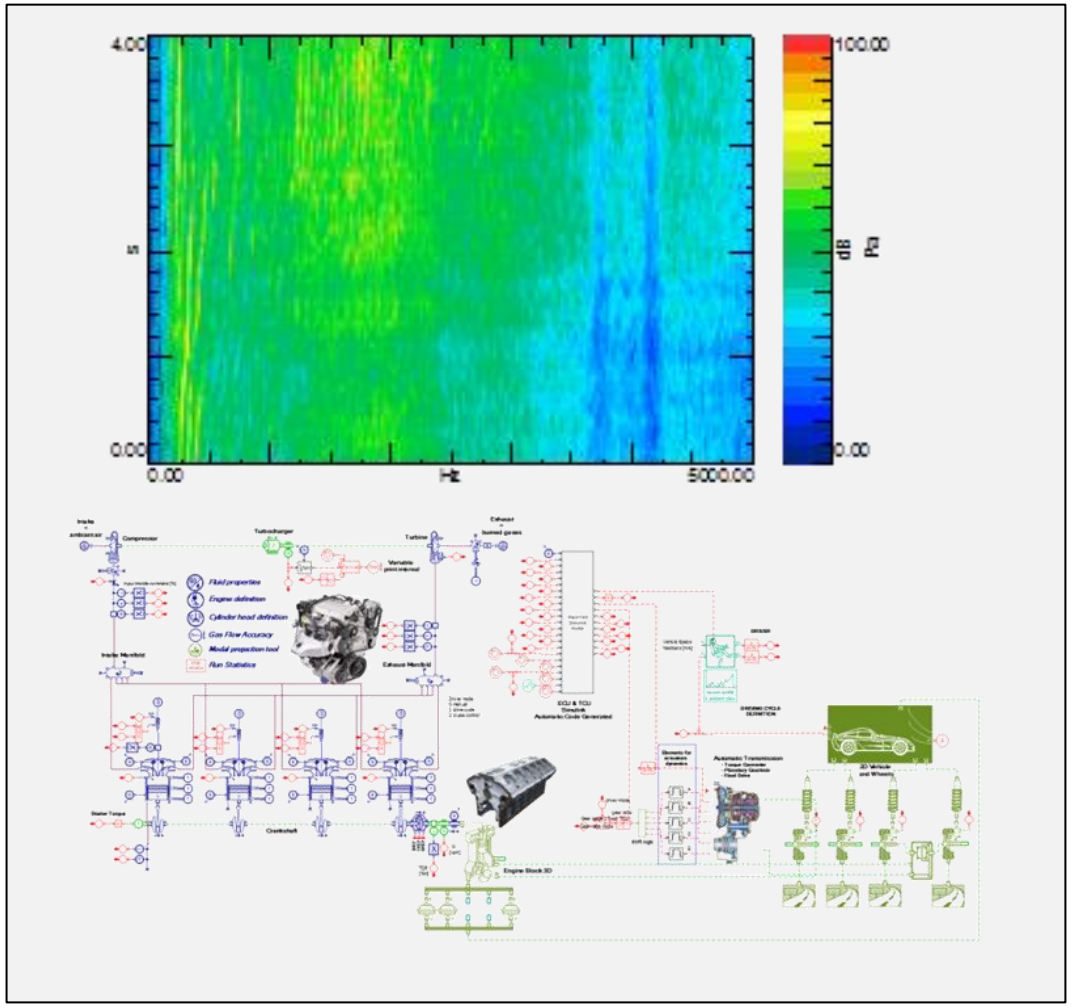
SIEMENS
Ingenuity for life

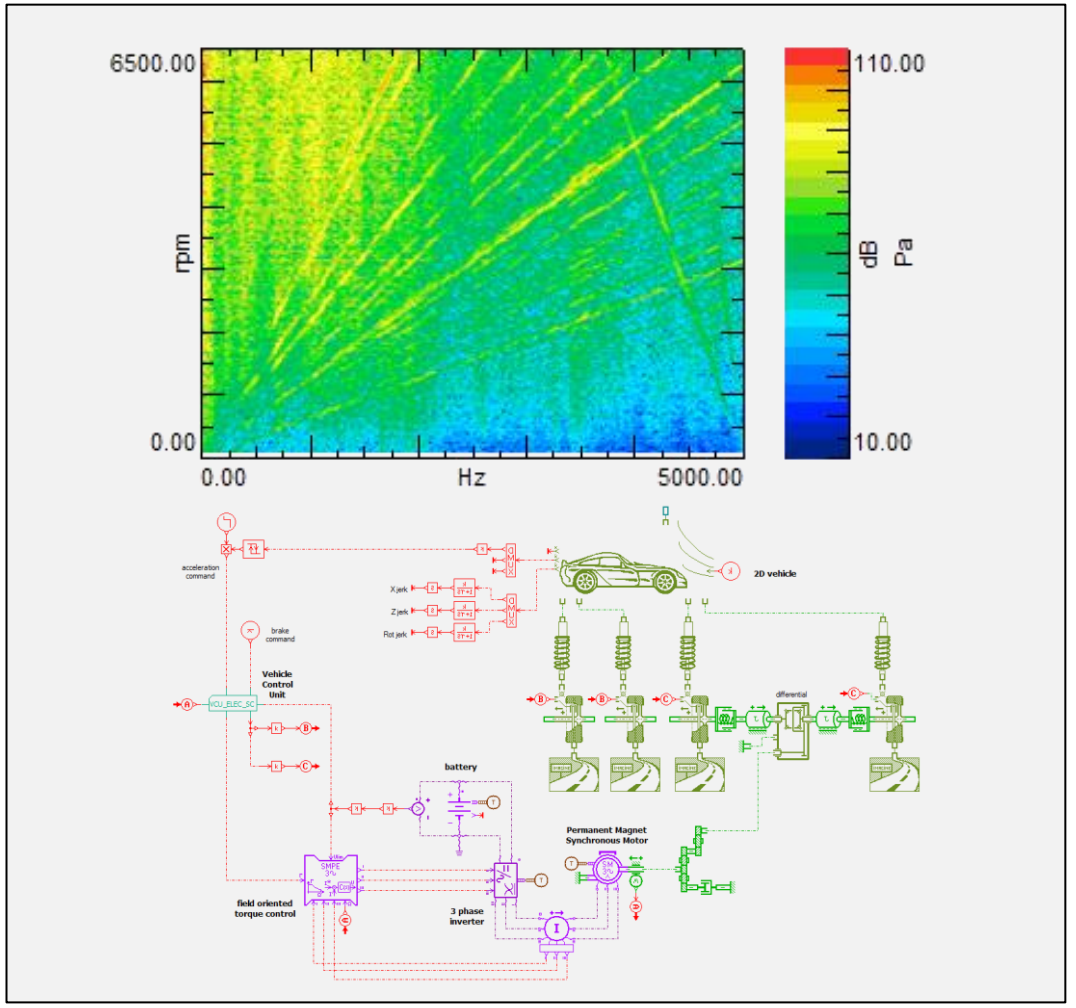


ICE

EM

Sound from ICE versus EM

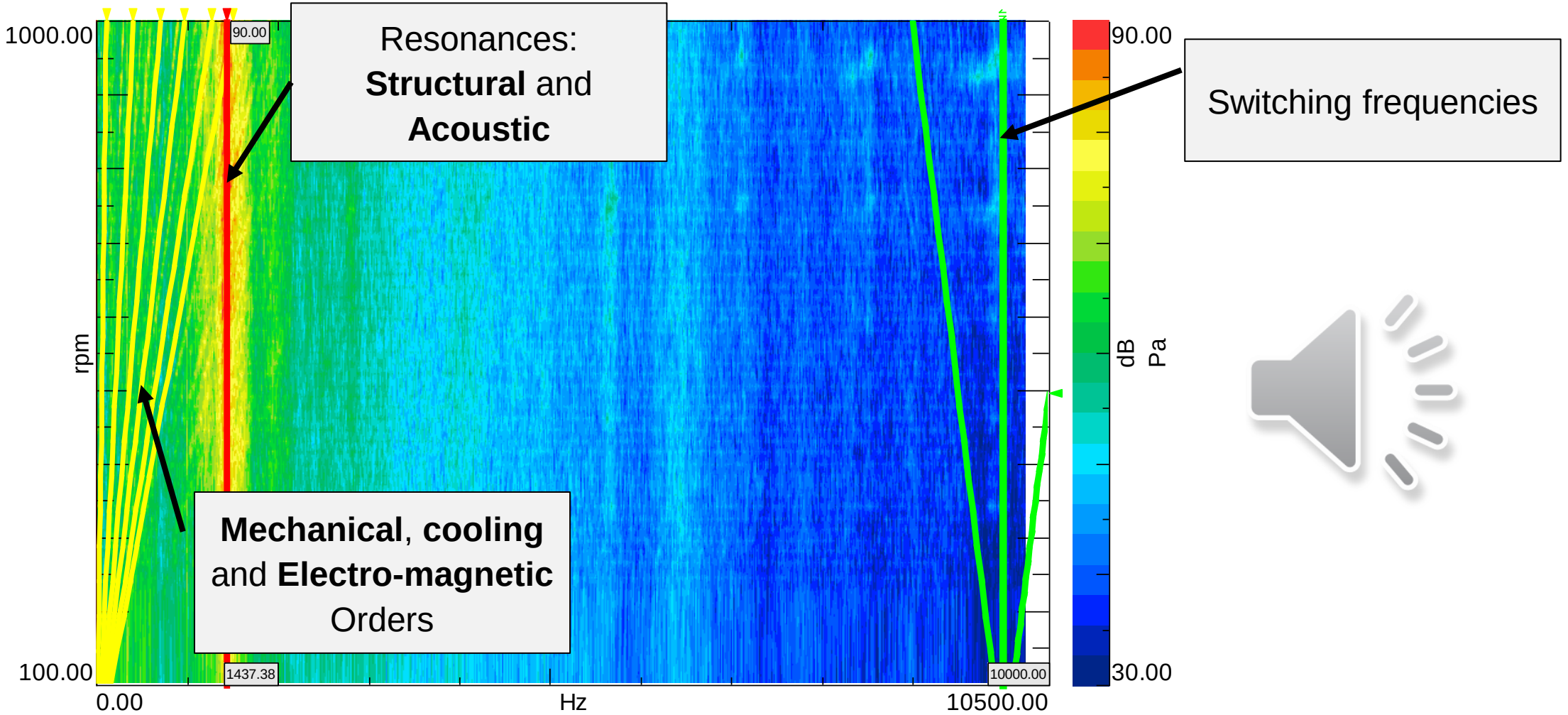




兆水科技應用案例

Noise spectrum from an Electric Motor

SIEMENS
Ingenuity for life



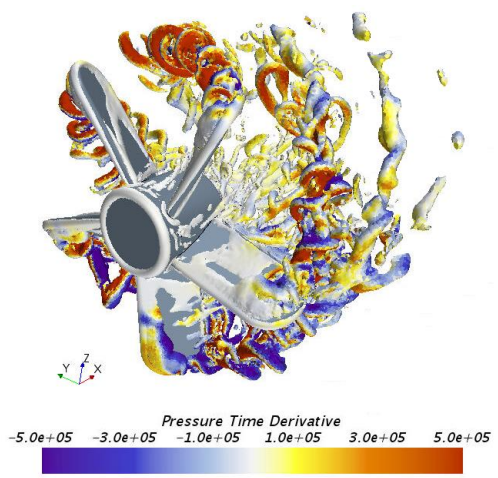
Noise Sources of Electric Machines

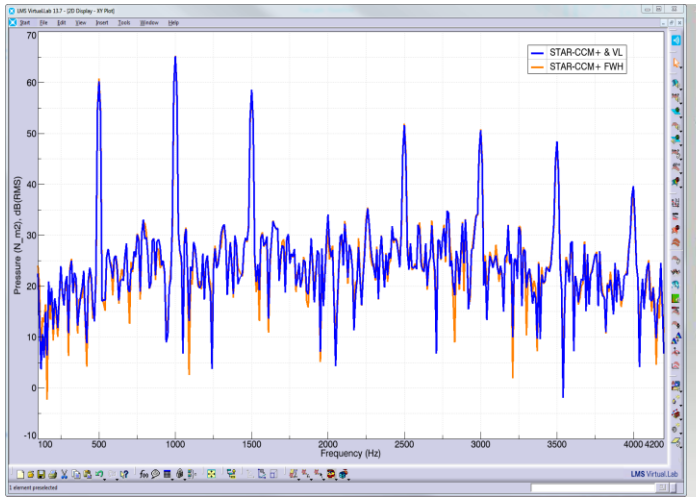
SIEMENS
Ingenuity for life

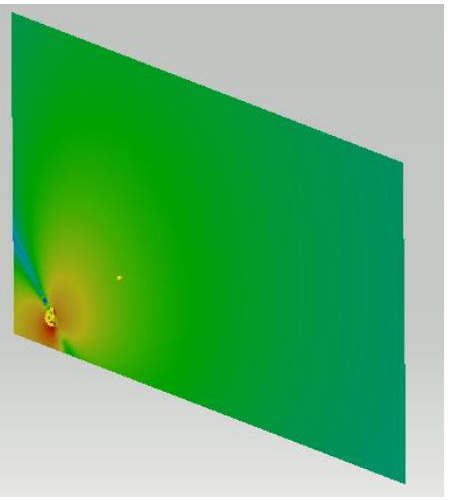
Flow induced: e.g. cooling fan	**Mechanical**: Misalignments, bearing defects, eccentricity result in bearing forces on the stator	**Electro-magnetic**: EM mechanisms induce harmonic forces on the stator

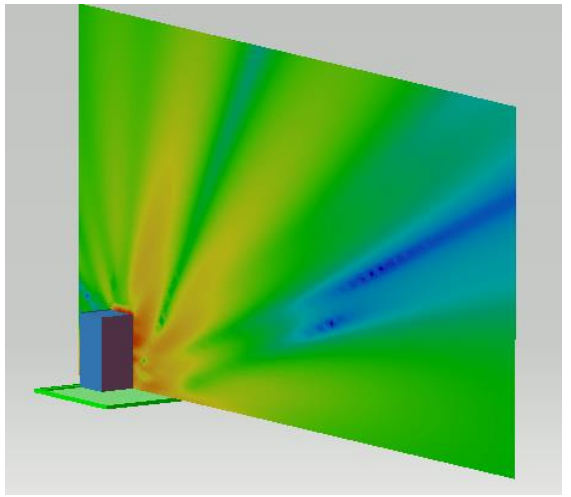
Cooling Fan Noise Simulations
with STAR-CCM+ and LMS Virtual.Lab

SIEMENS
Ingenuity for life









Compute unsteady flow field around source region with STAR-CCM+

Using the transient blade pressure, compute free-field acoustic propagation with STAR-CCM+ FW-H or LMS Virtual.Lab

Add installation effects, reflective/absorbing surface, infinite plates, porous volumes in LMS Virtual.Lab

Noise Sources of Electric Machines

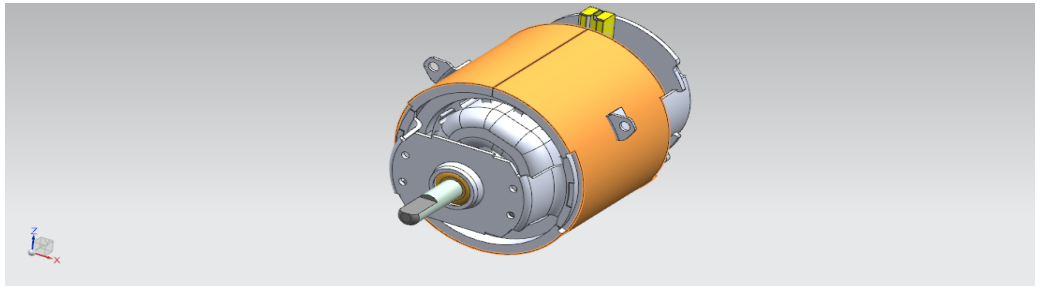
SIEMENS
Ingenuity for life

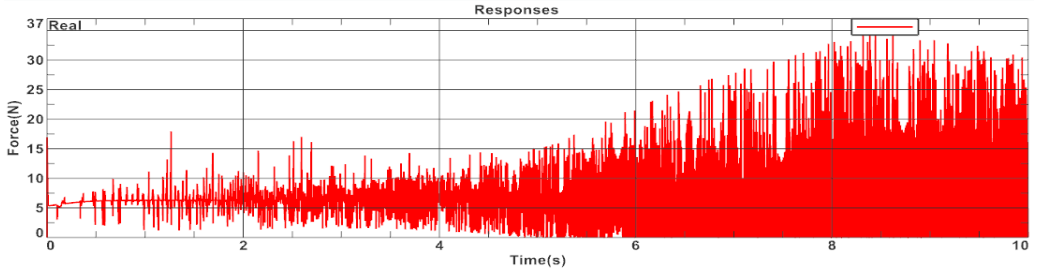
Flow induced: e.g. cooling fan	**Mechanical**: Misalignments, bearing defects, eccentricity result in bearing forces on the stator	**Electro-magnetic**: EM mechanisms induce harmonic forces on the stator

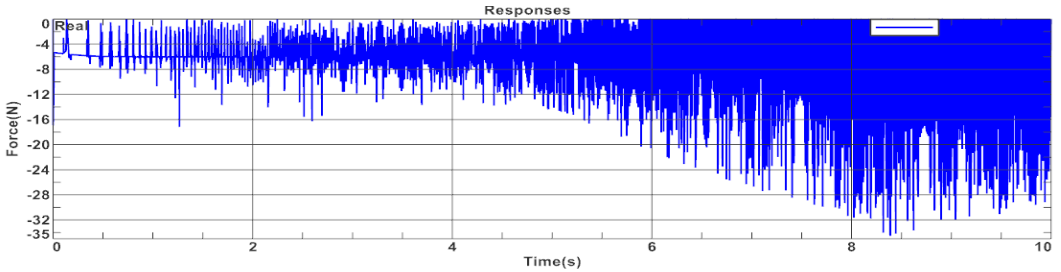
Example: DC Electric Motor

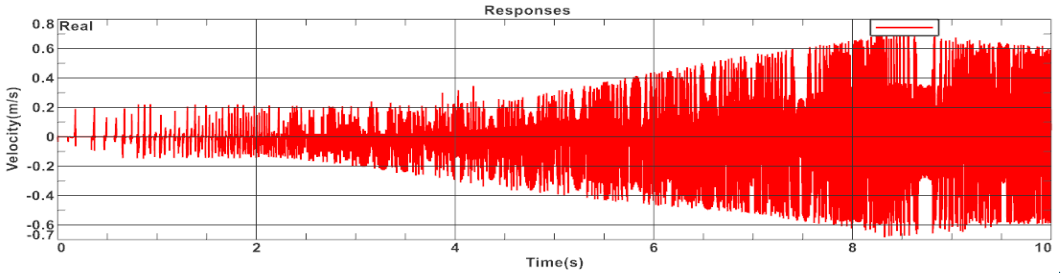
Multi-Body Simulation in Simcenter Motion: Commutation

SIEMENS
Ingenuity for life









Normal Contact Force on Commutator

- Speed-ramp 0-3000 RPM in 10s
- DC offset of 5.5N (by design)
- Variations ~±5N
- Cannot be measured
- Force impulses cause noise

Brush Radial Force and Velocity

- Speed-ramp 0-3000 RPM in 10s
- Brush force mirrors contact force (logical)
- Brush velocity variations of 0.8m/s
- can be measured with laser Doppler vibrometer

Example: DC Electric Motor

Propagation of loads to NVH model & Noise Prediction

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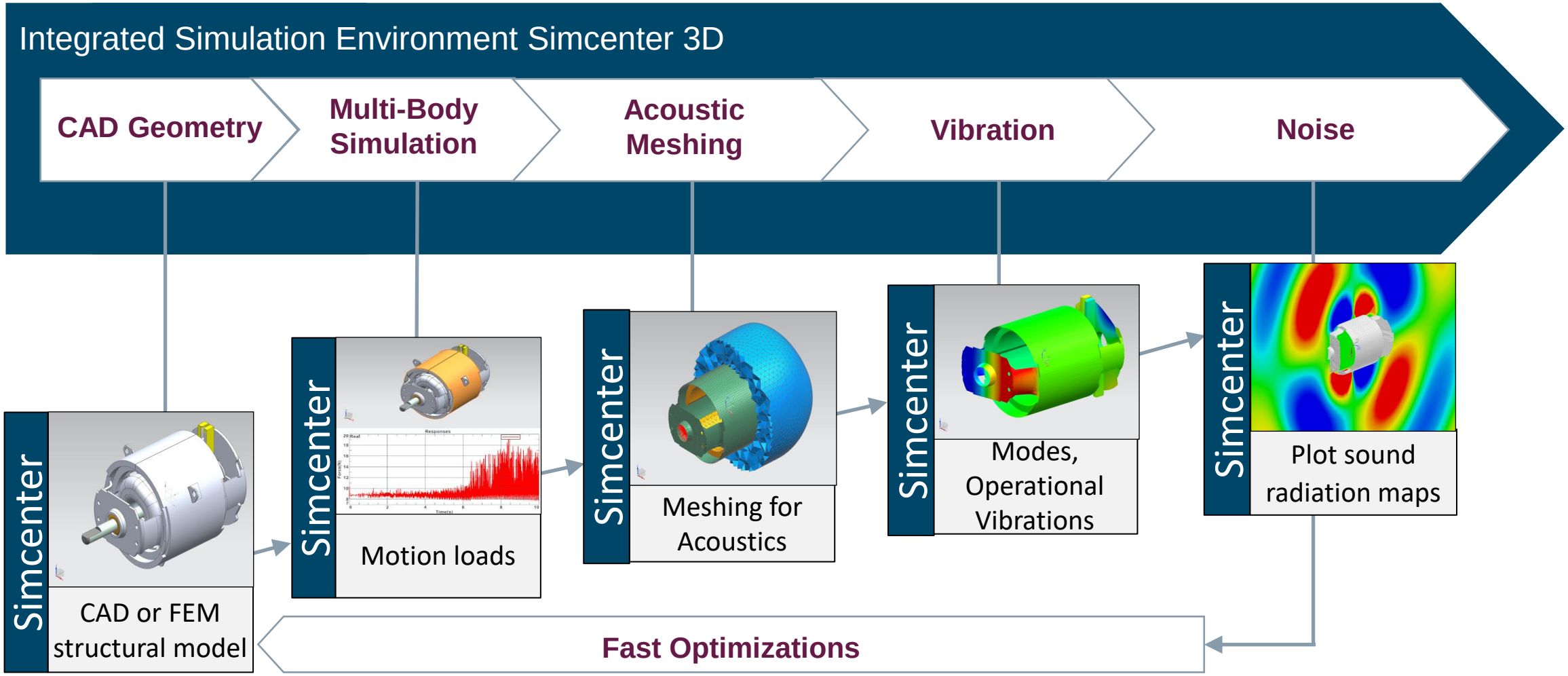
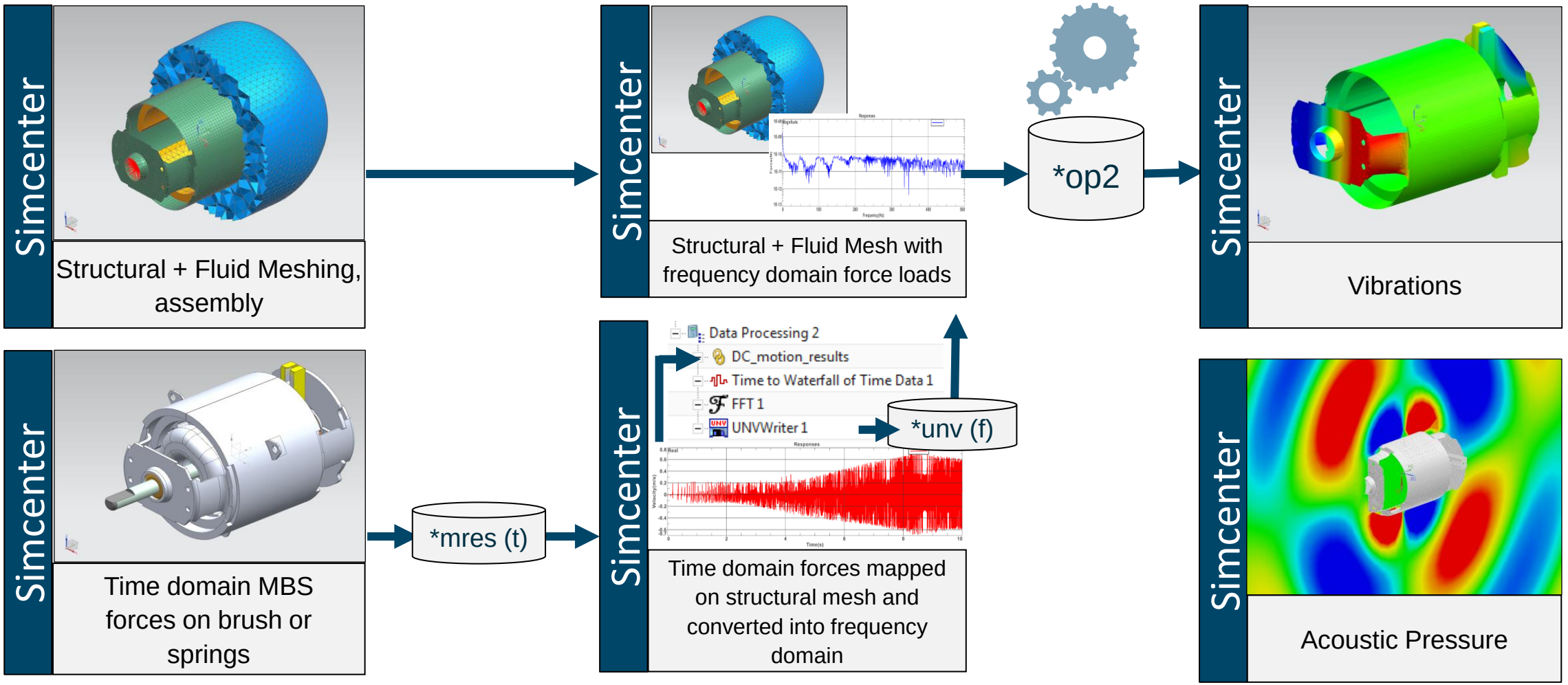


Simcenter 3D
DC Electric Motor **Vibration** Simulation with Simcenter Motion data

SIEMENS
Ingenuity for life



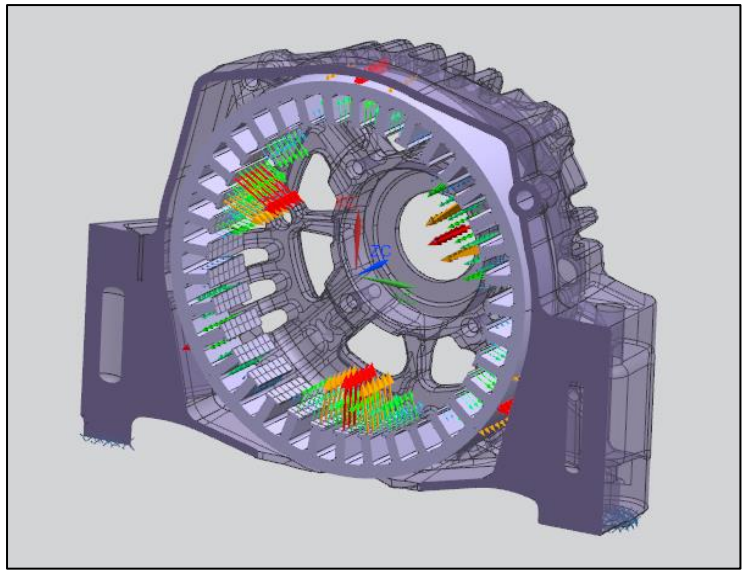
Noise Sources of Electric Machines

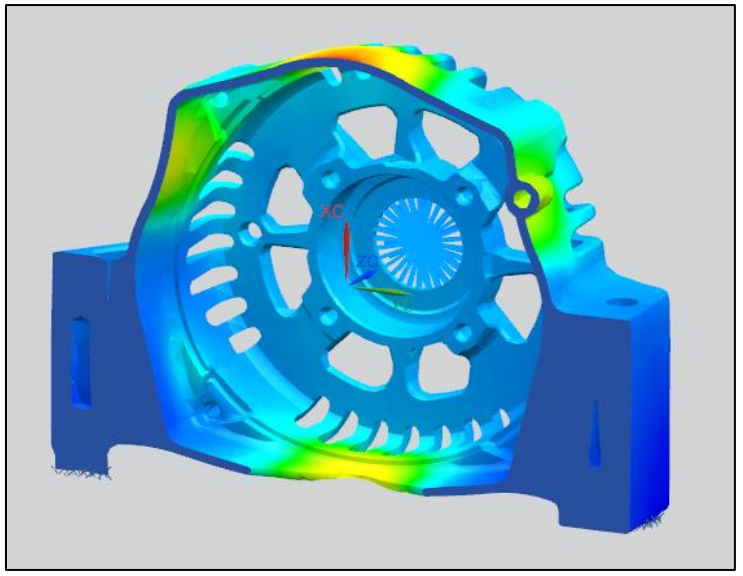
SIEMENS
Ingenuity for life

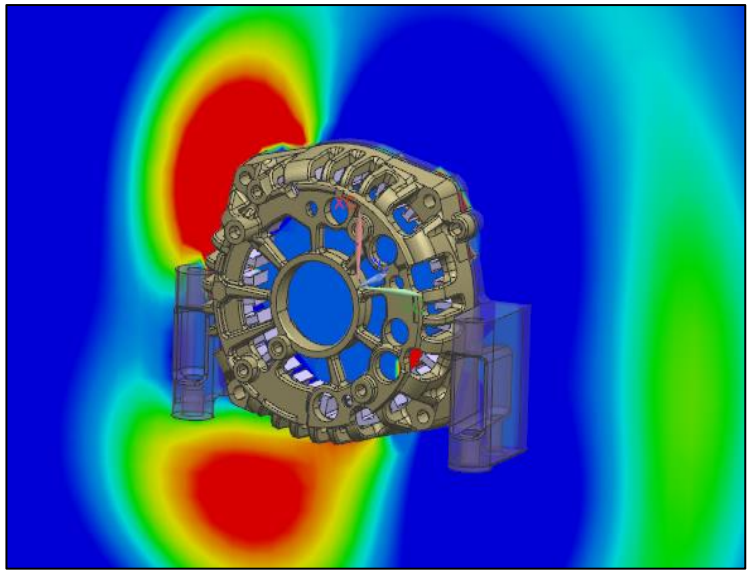
Flow induced: e.g. cooling fan	**Mechanical**: Misalignments, bearing defects, eccentricity result in bearing forces on the stator	**Electro-magnetic**: EM mechanisms induce harmonic forces on the stator

Electro-magnetic noise
How noise is created

SIEMENS
Ingenuity for life







Forces from Electro-Magnetic Simulation / Analytical Reference **forces**

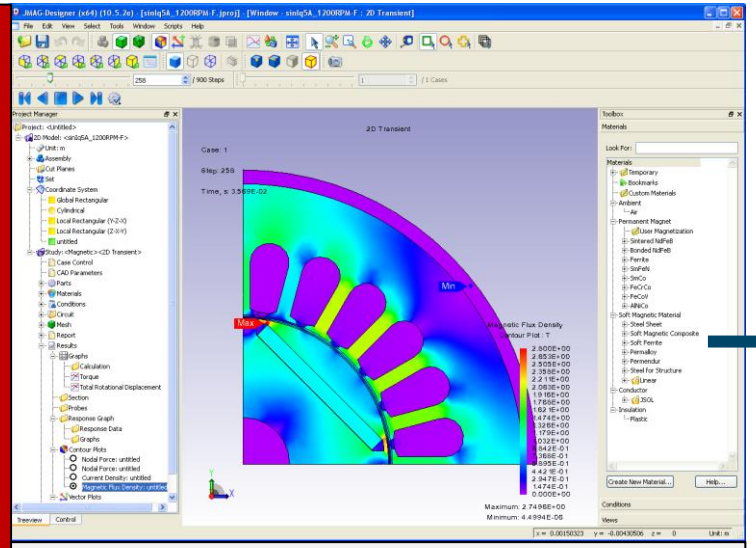
Resulting in **Vibrations** of the housing

Radiating off as unwanted **noise**

Forces from **Electro-Magnetic** Simulation
EM software provides force (Hz) on structural mesh directly

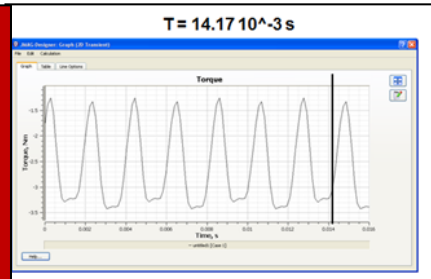
SIEMENS
Ingenuity for life

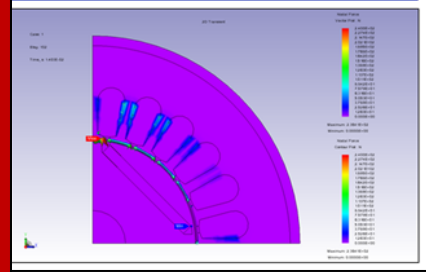
JMAG



Time domain, non-linear EM simulation
Magnetic FLUX

JMAG





- Torque ripple caused by fluctuating EM Forces
- EM Forces, highly concentrated at the stator and rotor surface

Frequency domain Maxwell forces

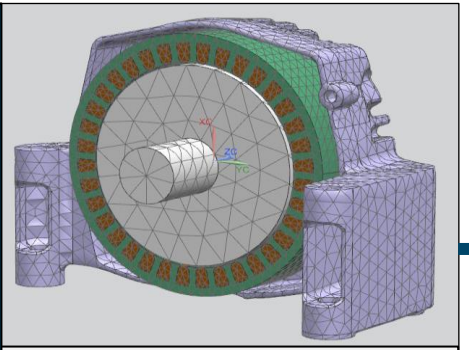
Loads file
*bdf

Supported EM Software	Dr. Binde Ingenieure BINDE Design & Engineering	JMAG Simulation Technology for Electromechanical Design	Flux by CEDRAT

Simcenter 3D
Housing **Vibration** Simulation with JMAG data

SIEMENS
Ingenuity for life

Simcenter

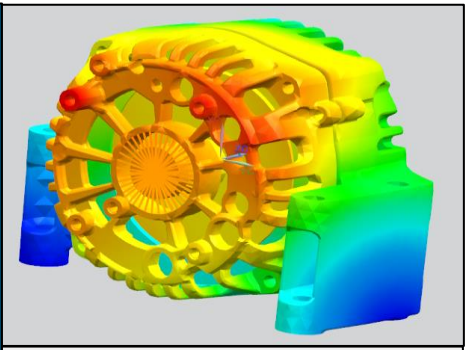


Structural Meshing, assembly, BC

*bdf

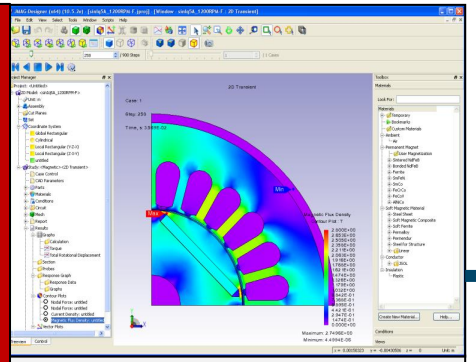
*op2

Simcenter



Modes, Operational Vibrations

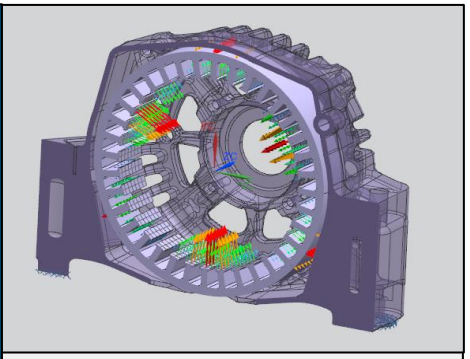
JMAG



Frequency domain Maxwell forces

*bdf

Simcenter



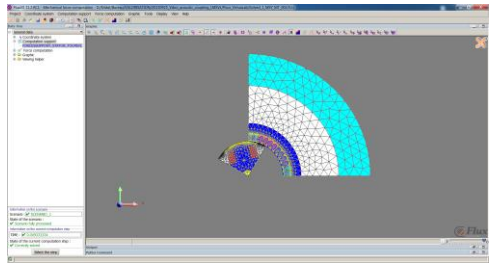
Analyze forces

Forces from **Electro-Magnetic** Simulation
EM software provides force (t) on EM mesh, SC takes it from there

SIEMENS
Ingenuity for life

FLUX

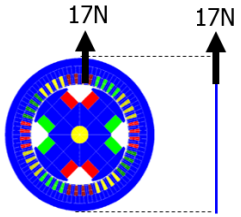
Lap winding considering 48 slots, 4 poles



To calculate time domain magnetic forces with FLUX

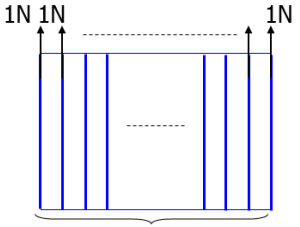
FLUX

Exporting procedure From Flux 2D to UNV file → Must indicate the number of layers on the depth of the machine



Forces calculated in Flux 2D

(The total forces on the depth)



17 Layers on 170 mm

Forces exported in UNV file

(We must indicate the number of layers on the depth)

Export time domain magnetic forces

Loads file *unv

Supported EM Software	infolytica corporation	JMAG Simulation Technology for Electromechanical Design	Flux by CEDRAT	ANSYS Maxwell	BLINDE Design &

Simcenter 3D
Housing **Vibration** Simulation with FLUX data

SIEMENS
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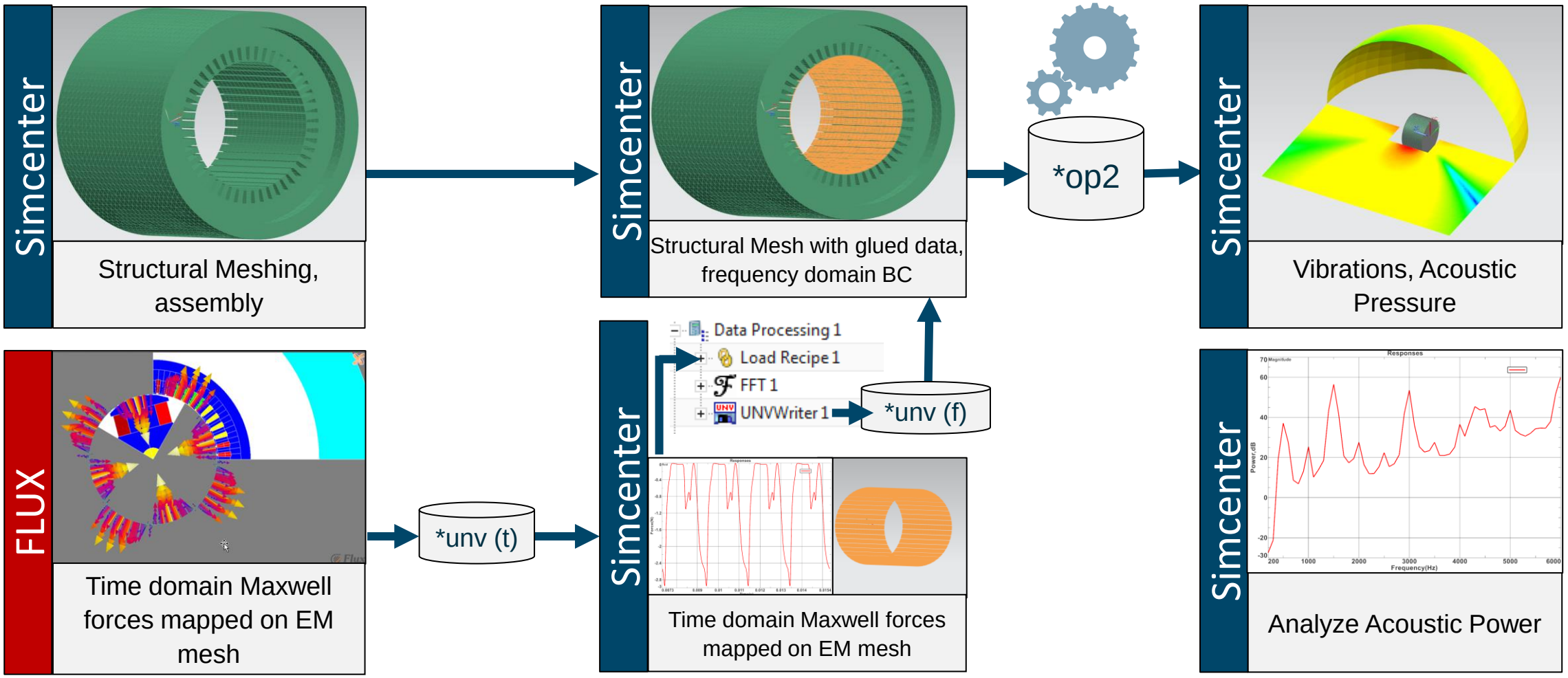
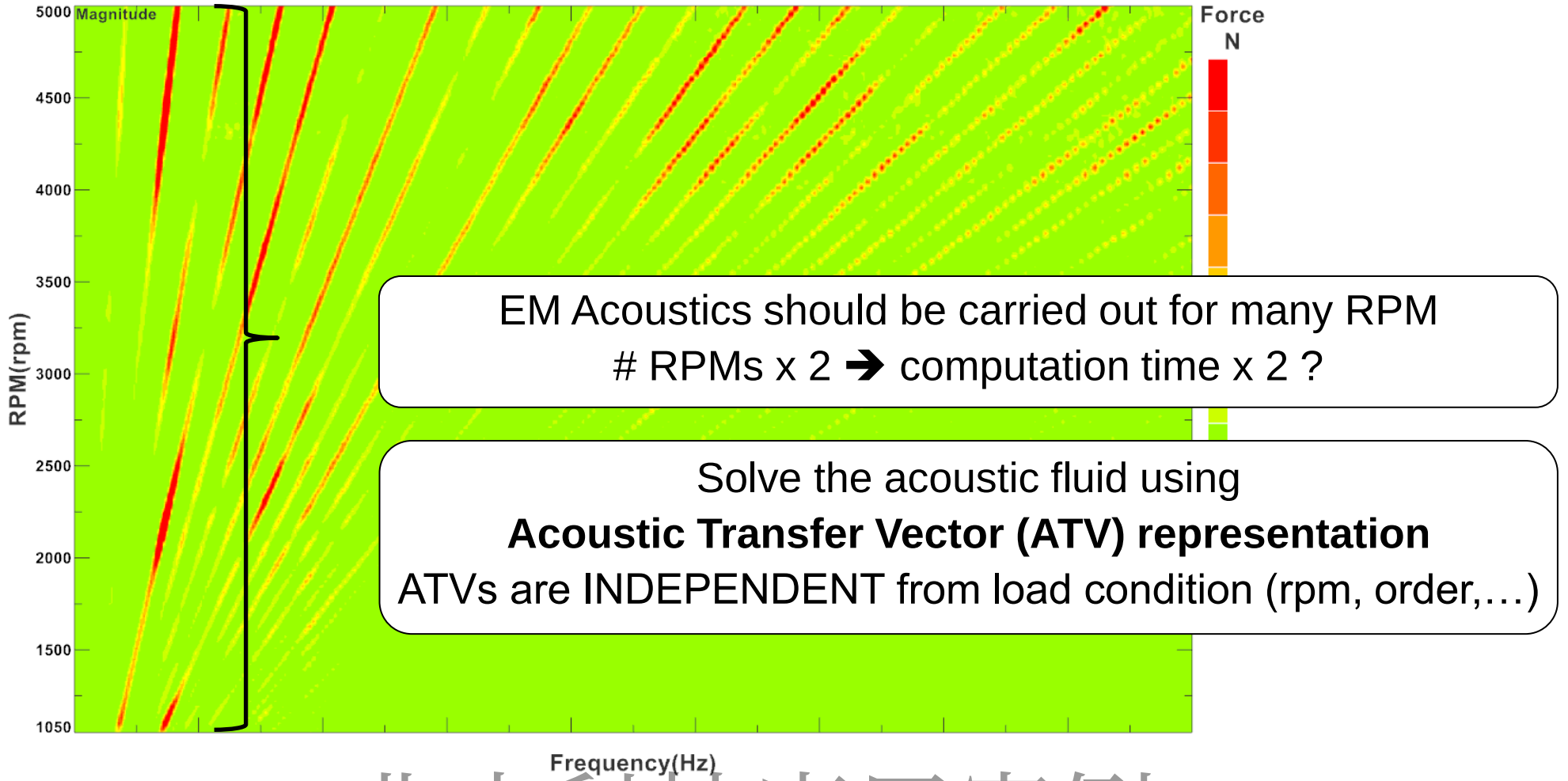


Electric Motor Noise: Multi-RPM vibro-acoustic simulation
Performance



EM Acoustics should be carried out for many RPM

RPMs x 2 ➔ computation time x 2 ?

Solve the acoustic fluid using

Acoustic Transfer Vector (ATV) representation

ATVs are INDEPENDENT from load condition (rpm, order,…)

Simcenter Acoustics - ATV representation

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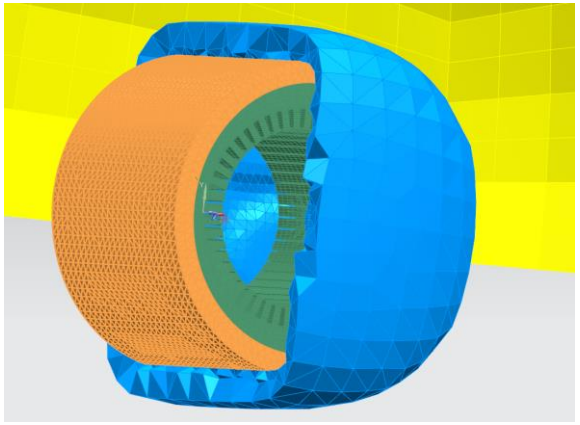

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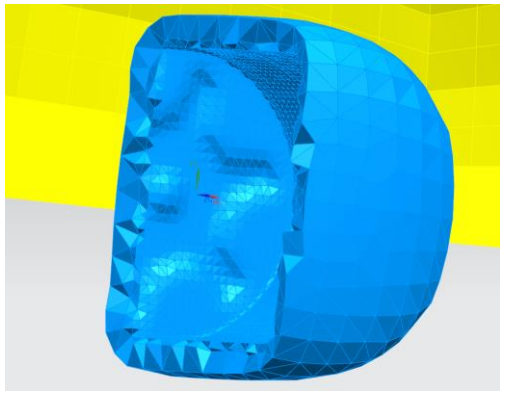

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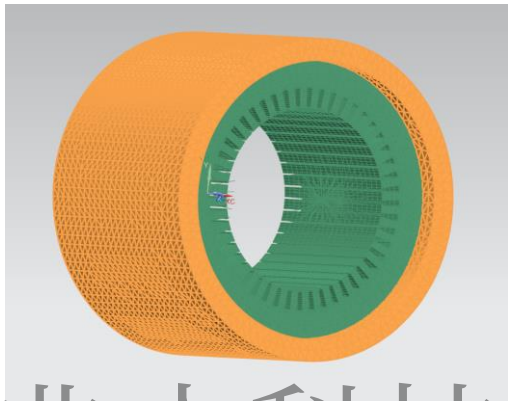
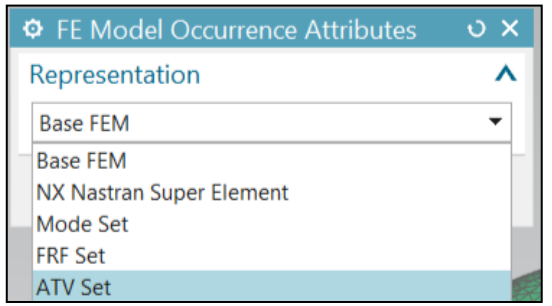


Switch to equivalent representation of the fluid



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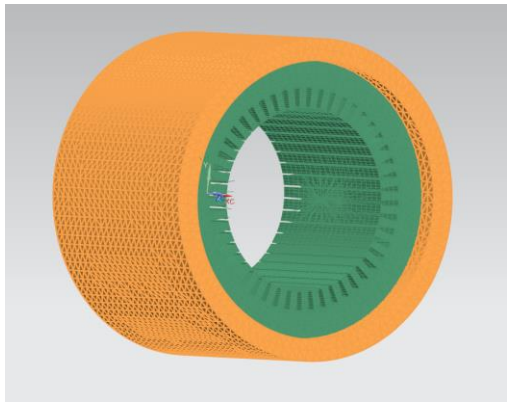
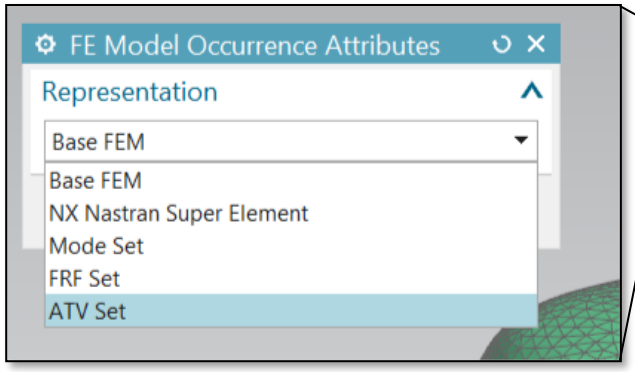
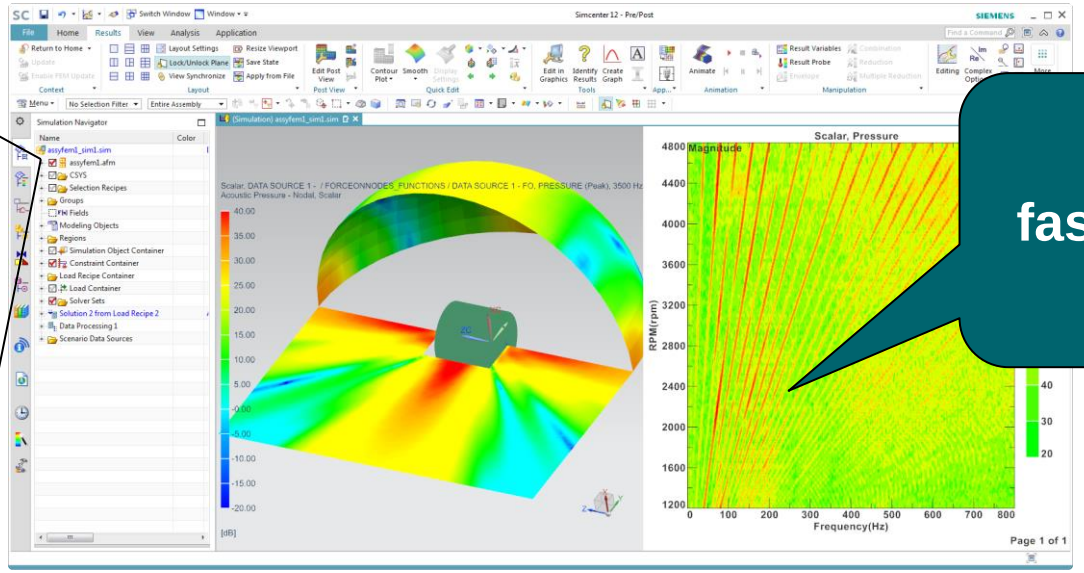
ATV Acoustic Transfer Vector

+

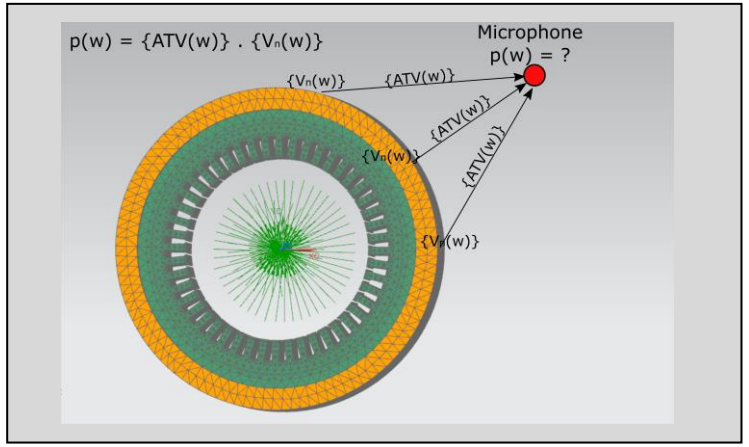


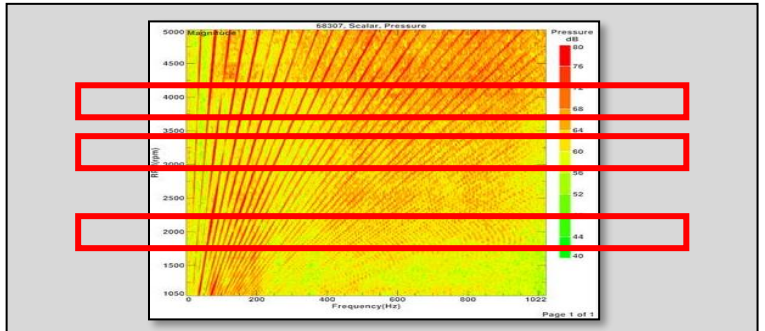
Simcenter Acoustics – ATV (Acoustic Transfer Vector) Set



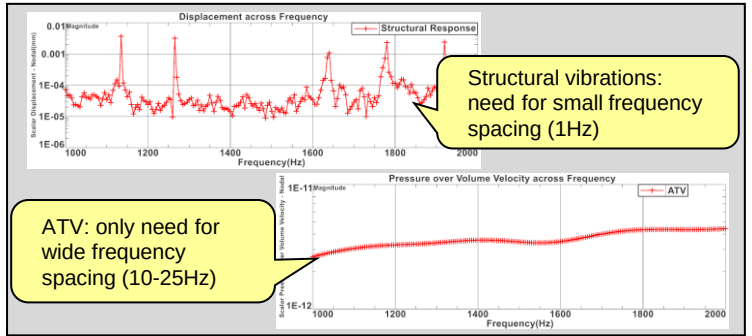


ATV enables fast multi-rpm acoustic analysis





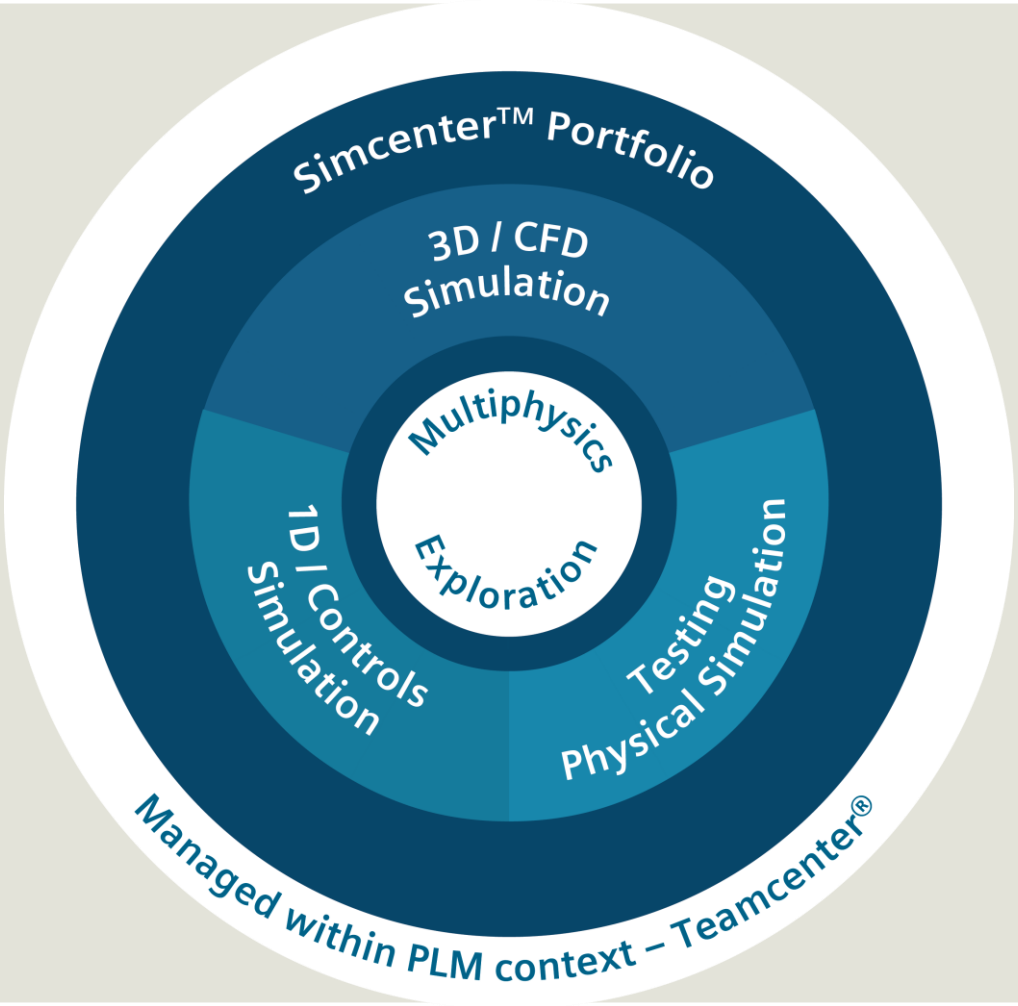
ATVs are INDEPENDENT from load conditions (rpm, order…)



For exterior radiation, ATVs are SMOOTH functions (f), which can be interpolated

Simcenter 3D Solutions
A part of a broader vision

SIEMENS
Ingenuity for life



- 1D - 3D co-simulation :
  - 1D control, Structural, Acoustics
  - System of systems simulation and design
- 3D tests hybrid modelling :
  - Model updating (improve trust in CAE)
  - Real time hybrid testing
- Out of the box integration with Teamcenter:
  - Synchronize simulation and design
  - Easily manage simulation data out-of-the-box with Teamcenter Simulation
  - Knowledge capture and process automation

Further System-level approach
1D – 3D integrated solution

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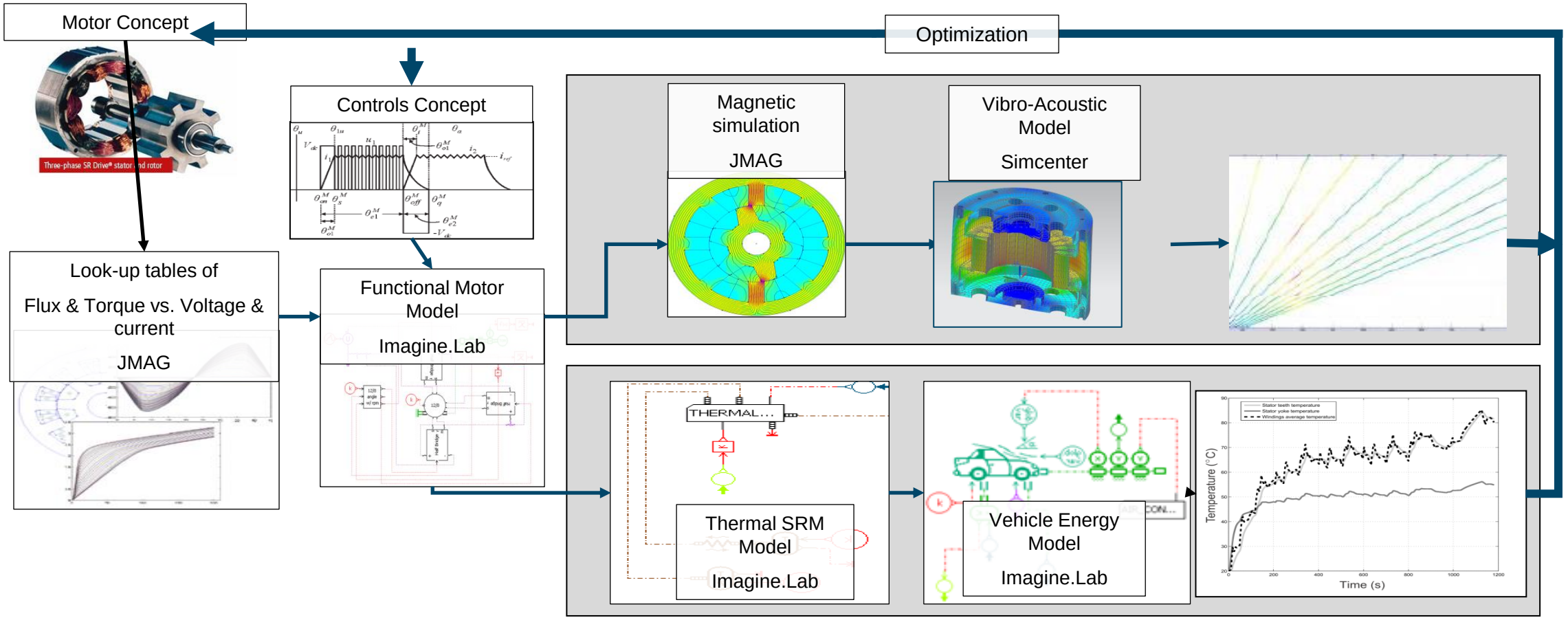
Ingenuity for life



Optimization of switched reluctance electrical motor and controls design for NVH & thermal performance

Simcenter 3D Acoustics
Benefits

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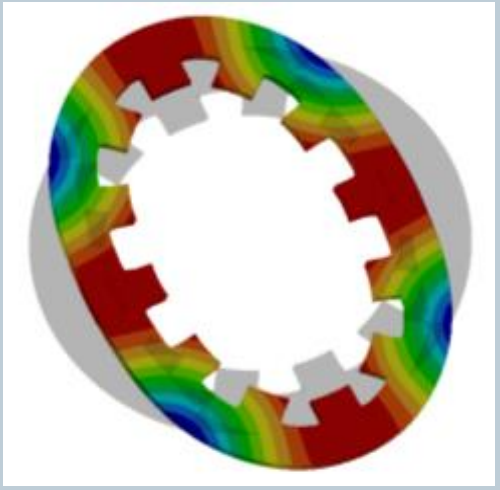
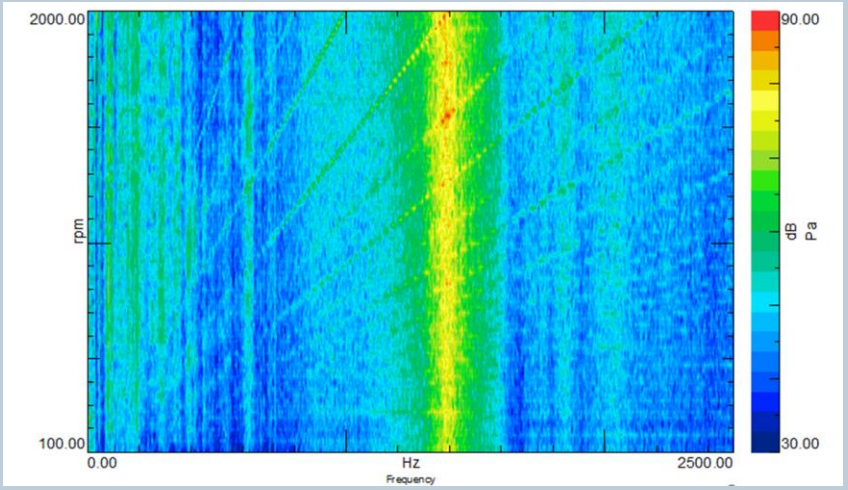
Simcenter 3D Acoustics	Benefit
• Best-in-class Acoustics technology • Single pre/post engineering platform for multiple disciplines: structural, acoustics, meshing, results animation and reporting • Open support for external solvers and CAD; including e.g. JMAG for Electro-magnetic and 1D for motor control • Integrated optimization and fast design change	• Increase team flexibility and helps optimizing resource/skills constraints • Decrease costs, time wasted translating data and potential errors • Adhere to acoustics requirements in the most effective and efficient way

Punch Powertrain

New generation of switched reluctance motors with superior NVH performance

SIEMENS
Ingenuity for life





- Reduced total development time by at least 50 percent
- Developed new generation of motors with better NVH performance
- Implemented a new simulation-based process with knowledge transfer

- Leverage simulation to guarantee the product meets expectations
- Use Acoustic Simulation to understand complex sound fields
- Customize software for specific applications

‘When we consider the fact that it took only half a year to put this process in place, we can definitely say that the total development time has been reduced by at least a factor of 2’

Diederik Brems; Mechanical Engineer; Punch Powertrain

Punch Powertrain

SIEMENS
Ingenuity for life

SIEMENS

Automotive and transportation

Punch Powertrain

Punch Powertrain uses LMS Engineering services and tools to cut development time by at least a factor of 2

Product
LMS

Business challenges
Implement simulation-based approach, combining electromagnetics and vibro-acoustics
Reduce motor noise to target level
Avoid tonal noise on critical frequencies

Keys to success
Combine test and simulation for the creation of validated simulation models
Couple the vibro-acoustic model with the electromagnetic model
Analyze modifications to the validated simulation model

Results
Reduced total development time by at least 50 percent
Developed new generation of motors with better NVH performance
Implemented a new simulation-based process with knowledge transfer

Siemens PLM Software helps automotive manufacturer develop new generation of switched reluctance motors with superior NVH performance

Developing a powerful partnership
The development of electrical motors for hybrid and electrical automotive propulsion presents many engineering challenges. Mechanical engineers can choose from a large variety of motor types and configurations, and have to effectively evaluate all possibilities. Besides the right conceptual configuration and control strategy for maximized energy efficiency, the demanding passenger car industry also requires optimal noise, vibration and harshness (NVH) behavior of the motor.

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CAE Based Noise Optimization of Switched Reluctance Electric Motors for Automotive Powertrains

Joris Van Herbruggen[1], Stefano Orlando[1], Jan Anthonis[1]
Saphir Faid[2], Diederik Brems[2], Fabrice Boon[2]
[1]*LMS, a Siemens Business –LMS International N.V. – Interleuvenlaan 68, B-3001 Leuven (Belgium)*
[2]*Punch Powertrain N.V. – Industriezone Schurhovenveld 4 125 – B-3800 Sint-Truiden (Belgium)*

Abstract

This paper focuses on simulation of noise radiated by Switched Reluctance Motors for automotive powertrains. Since control for maximum efficiency leads to high torque ripple and noise radiation, optimizing the NVH behaviour is essential. The simulation approach, based on electro-magnetic and vibro-acoustic finite element models and applicable to other electric motors, is illustrated with concrete results.

Keywords: switching reluctance motor, optimization, simulation, finite element calculation

1 Introduction

Switched Reluctance Motors are an interesting alternative to Permanent Magnet Synchronous Motors, currently used in most electric powertrains. PMSMs provide high efficiency, but limited availability of rare earth elements could increase their costs.
A reluctance motor produces torque by the tendency of its rotor to move to a position where the inductance is maximized. Figure 1 shows that, by exciting a pair of opposed stator windings, the principle of minimal reluctance causes a torque aligning the rotor and the stator poles.
The industrial use of SRMs has become feasible thanks to the availability of inexpensive, high-power switching devices.
An SRM has no permanent magnets and the rotor consists of laminated iron, resulting in low manufacturing costs. Additionally, SRMs achieve maximum efficiency over a wide speed range, making their average efficiency over a real drive cycle similar to PMSMs.
Next to these advantages, SRMs also pose challenges: complex controls including phase overlap are needed to limit torque ripple caused by phase switching and their operation results in high noise radiation. Optimization of the control strategy to reduce torque ripple has a beneficial effect on noise radiation. Next chapter shows that structural optimization of the motor and its housing can further reduce the noise.

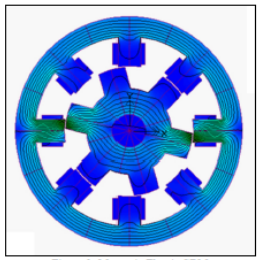

Figure 1: Magnetic Flux in SRM

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