Using Ansys MAXWELL, Motion & Mechanical solve NVH Problems

虎門科技技術團隊
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Ansys

結構

Mechanical Enterprise
耦和、聲場

Mechanical Premium
振動

Mechanical Pro
靜態、熱傳

顯式求解器

LS-DYNA (2019併購)
落下衝擊

Autodyn (2005併購)
爆炸

Sherlock (2019併購)
PCB可靠度

nCode DesignLife
高階疲勞

MBD for ANSYS
高階多體動力學

積層製造(2017併購3DSIM)

Additive Suite

Additive Print

流體

計算流體力學

Fluent (2006併購)
泛用型計算流力分析

CFX (2003併購)
泛用型計算流力分析

Polyflow
高分子聚合物流體分析

FORTE
內燃機引擎燃燒分析

FENSAP-ICE(2015併購)
飛行器除冰分析

Chemkin (2014併購)
化學動力學模擬

旋轉機械應用

BladeModeler
互動式葉片設計

Vista TF
2D旋轉機械分析

ICEPAK
電子產品散熱分析

CFD Post
CFD專用後處理

電磁場 (2008併購Ansoft)

電磁場分析

HFSS
高頻電磁場

Maxwell 3D
低頻電磁場

Q3D Extractor
寄生參數萃取

Maxwell 2D
低頻電磁場

PCB電路板電磁場

Siwave
電路板設計

Designer

系統控制分析

Twin Builder

機電參數設計

RMxprt
馬達設計

PExprt
變壓器設計

Optimetrics
參數分析

光學 (2018併購OPTIS)

SPEOS Enterprise
可視化

SPEOS Premium
光譜分析、逆追跡

SPEOS Pro
亮度、光源

SPEOS for NX

SPEOS for Creo Parametric

VRXPERIENCE

Driving Simulator

Headlamp

HMI

Sensor

Perceived Quality

材料資訊 (2019併購Granta Design)

Granta Materials Data
模擬專用材料庫

CES Selector
智慧選材工具

幾何處理工具

DesignModeler
參數式幾何建模工具

SpaceCliam Direct Modeler
直覺式幾何建模工具 (2014併購)

3D設計

Discovery Live
即時分析

AIM
多物理耦合

ANSYS Meshing
網格處理工具

DesignXplorer
最佳化設計

ANSYS Cloud
雲端運算

Customization Suite
二次開發

ANSYS Ensight (2017併購)
高階CAE後處理工具

ANSYS HPC PACK
高性能平行運算

Elastic Units
彈性授權

Engineering Knowledge Manager

ANSYS Workbench

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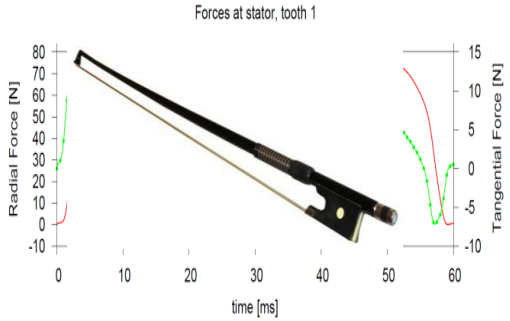
Listen to CAE

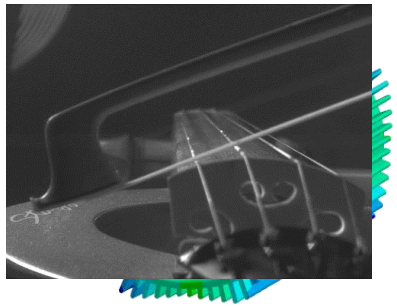
ANSYS Maxwell

ANSYS Mechanical

ANSYS VRXPERIENCE Sound

Emag Simulation → *Force* → Stator Excitation → *Excitation* → Dynamic behavior → *Vibration* → Acoustic *Radiation* → Sound synthesis → *Propagation*





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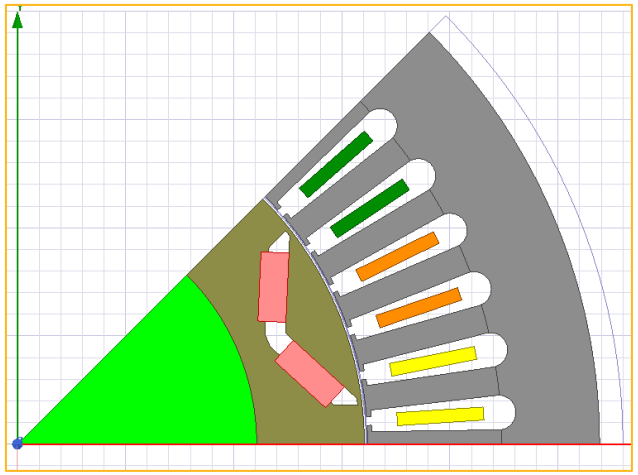
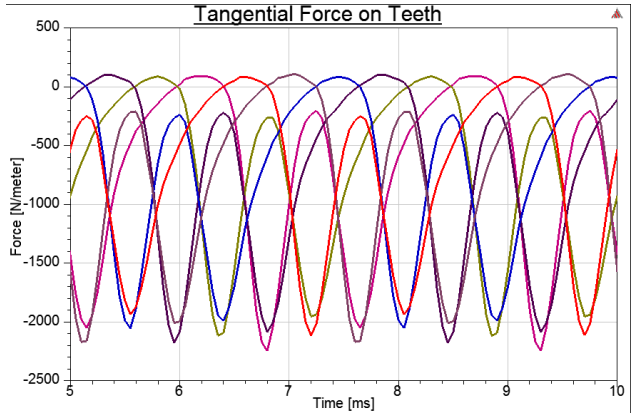
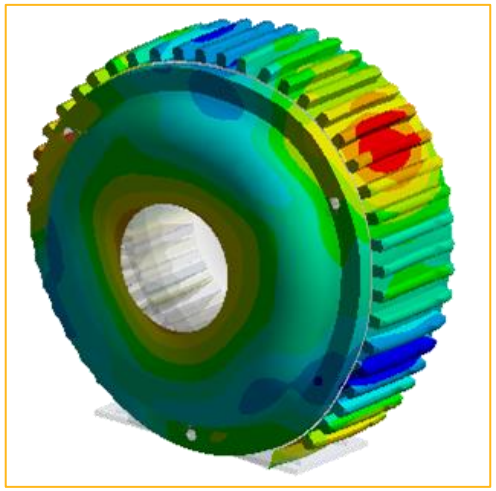
流程

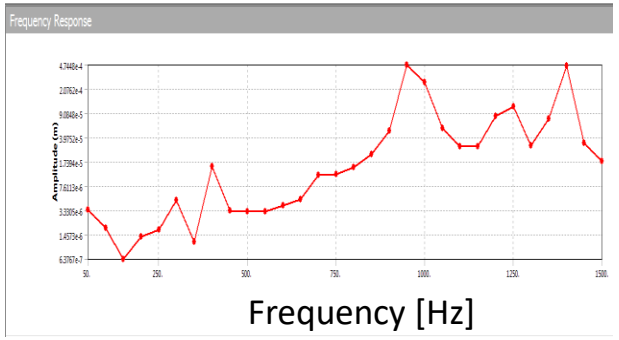
1. Magnetic Field Solution



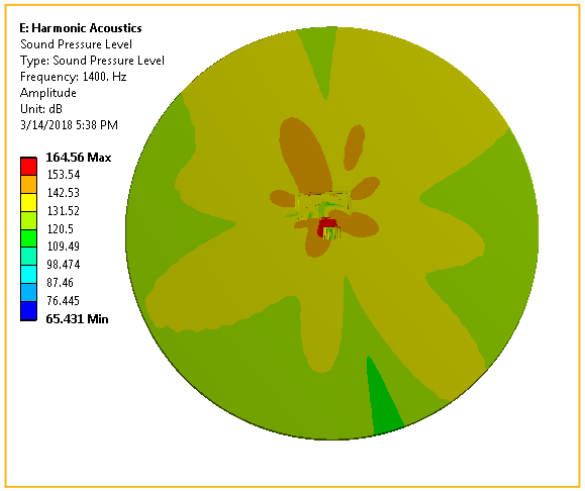


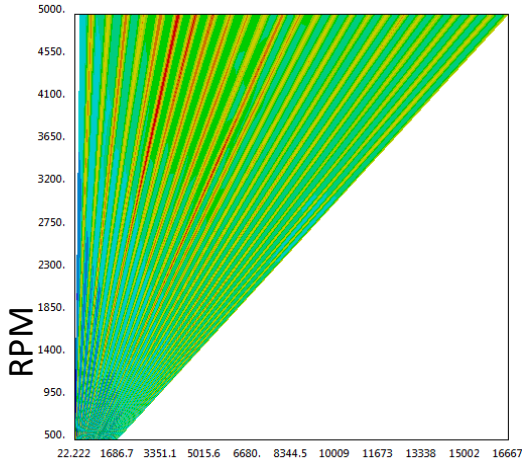
2. Modal and Vibration



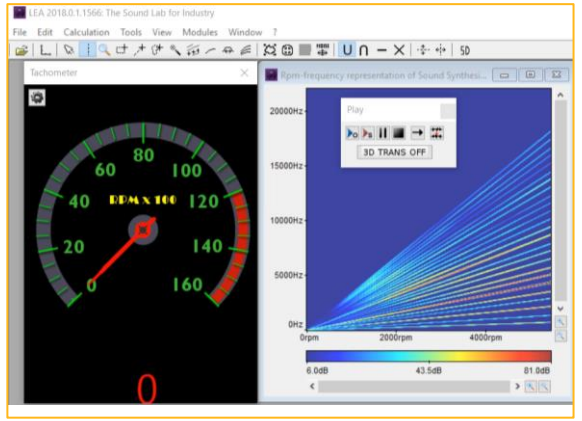


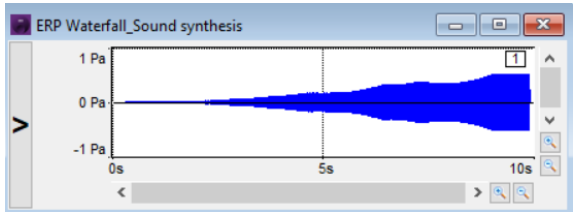
3. Acoustic





4. VRxperience





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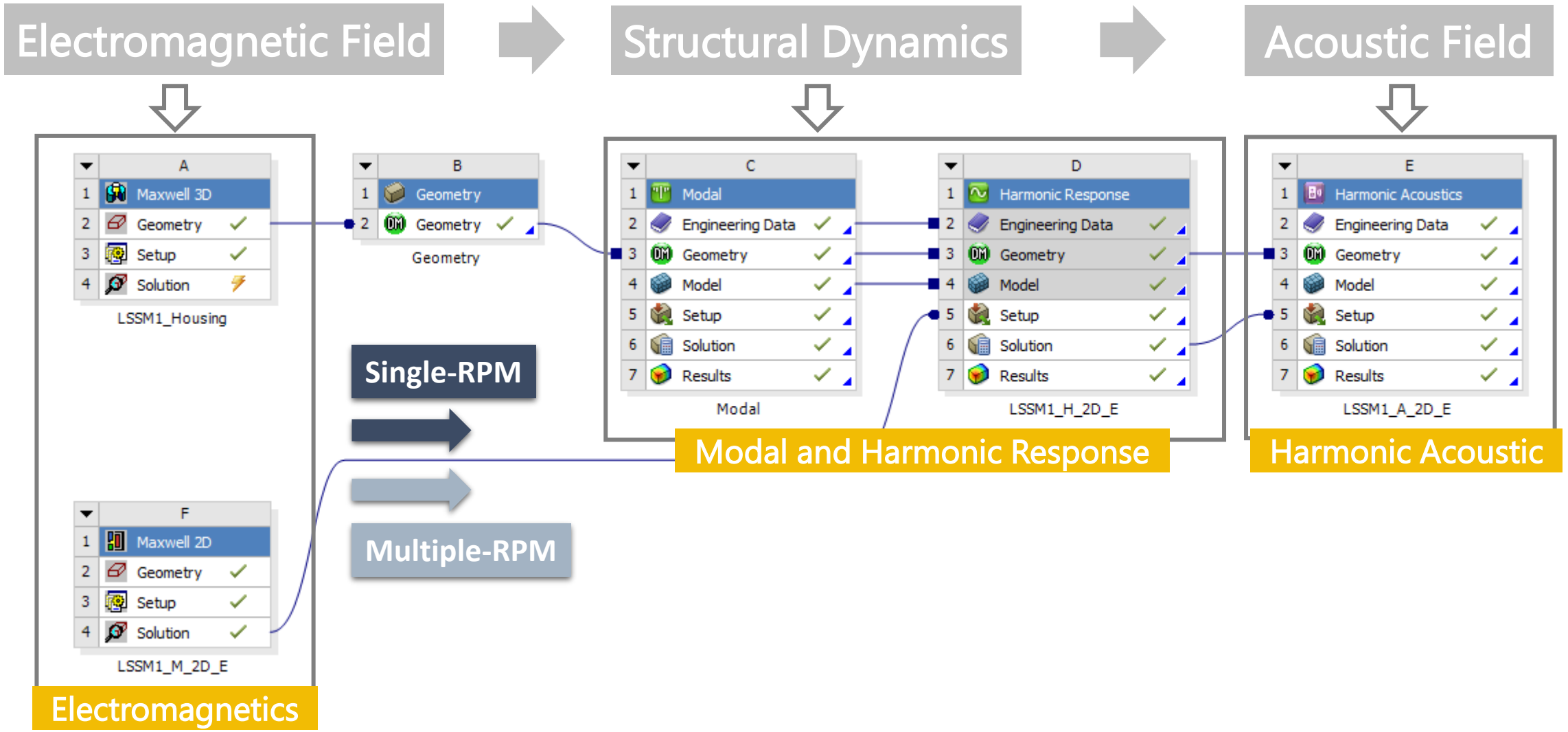
Project schematic



ANSYS Motion

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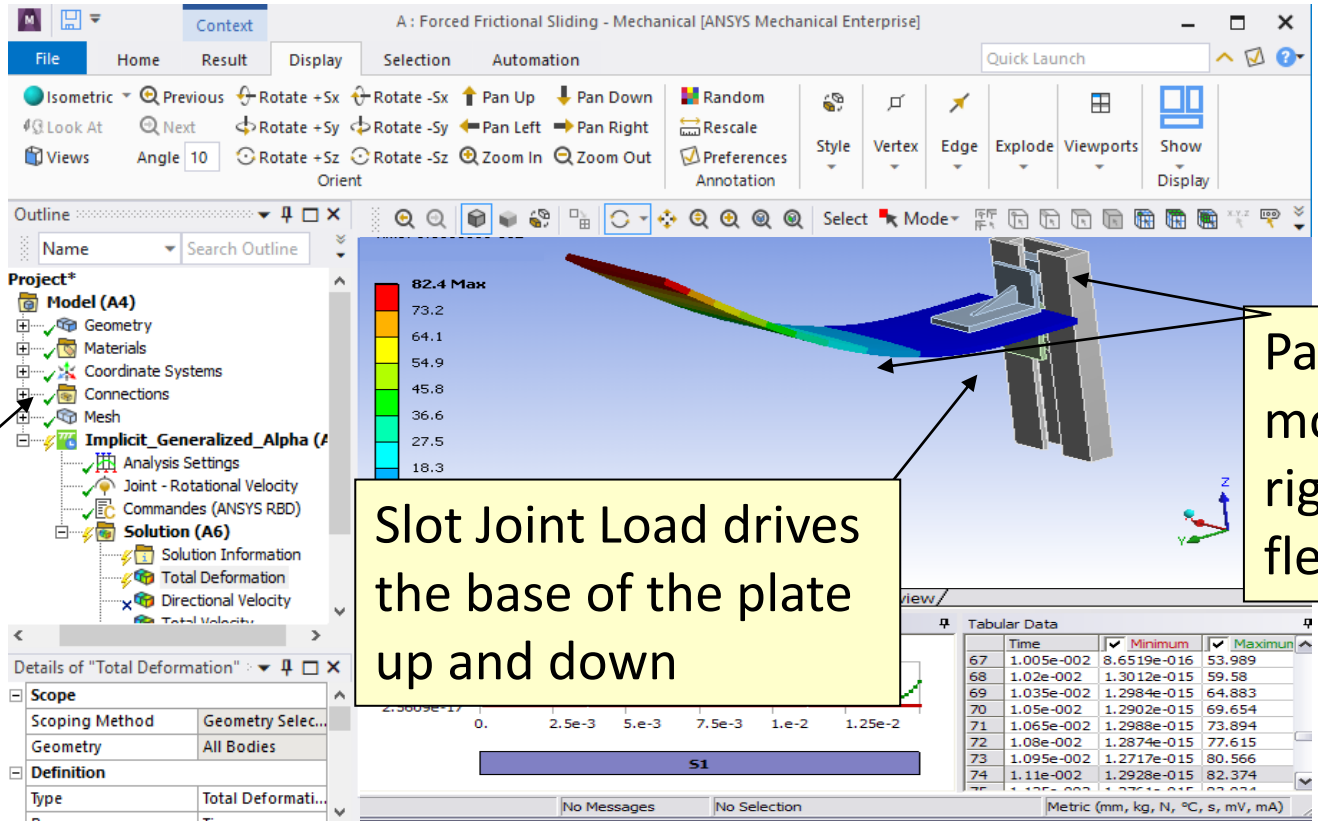
Ansys

What is Multibody Dynamic (MBD) Analysis?

- It is a means of analyzing the dynamic behavior of a system of interconnected bodies consisting of rigid and/or flexible components.

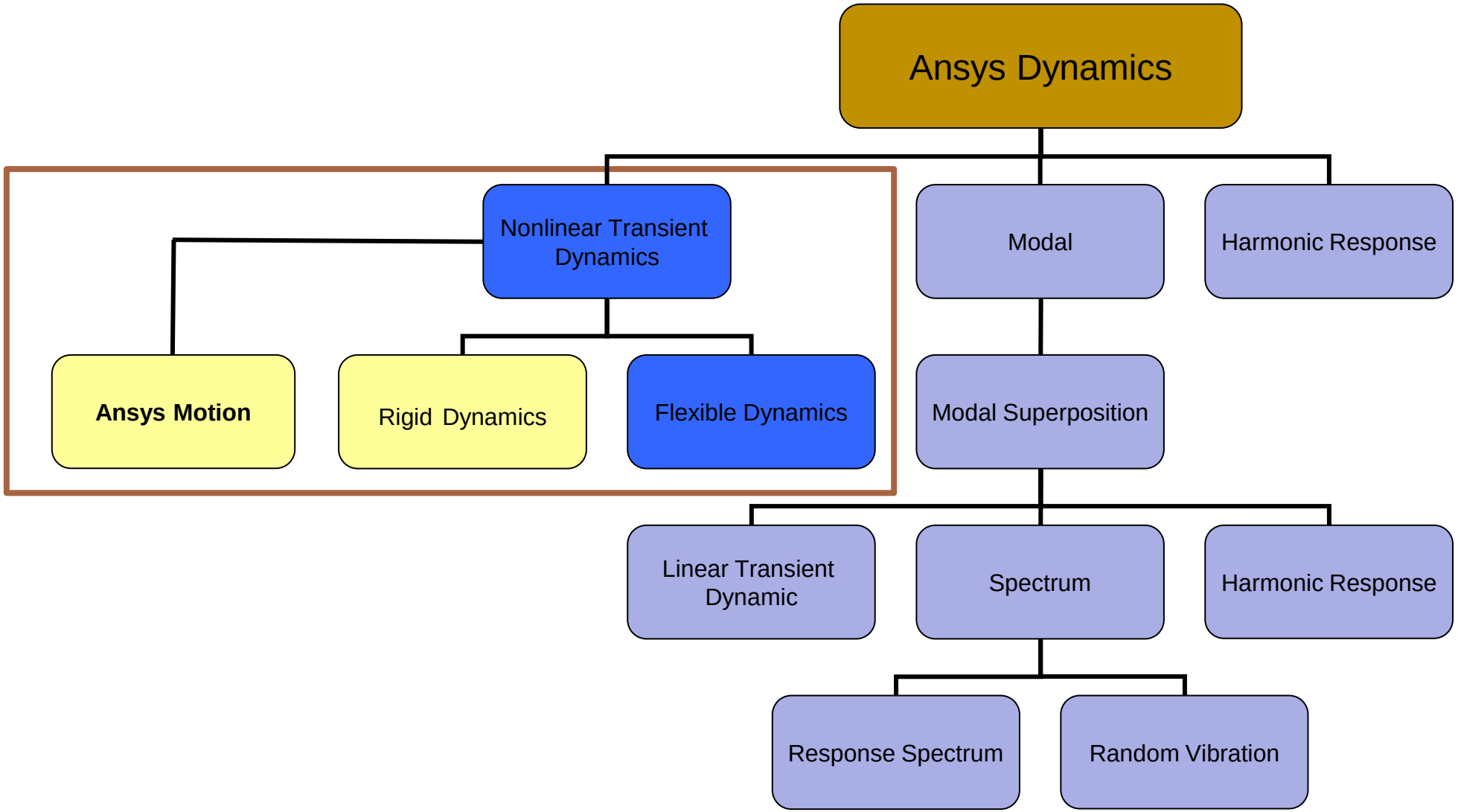


Parts are connected at Joints which allow some relative motion

Slot Joint Load drives the base of the plate up and down

Parts are modeled as rigid and/or flexible

Introduction



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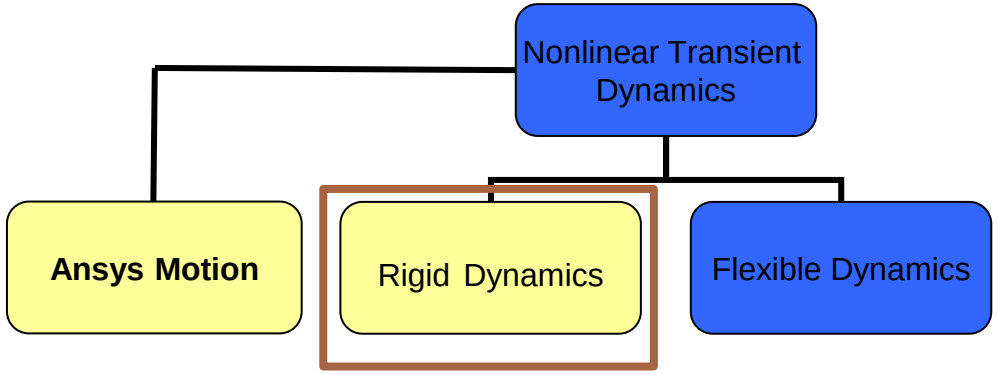
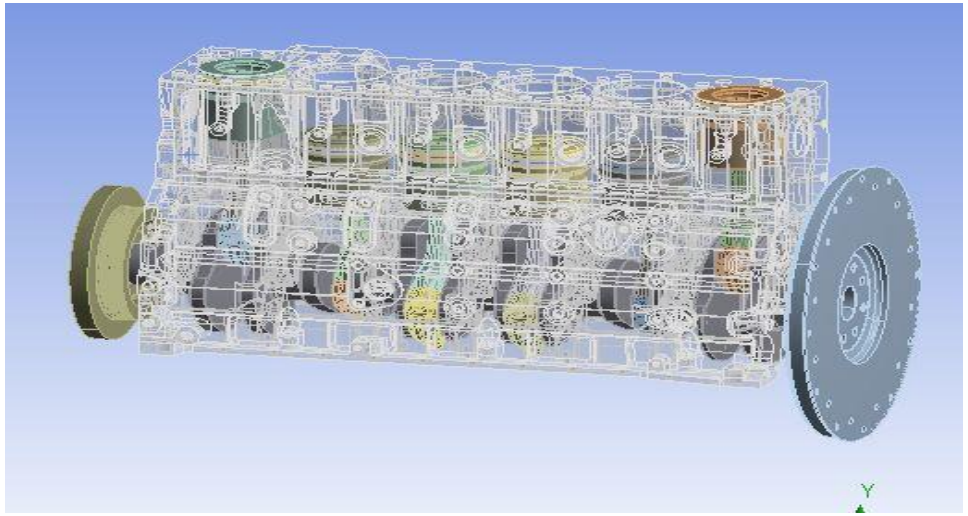
Introduction

Three Multibody Dynamic Analysis types are available:

Rigid Multibody Dynamics

- Consists mainly of rigid bodies
- May include condensed parts (CMS super elements)
- Motion due only to joints/contacts
- Goal is determination of Motion and Forces
- Few degrees of freedom, fast solves
- Best suited for short duration large deformation analysis
- Large deformation and large rotations capabilities
- Based on energy conservation

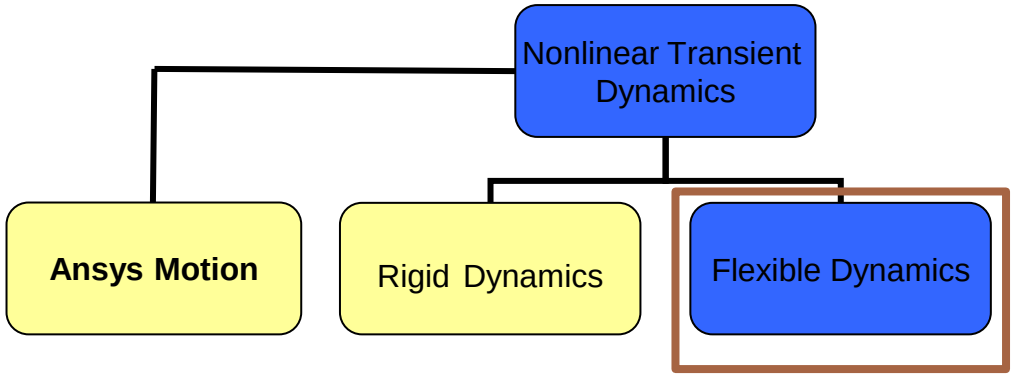


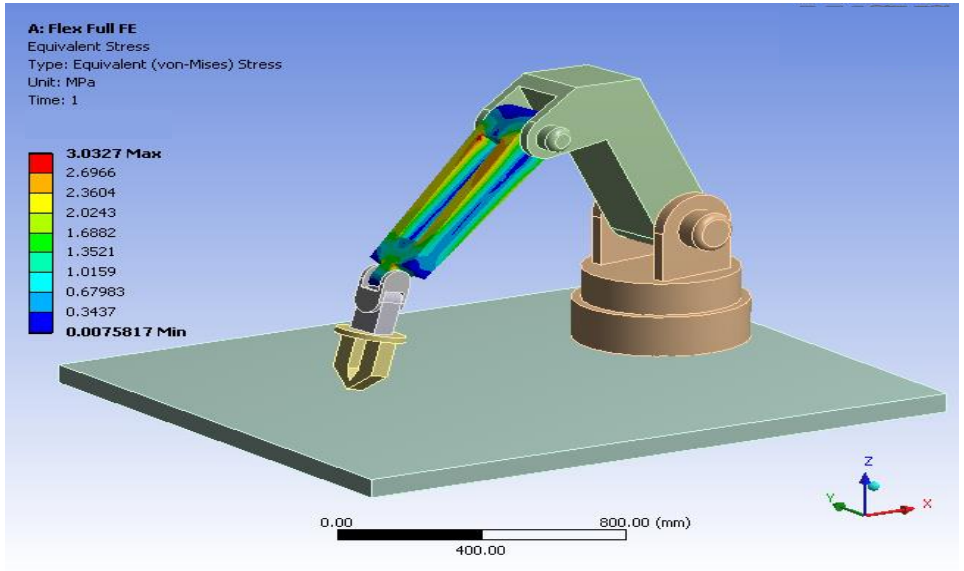


Introduction

Flexible Multibody Dynamics

- Consists of rigid and/or flexible bodies
- All types of nonlinearities are allowed
- Motion due to joints/contacts and flexible part deformation
- Goal is determination of Motion, Forces, Deformations, and Stresses
- Longer solves, but more results data
- CMS available to speed-up solves

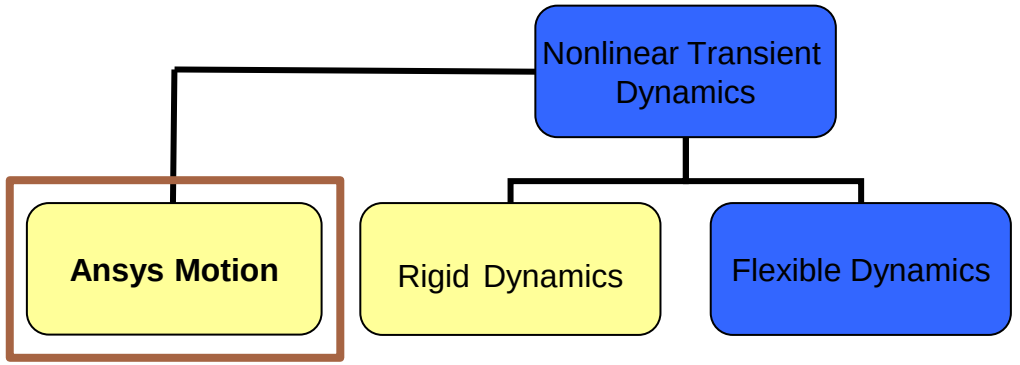


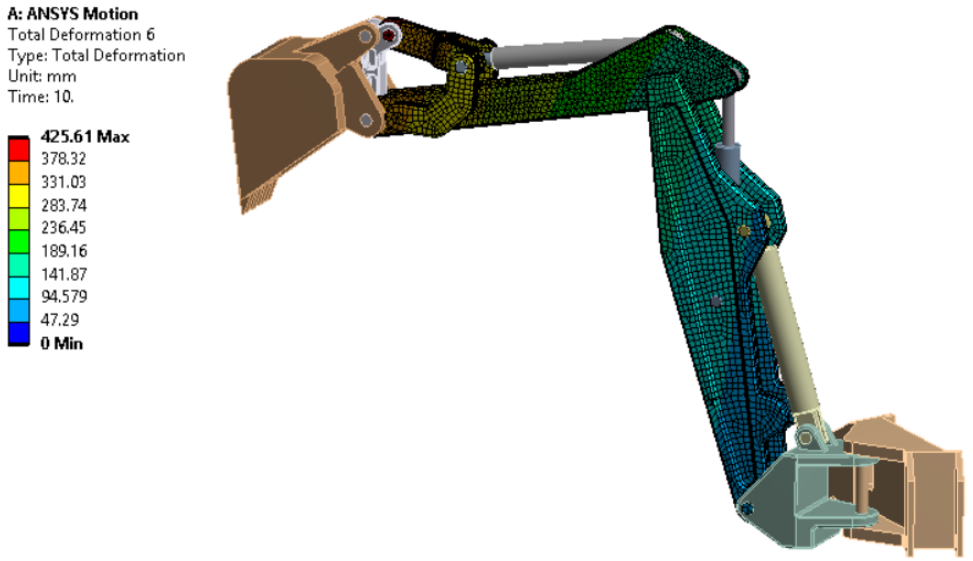


Introduction

Ansys Motion

- Consists of rigid bodies, modal bodies and/or nodal bodies
- All types of nonlinearities are allowed
- Motion due to joints/contacts and flexible part deformation
- Goal is determination of Motion, Forces, Deformations, and Stresses
- Recommended for high-speed large rotation systems
- Robust for 3D contacts systems
- Can be performed by "Motion" analysis system
- Specific toolkits available





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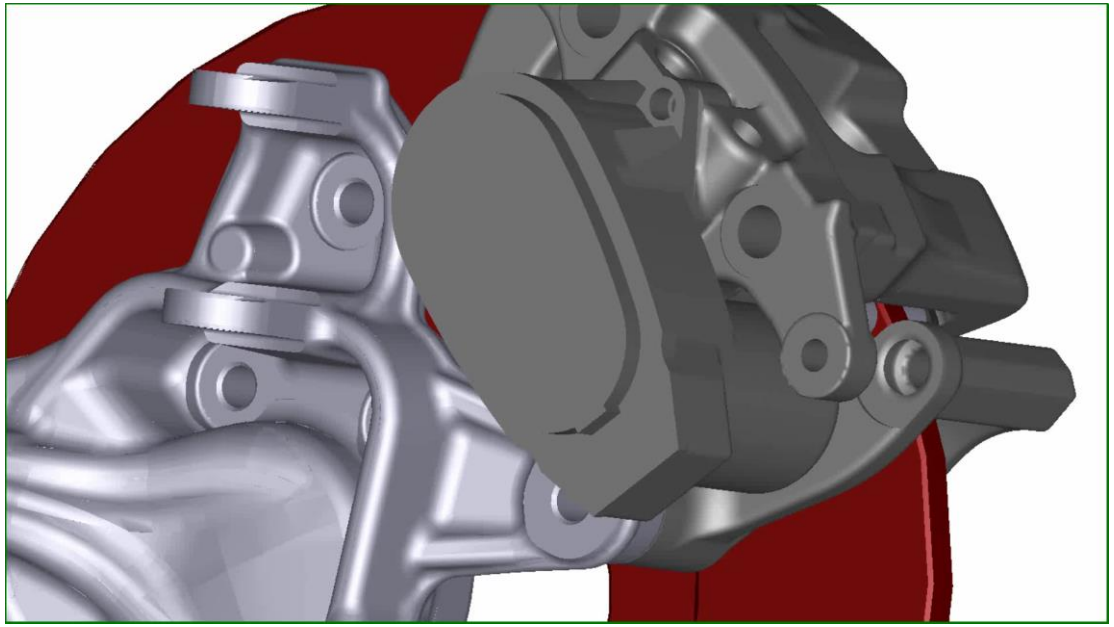
Ansys Motion

Transient Stress Analysis of Brake Assembly



Main Package Capabilities

- Multibody Dynamics
- Strength/Fatigue
- NVH (Linear & Transient)
- Heat Transfer
- FMI/FMU

Advanced toolkits

LINKS

Tracks, Chains And Belts

DRIVETRAIN

Gears, Bearings, Shafts

CAR

Auto Ride & Handling

EASYFLEX

Meshfree Flexible Solver

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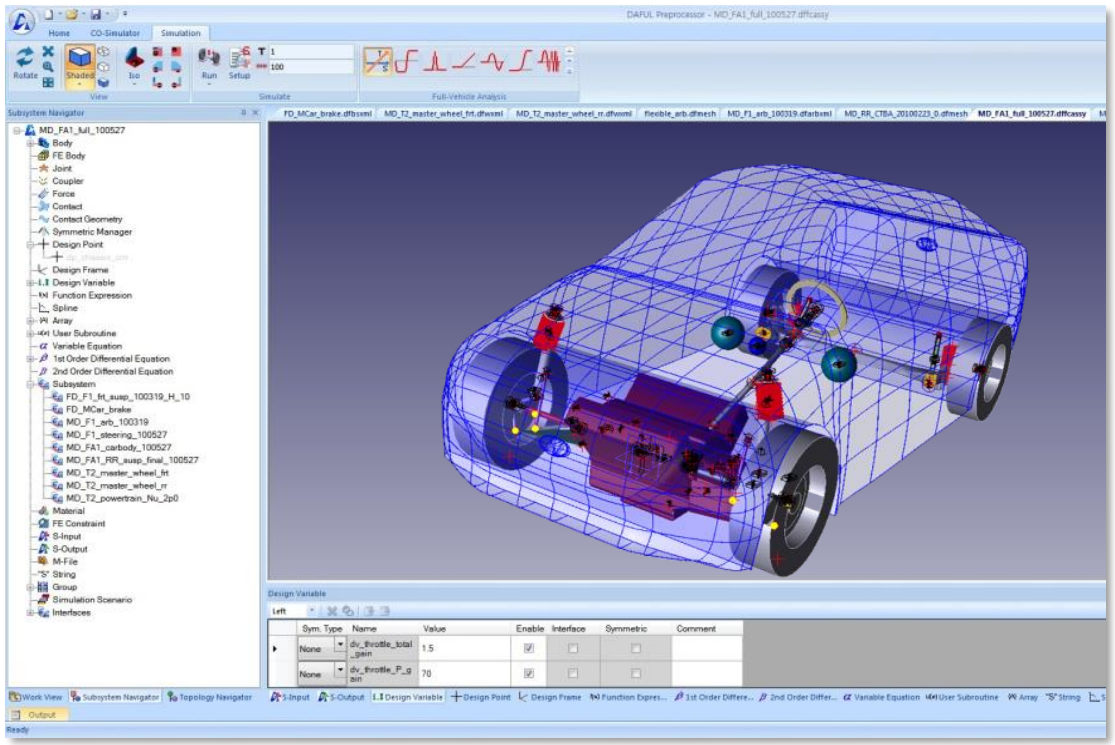
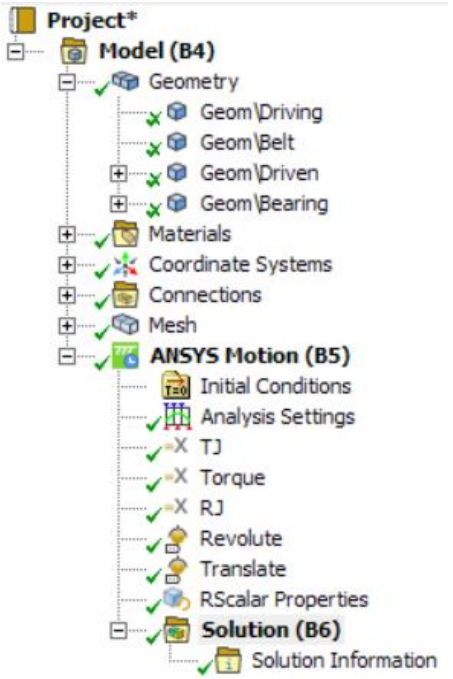
Ansys Motion ACT Application

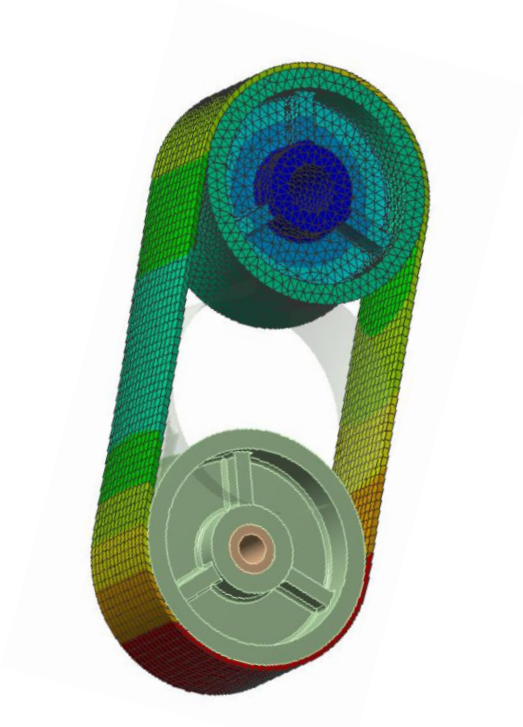
Preprocessor

Ansys Motion Standalone



Ansys Motion in Workbench





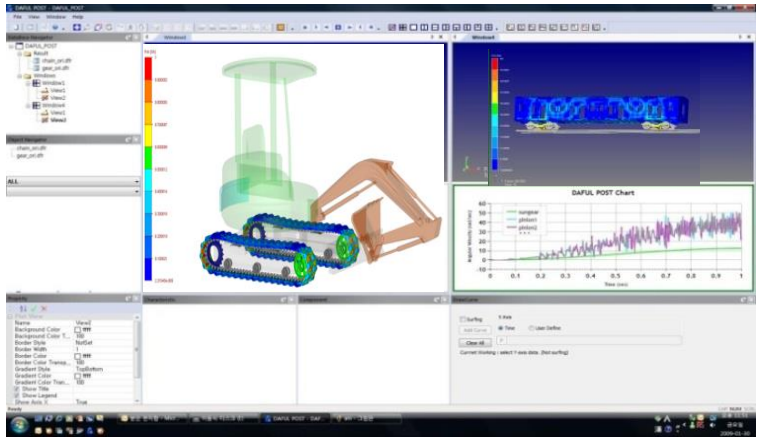
Provides the power of the Ansys Workbench and Mechanical Environments to facilitate the preprocessing of Ansys Motion models.

Ansys Motion ACT Application

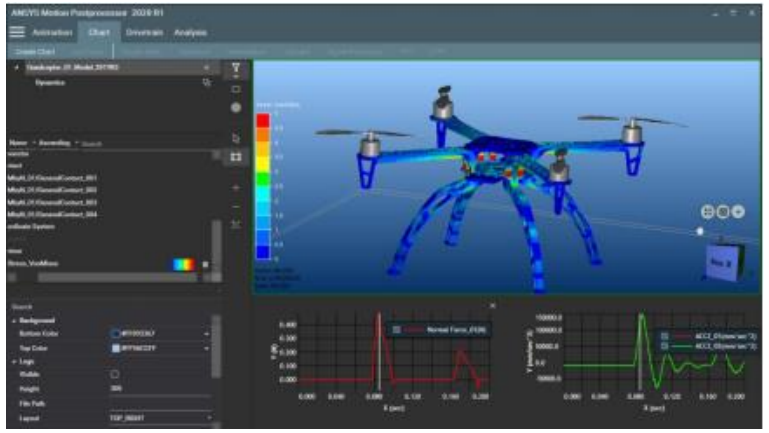
Postprocessor

Ansys Motion Standalone

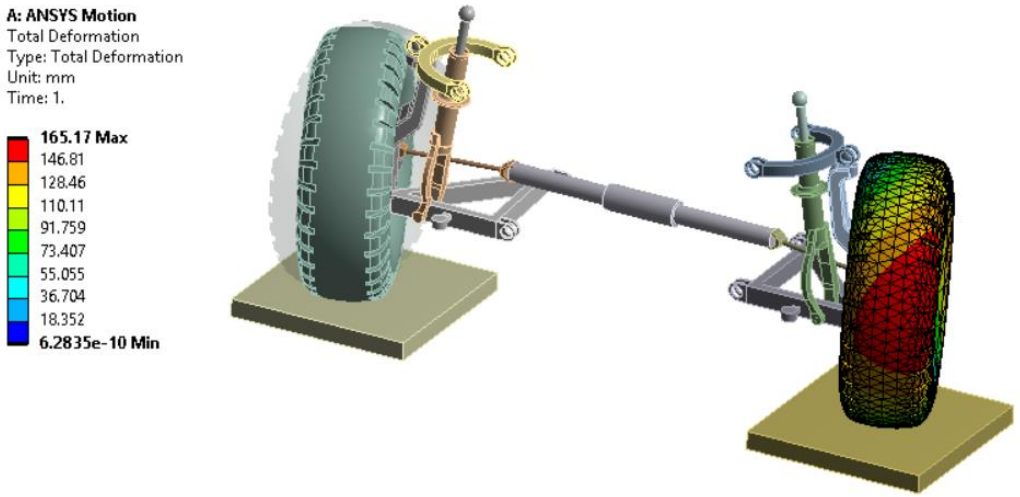
Classic postprocessor



New postprocessor



Ansys Motion in Workbench



- Only deformation, velocity and acceleration are available in Mechanical
- Ansys Motion postprocessor can be opened directly from Mechanical for others results

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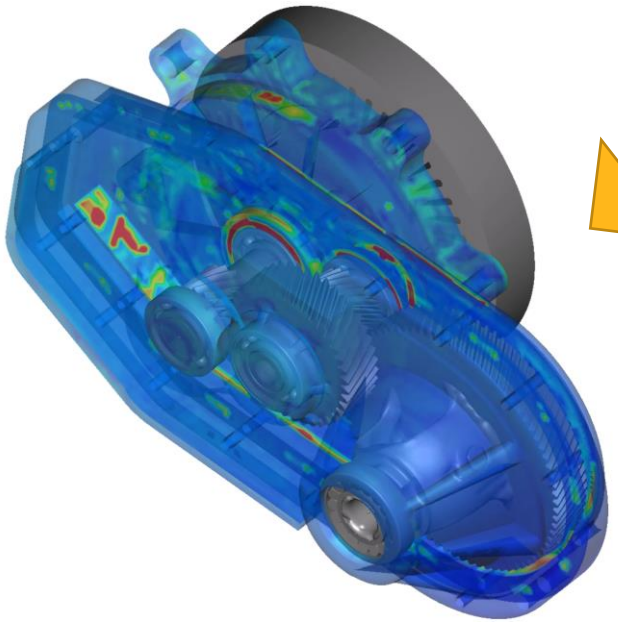
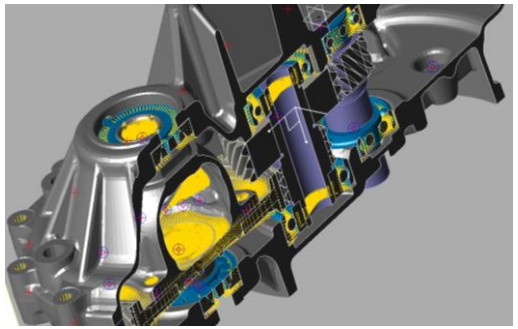
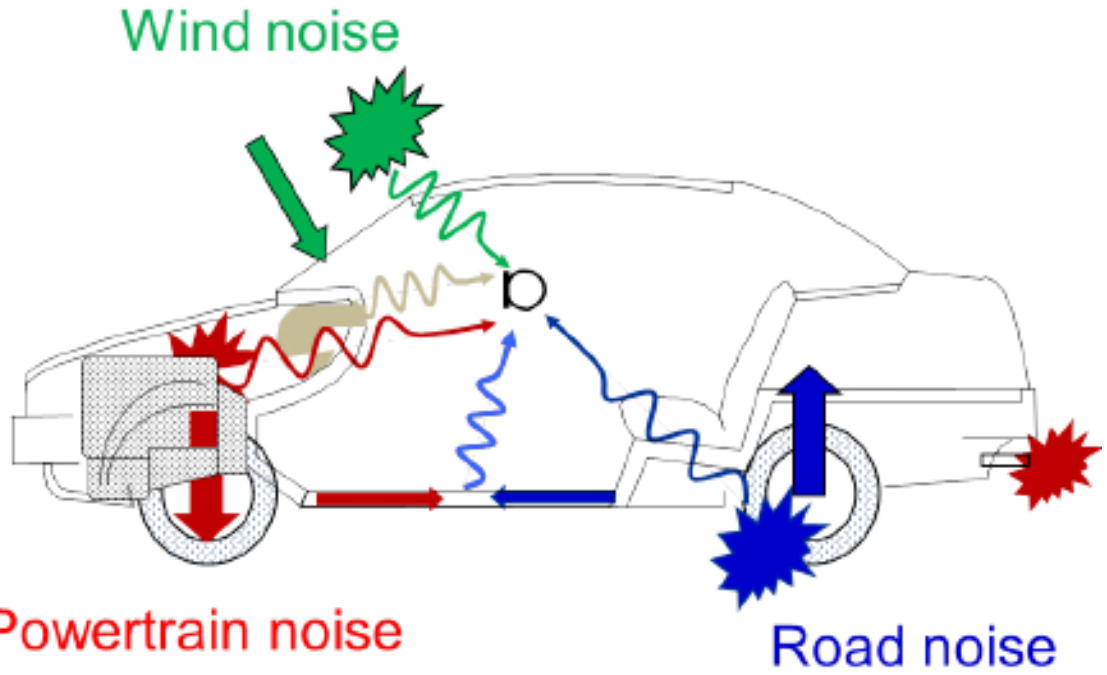
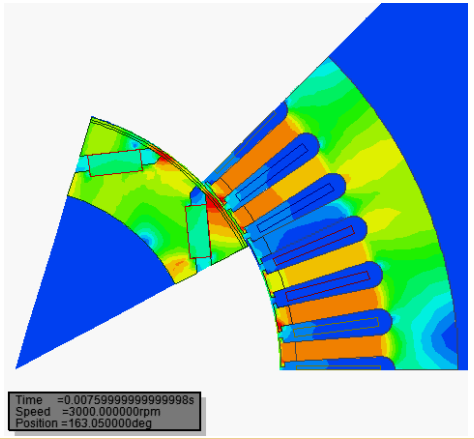






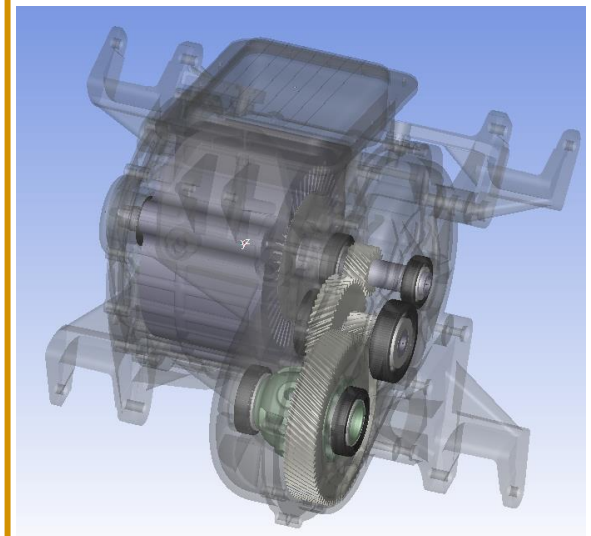
Ansys Maxwell

- Compute electromagnetic force of a rotor and stator



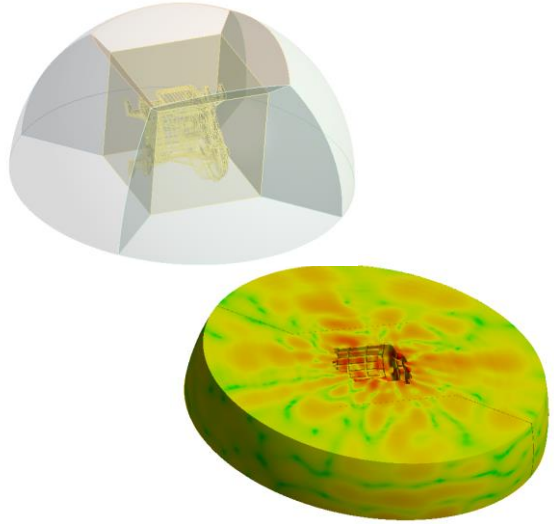
Ansys Motion

- MBD simulation of a complete assembly of E-powertrain system
- Whole system driven by EM force
- Surface velocity calculated and exported



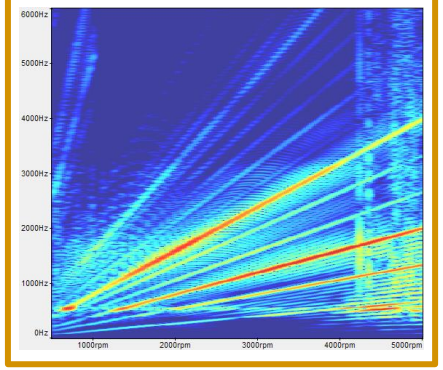
Ansys Mechanical

- High-fidelity acoustic simulation based on surface velocity calculated by Motion
- Calculate propagated sound pressure in near and far field



Ansys VRX Sound

- Order analysis
- Psychoacoustics analysis
- Mix and comparison with measurements



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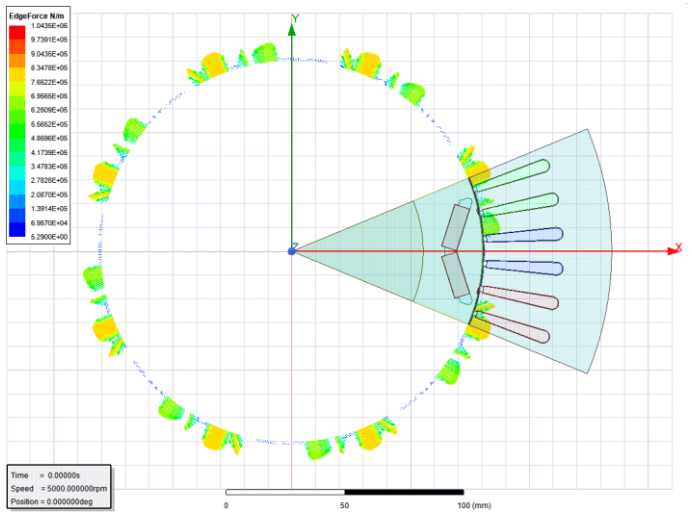
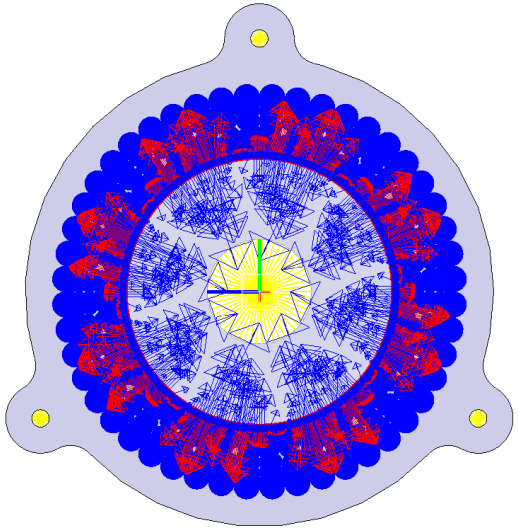
Noise Sources of E-Drivetrain

- Electromagnetic (EM) Force of a E-Motor
  - EM force on a rotor and stator excites a structure
  - The vibration of the rotor and stator transmitted to a housing which generates noise
  - Generally induces high-frequency vibration and noise

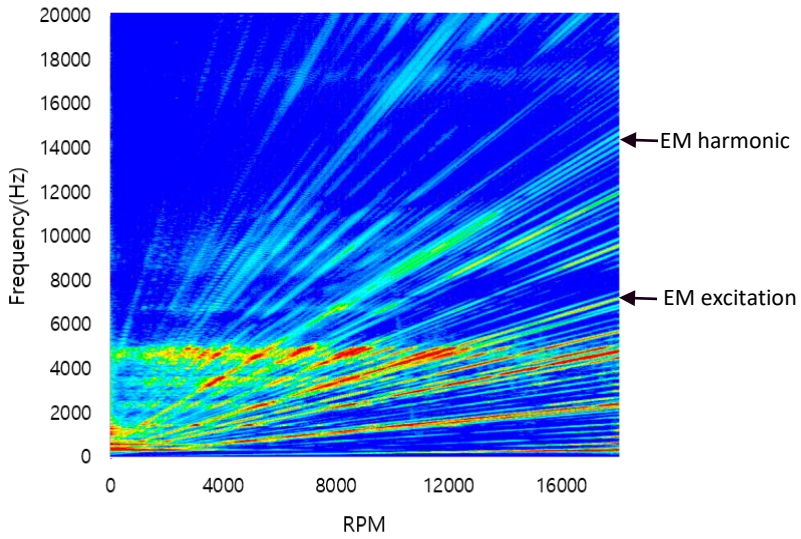
EM Forces



EM Forces mapped to the structure



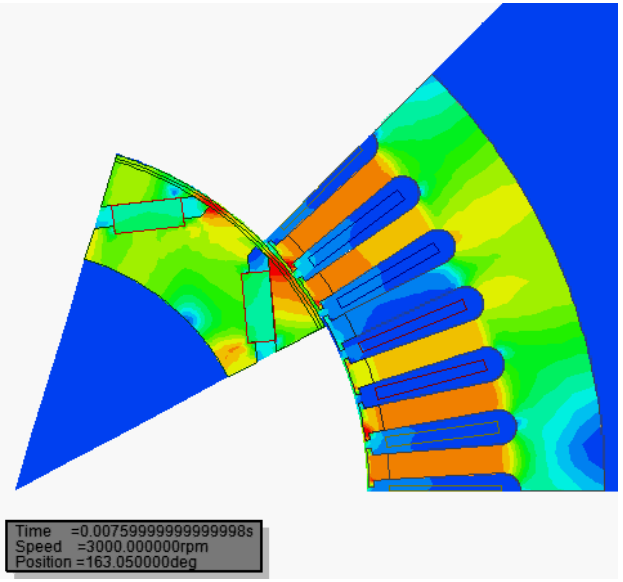
Acceleration Waterfall



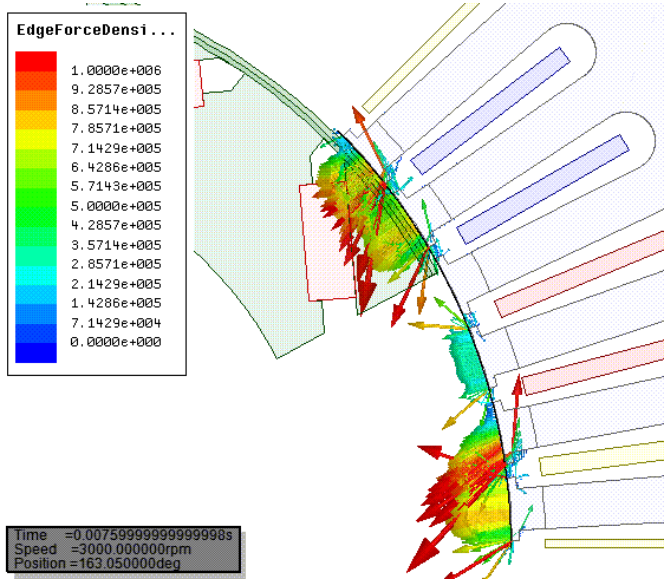
E-Drivetrain NVH Workflow: Electromagnetics

- Ansys Maxwell: Flagship Low-Frequency Electromagnetic Solver
  - Calculation of electromagnetic (EM) forces on both a rotor and stator in time domain
  - 2D/3D and Periodic/Full model of a motor can be simulated.
  - The effect of skew, eccentricity, switching frequency can be considered.

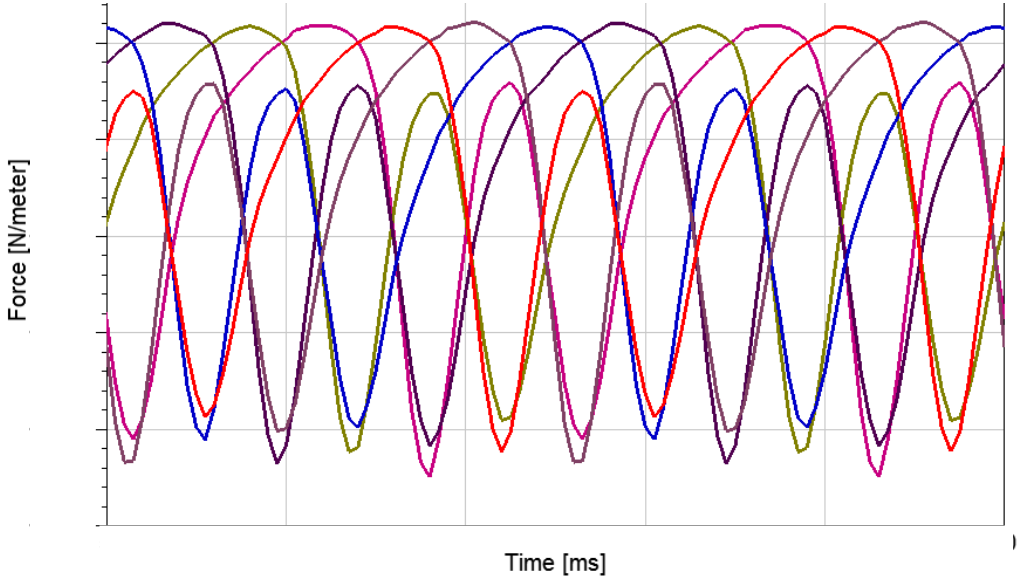
Magnetic Field



Magnetic Forces



Force on Stator Teeth



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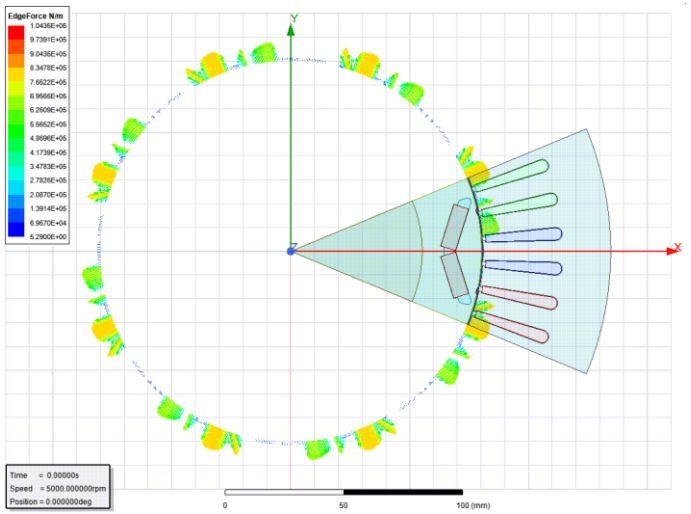
E-Drivetrain NVH Workflow: EM Force Mapping

- EM force mapped from an electromagnetics model to a FE structural model
- The entire E-drivetrain system driven and excited by the mapped EM forces
- Object-based (lumped force) and mesh-based (distributed force) mapping available

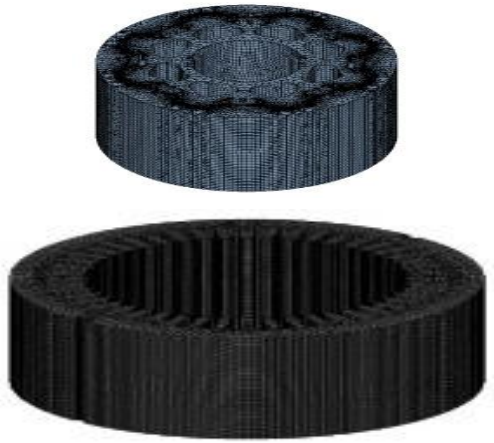
Ansys Maxwell



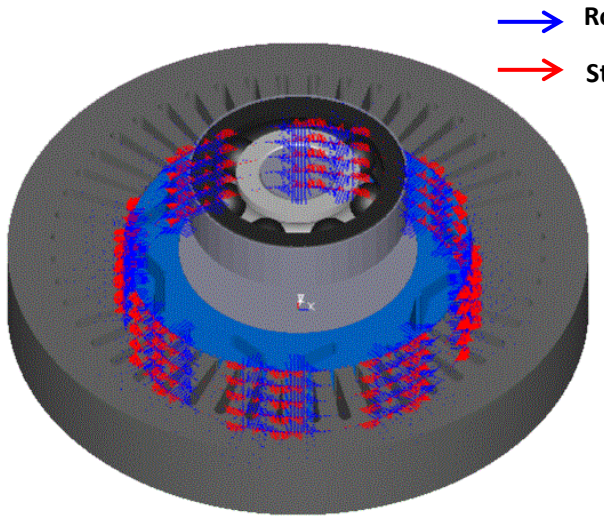
EM force calculation

Transfer EM Forces

Ansys Motion



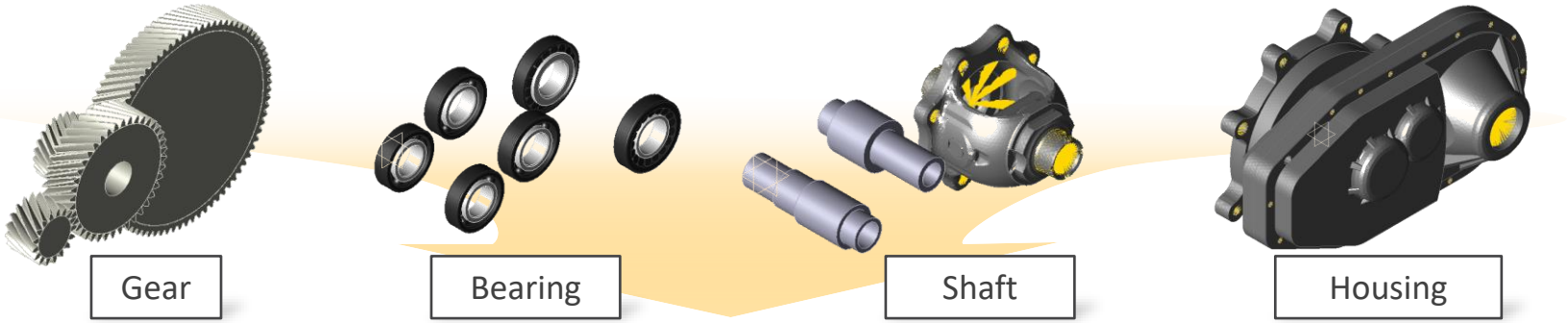
FE bodies of a rotor and stator

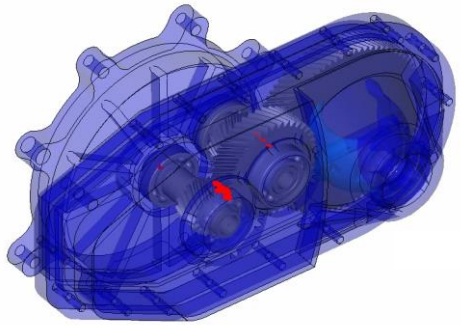


Mapped EM forces

E-Drivetrain NVH Workflow: Multi-Body Dynamics

- Ansys Motion: The 3rd Generation Multi-Body Dynamics (MBD) Solver
  - General-purpose MBD solver
  - Provides the advanced toolkits: Links, ***Drivetrain***, Car and EasyFlex

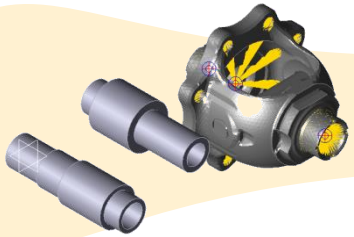




System
NVH
Analysis

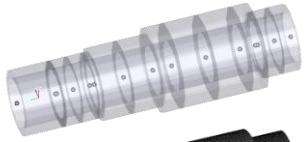
E-Drivetrain NVH Workflow: Multi-Body Dynamics

Shaft Modeling

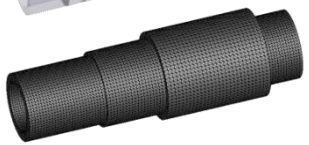


- Beam/FE/EasyFlex shaft
- Auto assembly with the components
- Component analysis for a deflection and mode shape

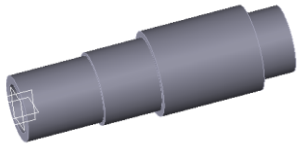
Beam



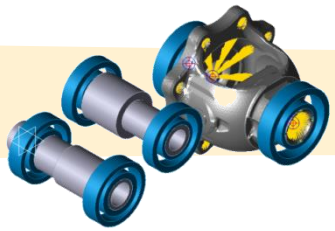
FE



EasyFlex



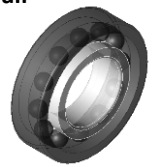
Bearing Modeling



- Variable stiffness with the elastic deformation
- Support the simple bearing (with stiffness matrix)
- Library from major bearing manufacturers (SKF, FAG, NSK, KOYO)

Rolling Bearing

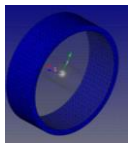
- **Ball**



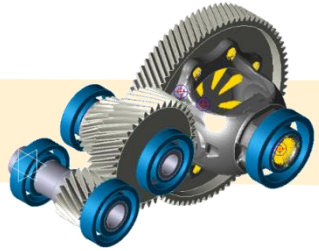
- **Roller**

Sliding Bearing

EHD Bearing

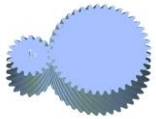


Gear Modeling

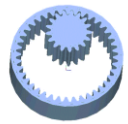


- Thin-slice model
- Specialized gear contact algorithm
- FE tooth stiffness
- Micro geometry modification

External Gear

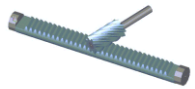


Internal Gear



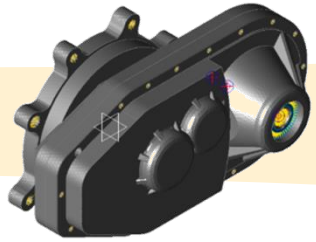
Planetary Gear

Rack and Pinion



Cross Helical

Housing Modeling



- FE/EasyFlex housing
- Eigenvalue analysis for the modal body
- Structural analysis with the finite element method
- Component analysis for a deflection and mode shape

FE

EasyFlex

Dynamic Analysis & Post-processing

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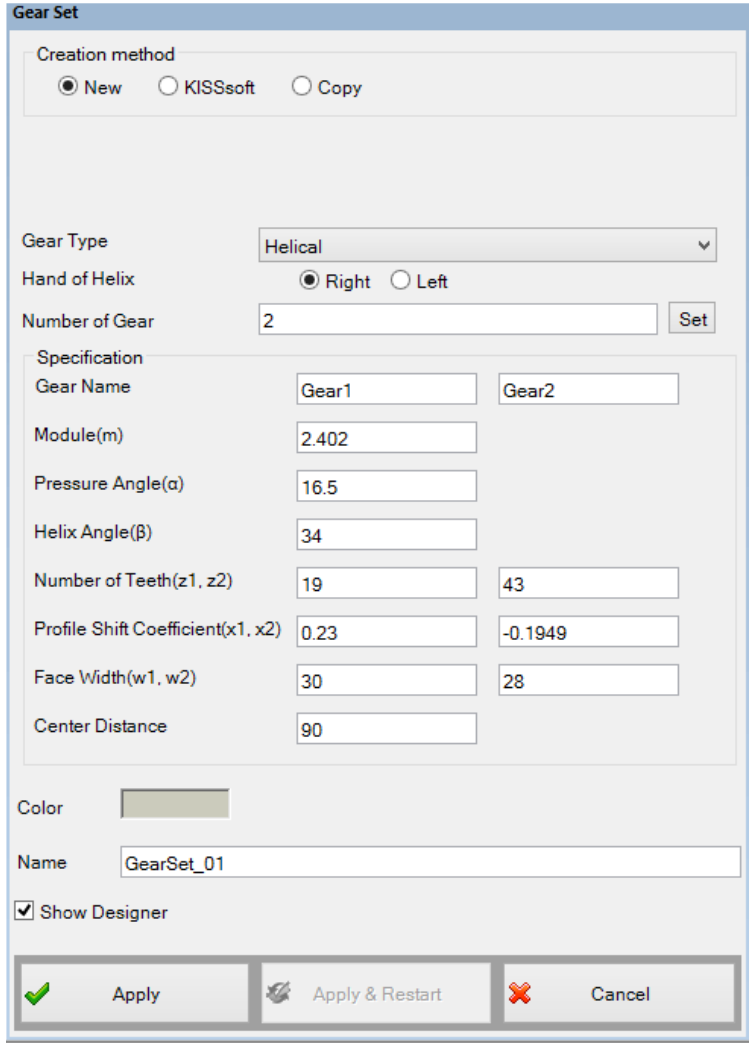
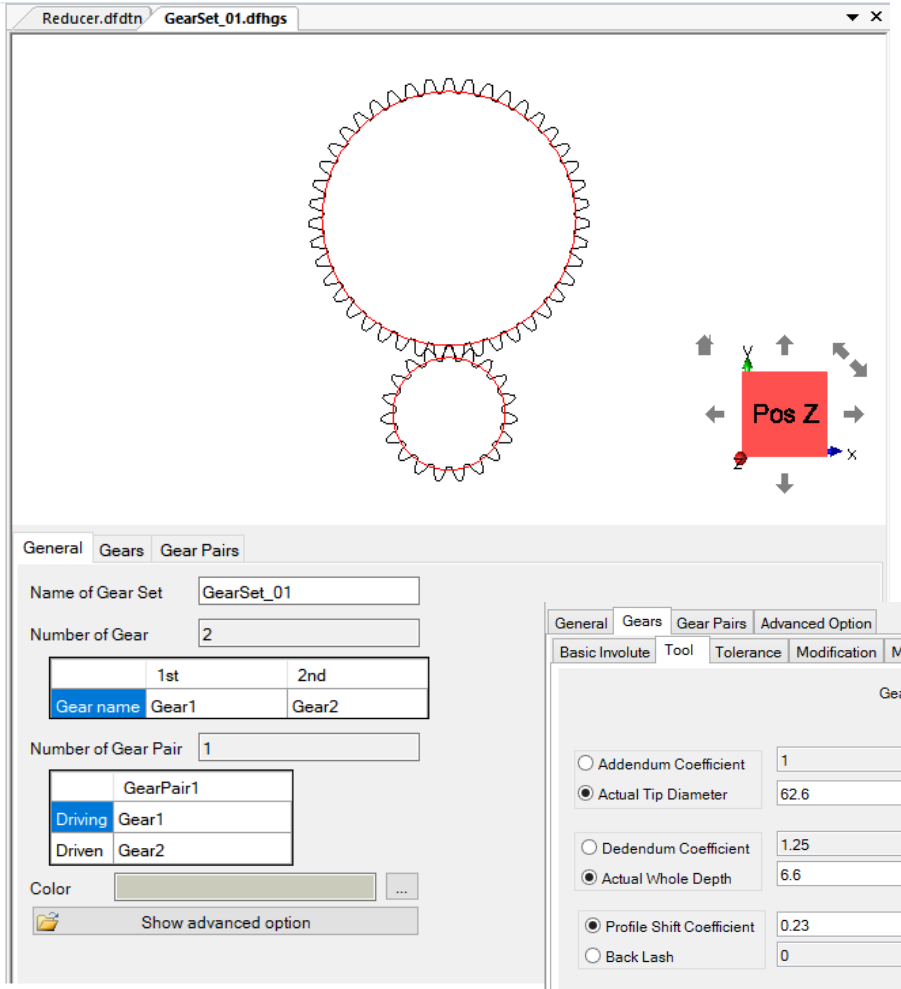
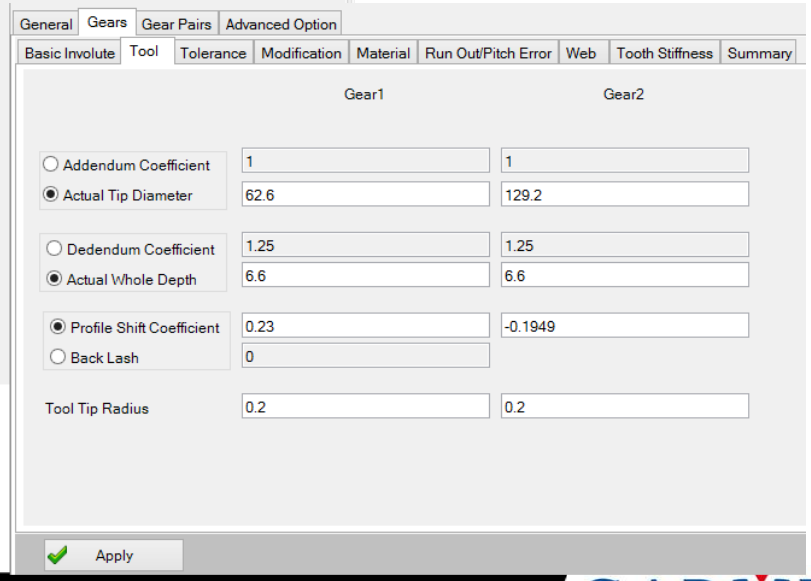
Setting gearset







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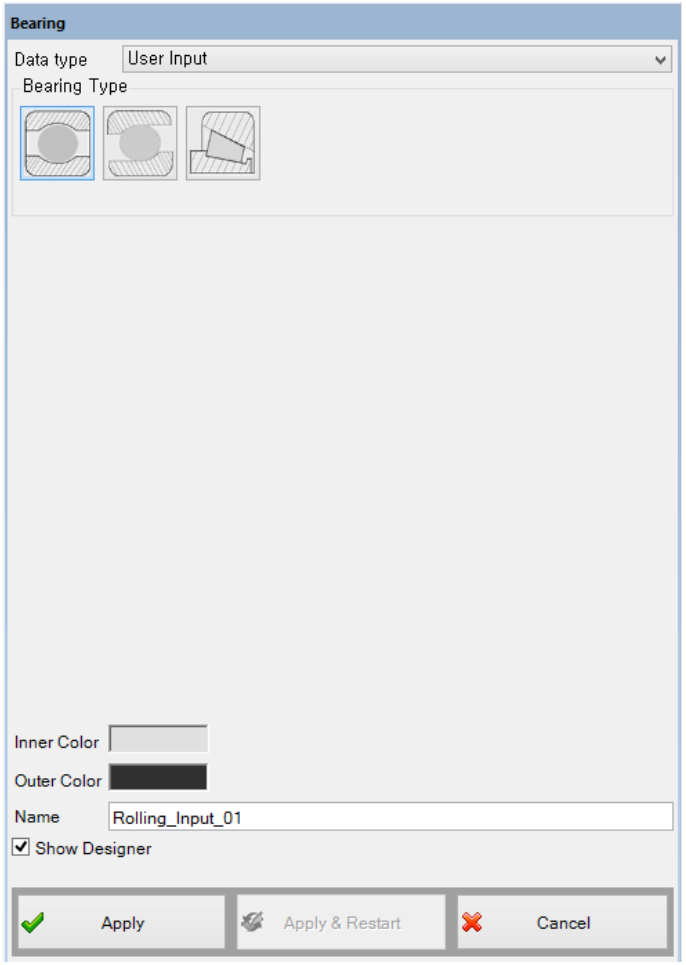
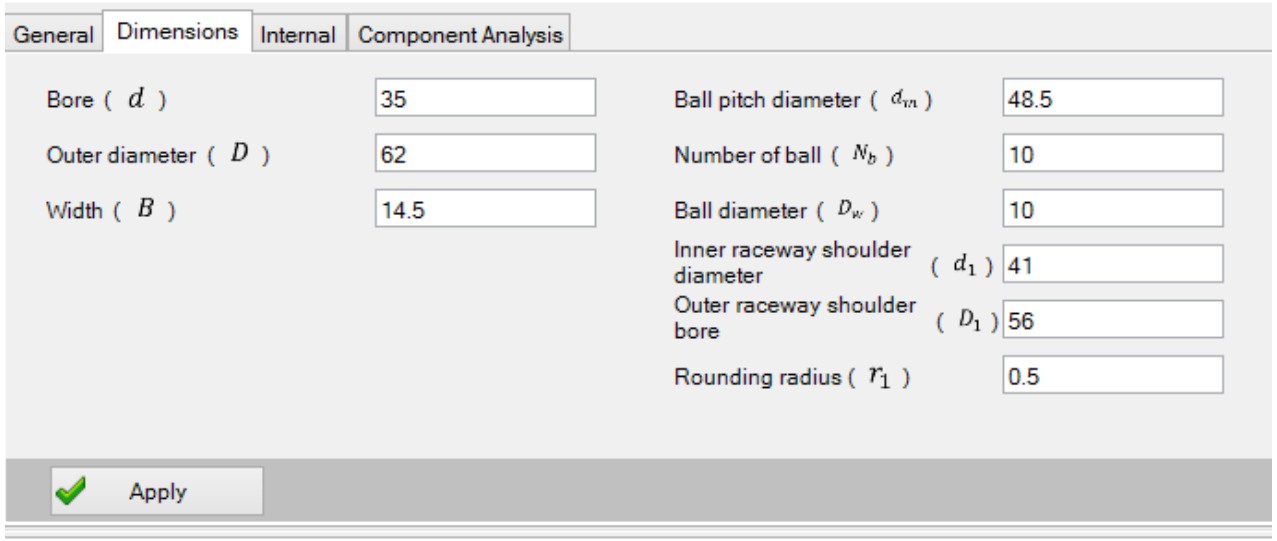
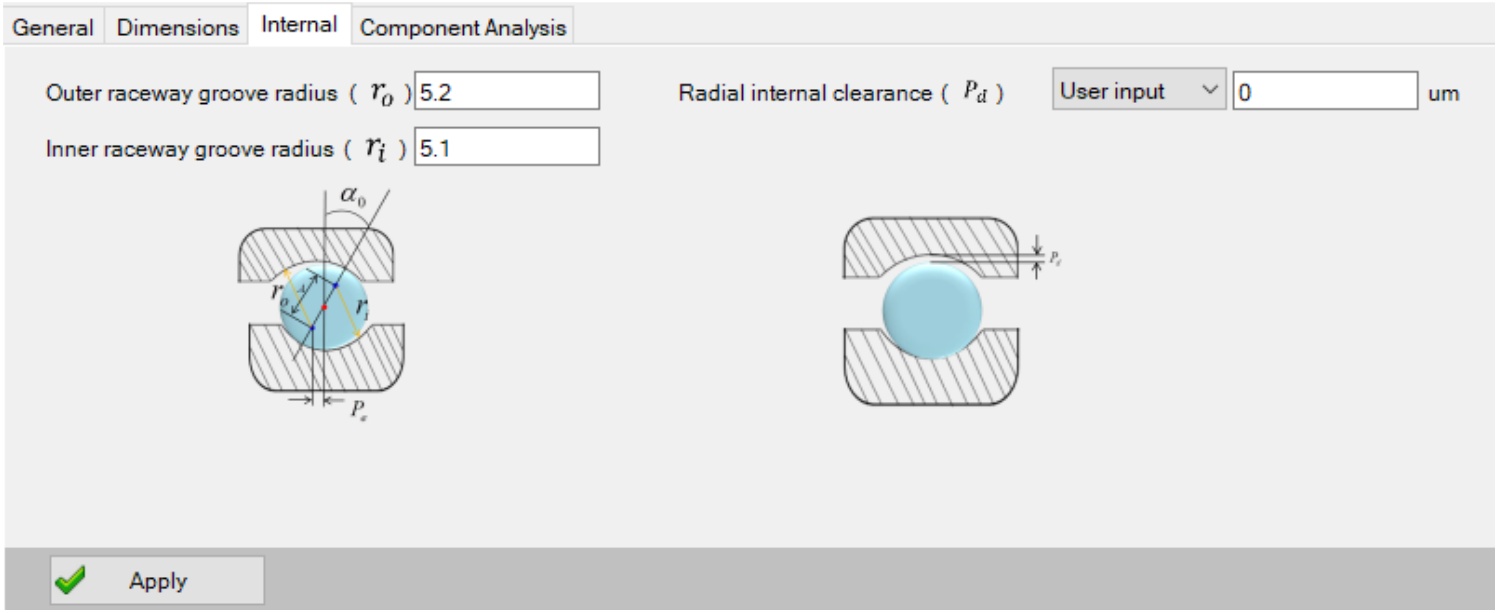
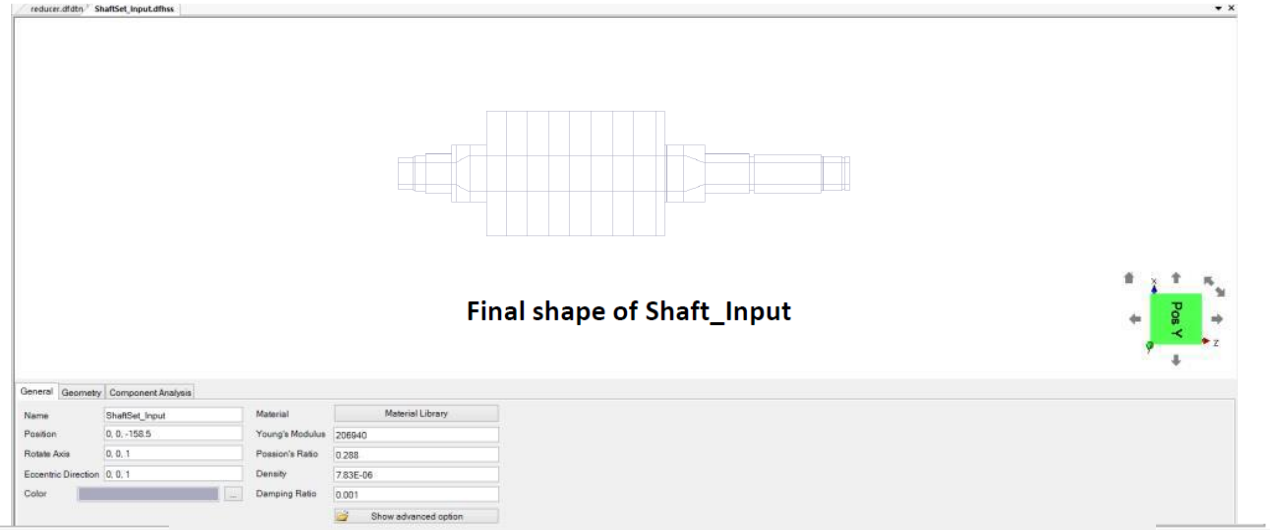
Setting rolling

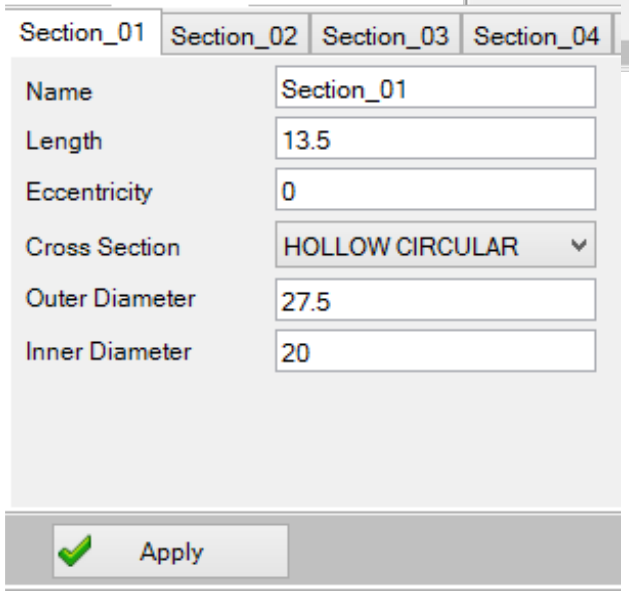


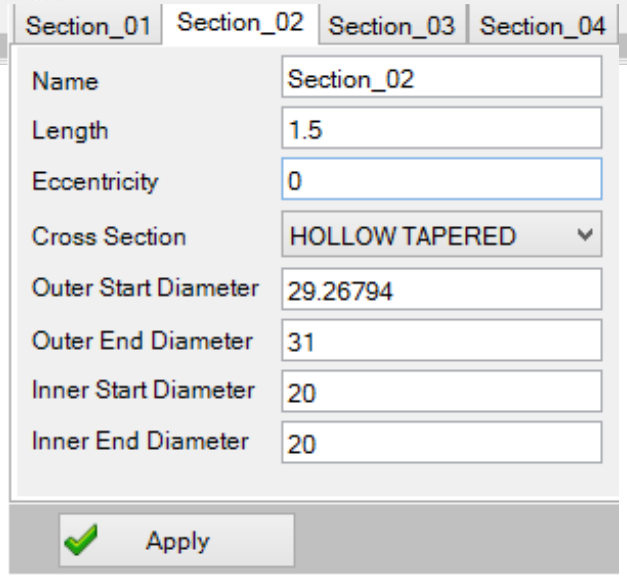


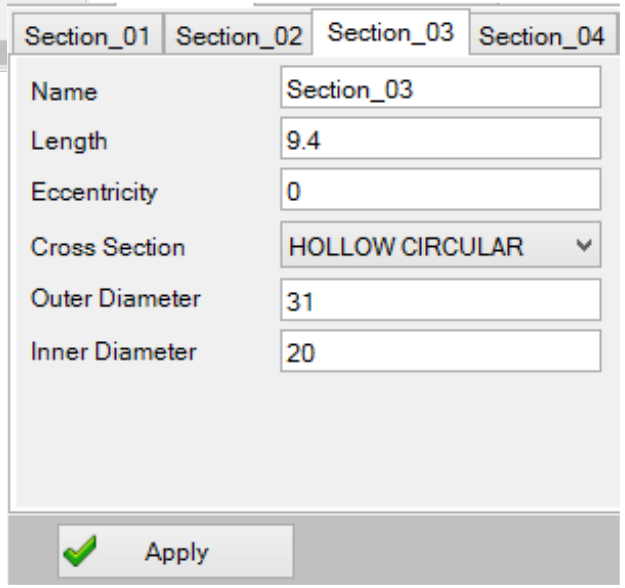


Setting shaft









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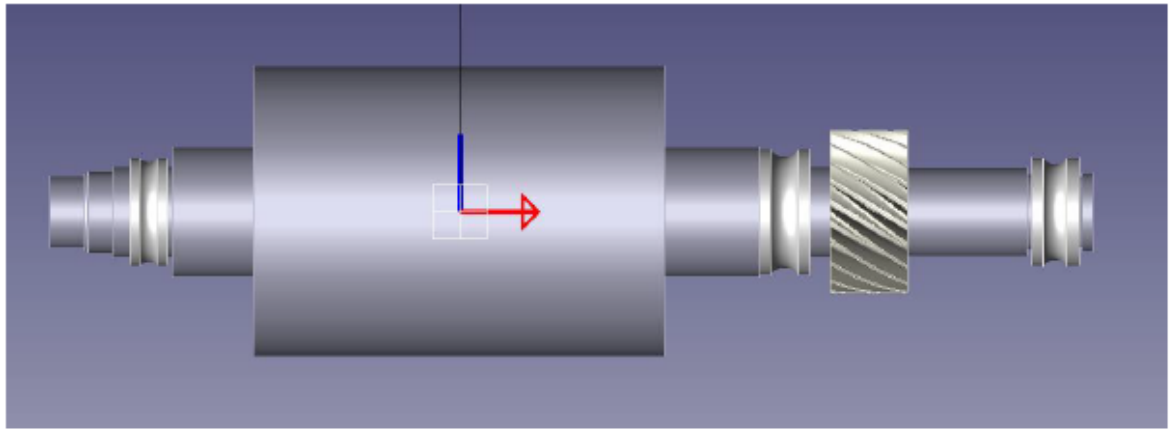
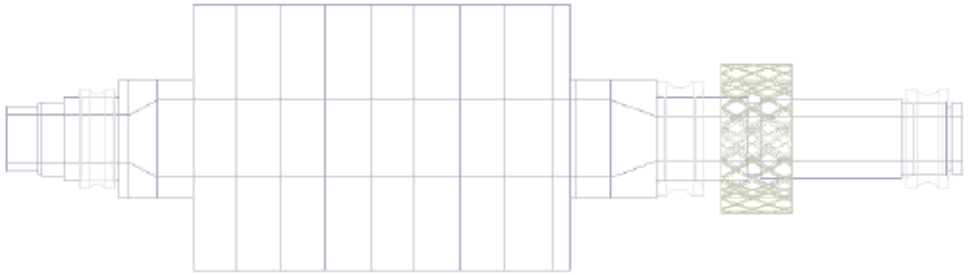
Assemble



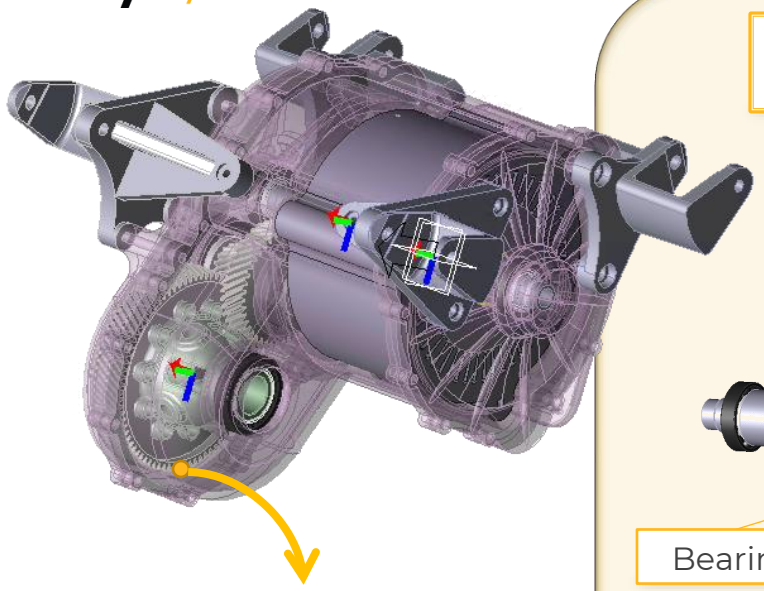
Shape in Designer



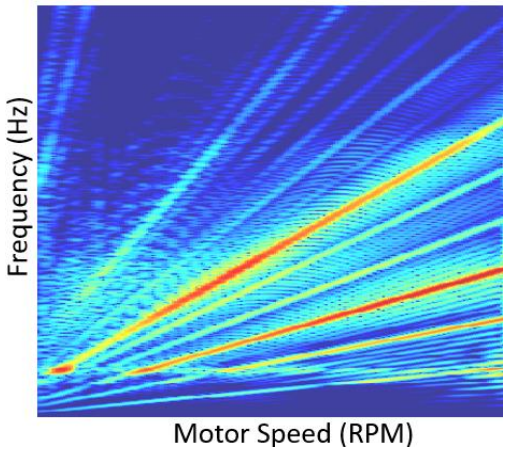
Shape in Subsystem

E-Drivetrain NVH Workflow: Multi-Body Dynamics

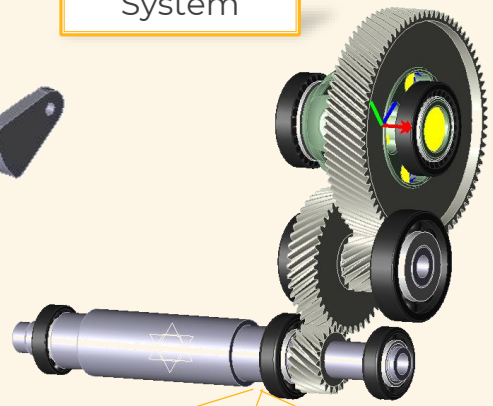
Ansys / MOTION



Acceleration



Drivetrain System



Bearing

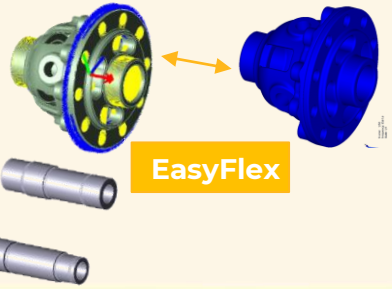
Drivetrain

Gear

Drivetrain

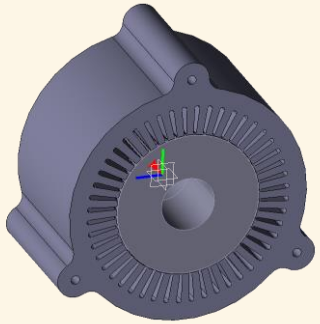
Shaft

Drivetrain



EasyFlex

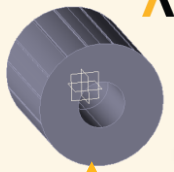
Motor

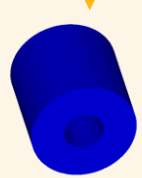


Rotor

EasyFlex

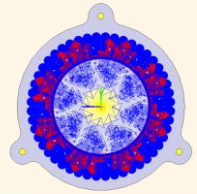
Ansys / MAXWELL





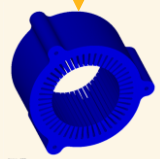
EM Force

Drivetrain

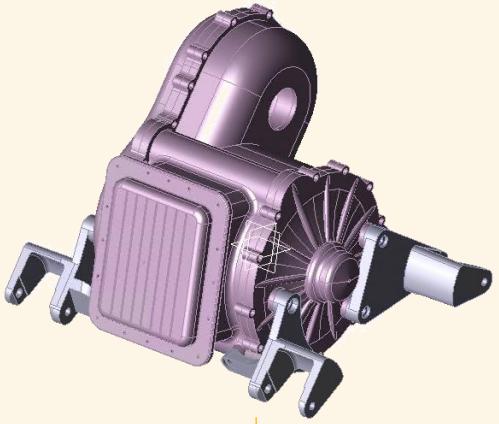


Stator

EasyFlex

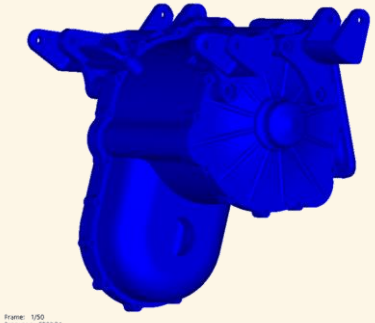


Housing



Housing

EasyFlex



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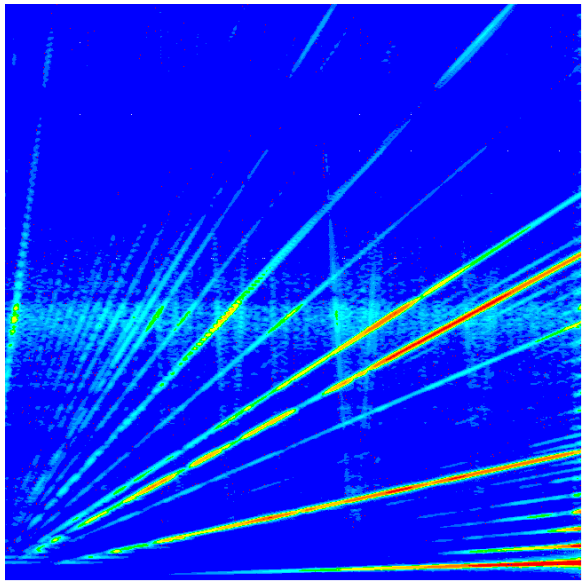
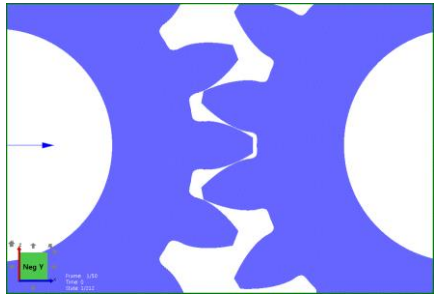
Noise Sources of E-Drivetrain

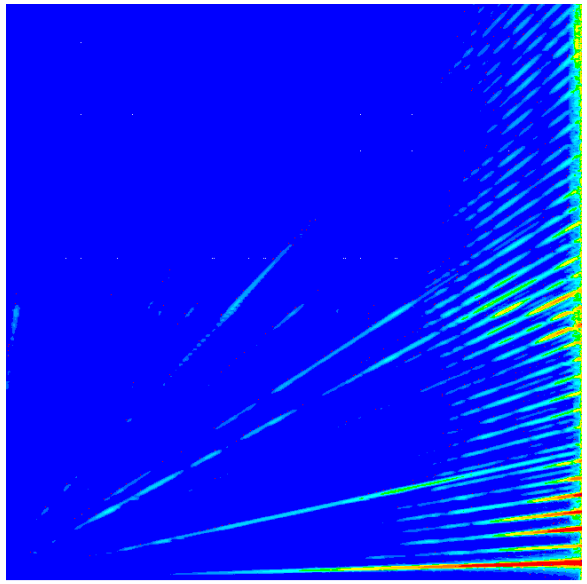
- Gear Train

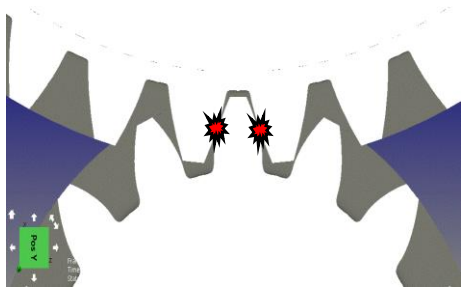
Gear whine



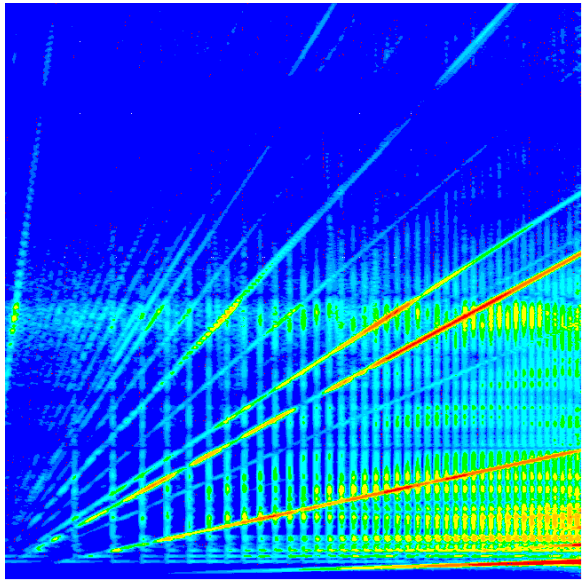


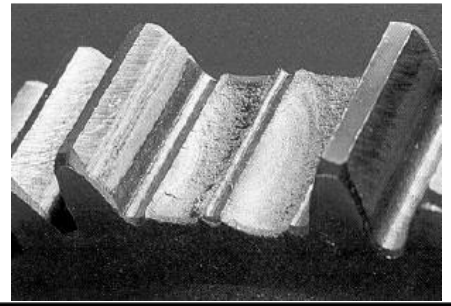
Gear rattle



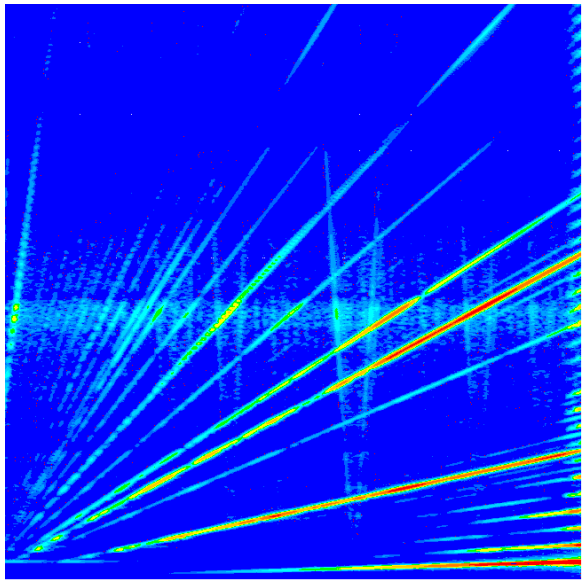


Gear fault

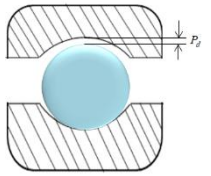




Bearing



BRG Clearance/Stiffness, Rigid housing, etc.



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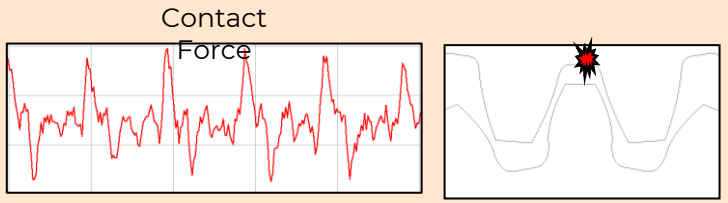
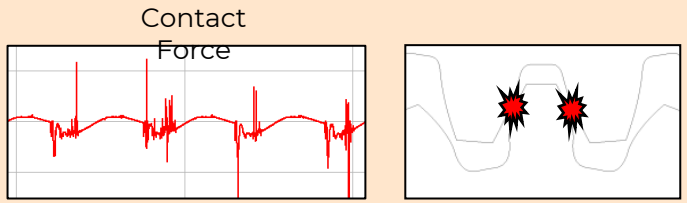
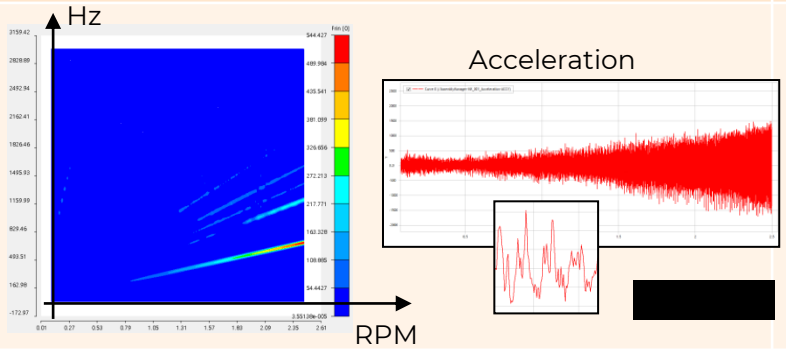
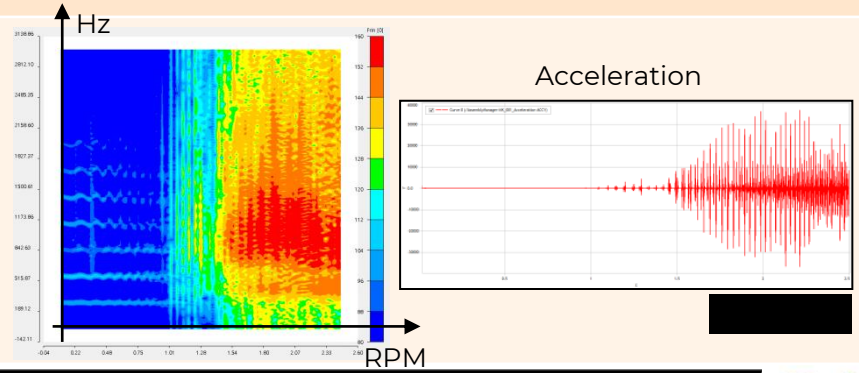
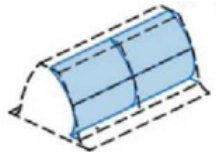
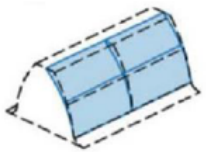
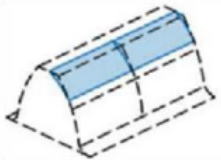
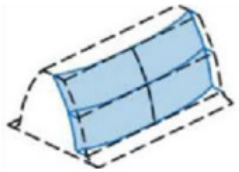
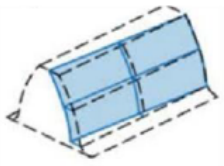
Noise Sources of E-Drivetrain: Gear Train

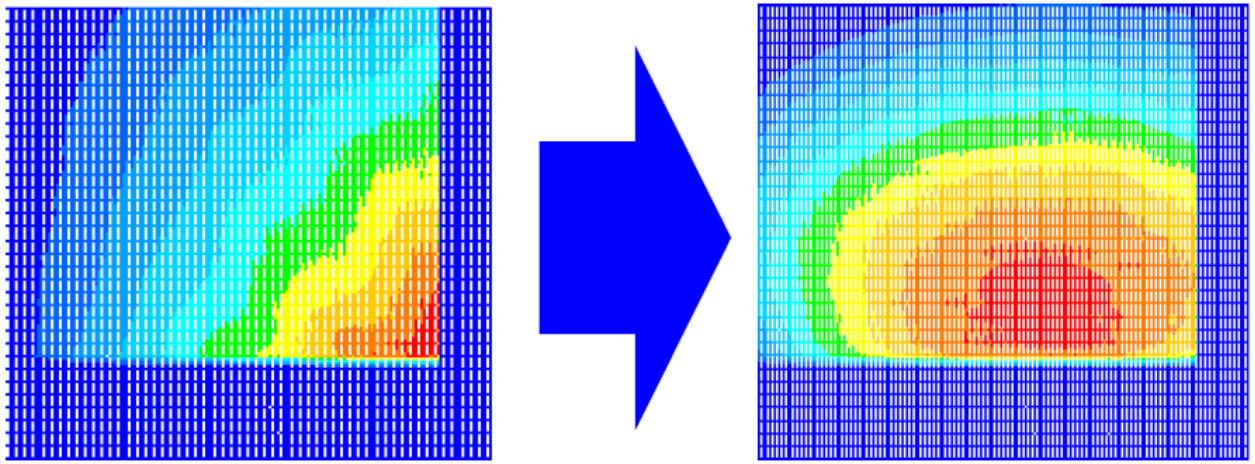
	Whine noise	Rattle noise
Causes	▪ Time-varying mesh stiffness ▪ Manufacturing error ▪ Assemble error	▪ Varying driving torque/speed ▪ Large backlash ▪ Load fluctuation
Characteristics	▪ High frequency noise. ▪ Related to the rotational speed. ▪ Harmonic components.	▪ Impulsive noise ▪ Broad-band noise
Sources	▪ Periodic excitation force due to No. of tooth ▪ Peak to Peak transmission error ▪ One side contact 	▪ Impulsive mesh force ▪ Unstable one side contact or two side contact 
Result		

Types of NVH problems(gear whine)

How can improve?

- Reduces the excitation force of the gear by improving the tooth characteristics through tooth shape correction

Profile Crown	Profile Slope	Profile Relief	Lead Crown	Lead Slope
				



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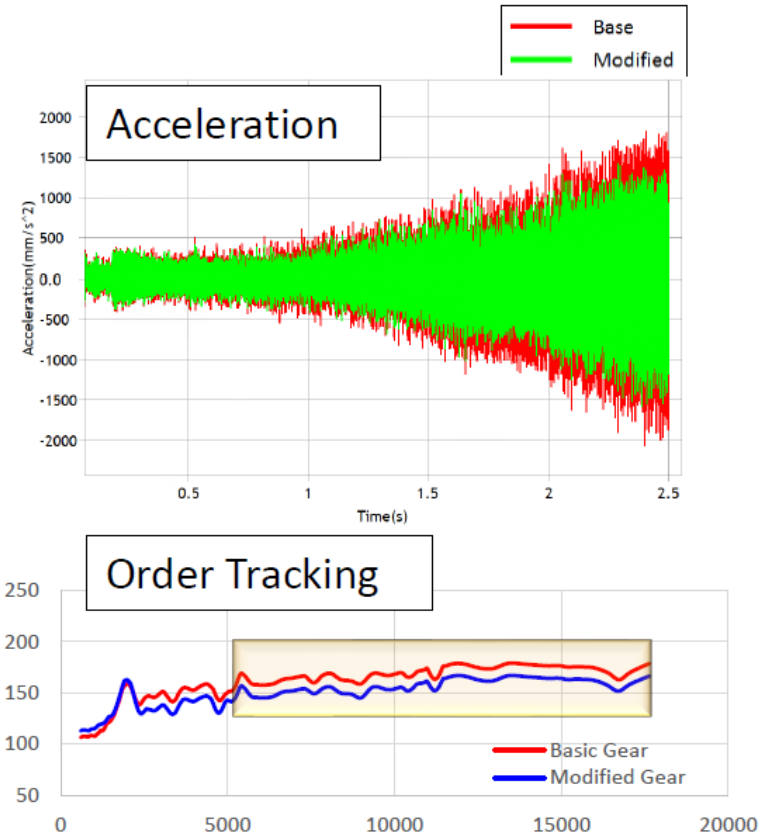
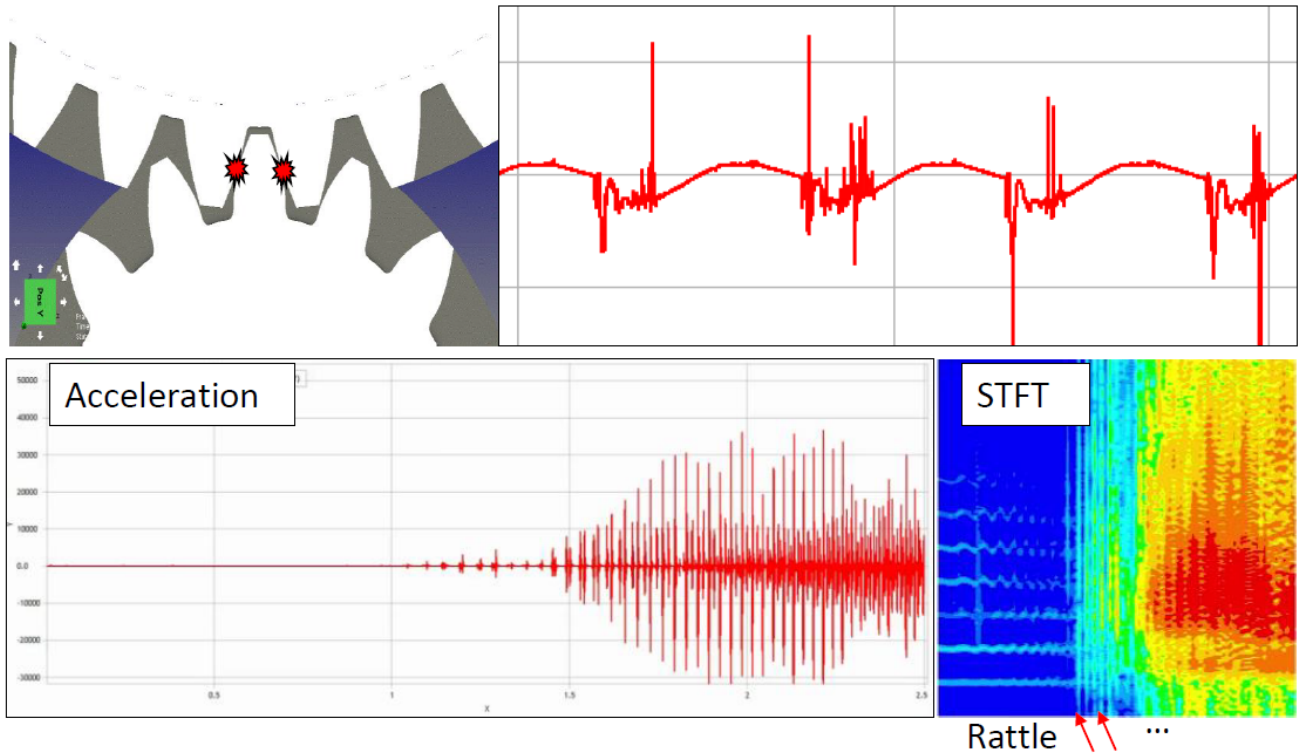
<TCP (Modified)>



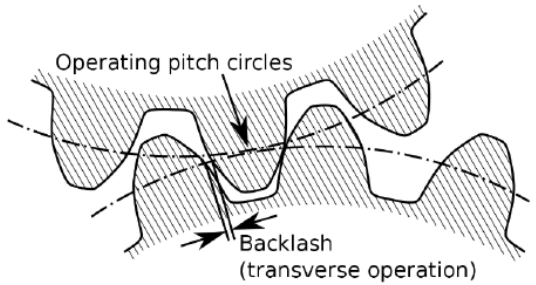
Types of NVH problems(gear rattle)

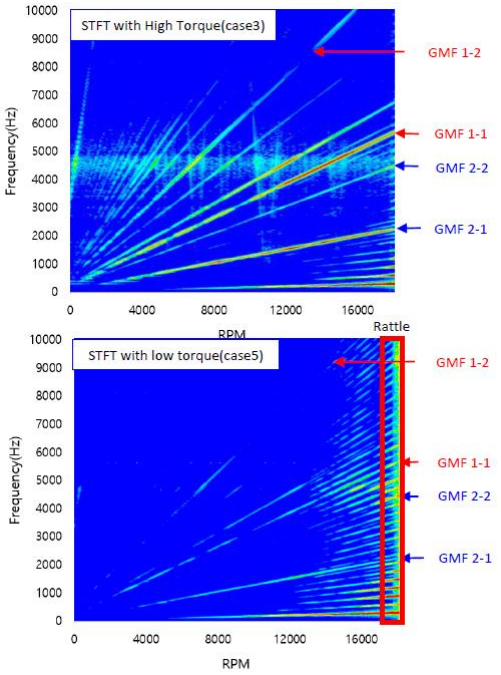
- The gear rattle noise happens in transmission system due to the torque fluctuation from the output shaft. Such a vibratory energy excitation of the gear teeth within the working clearance generates the annoying rattle noise.



How to improve?

- Increase the torque, higher than the minimum required torque
- reduce the backlash of gear (use anti-backlash gear)





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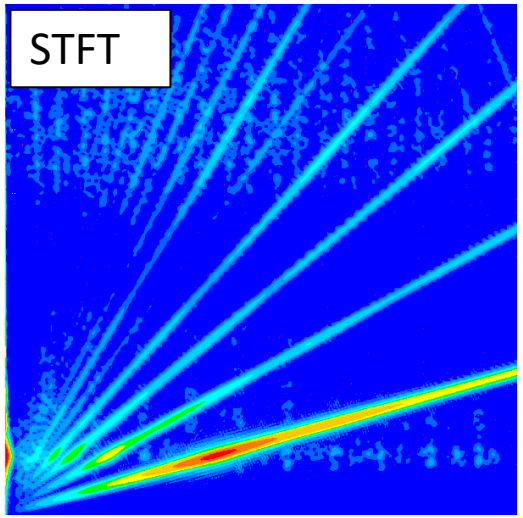
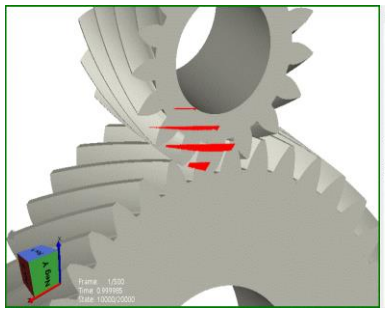
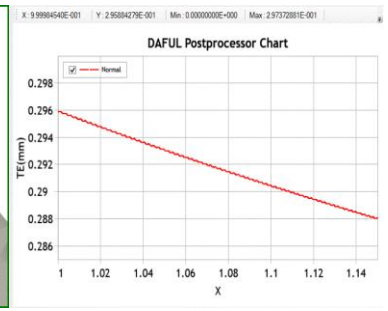
Types of NVH problems(gear fault)

- Gear Fault

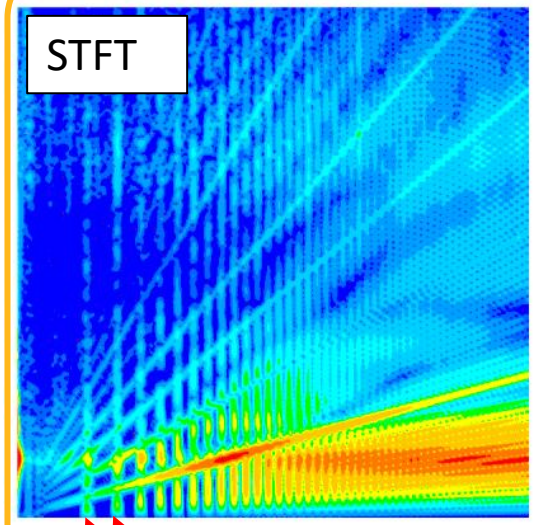
Without gear fault





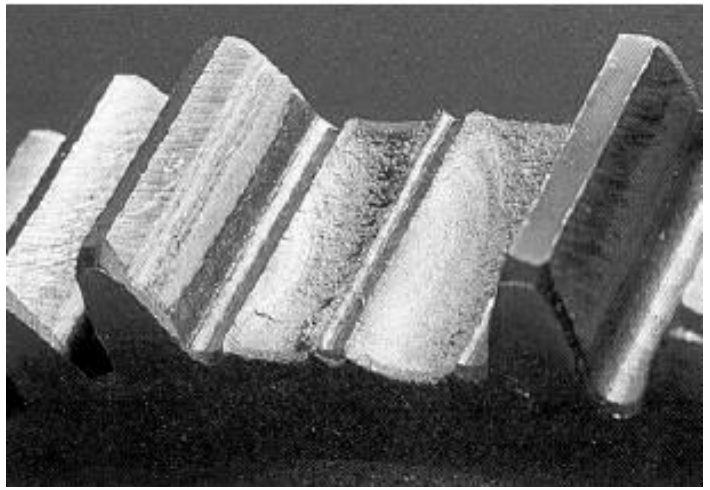


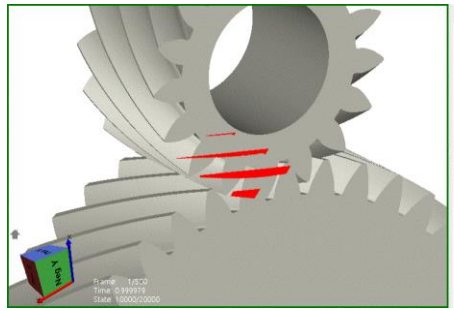
With gear fault

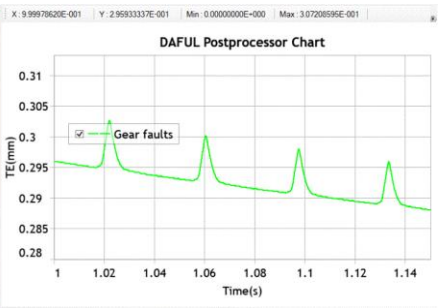


...

Rattle







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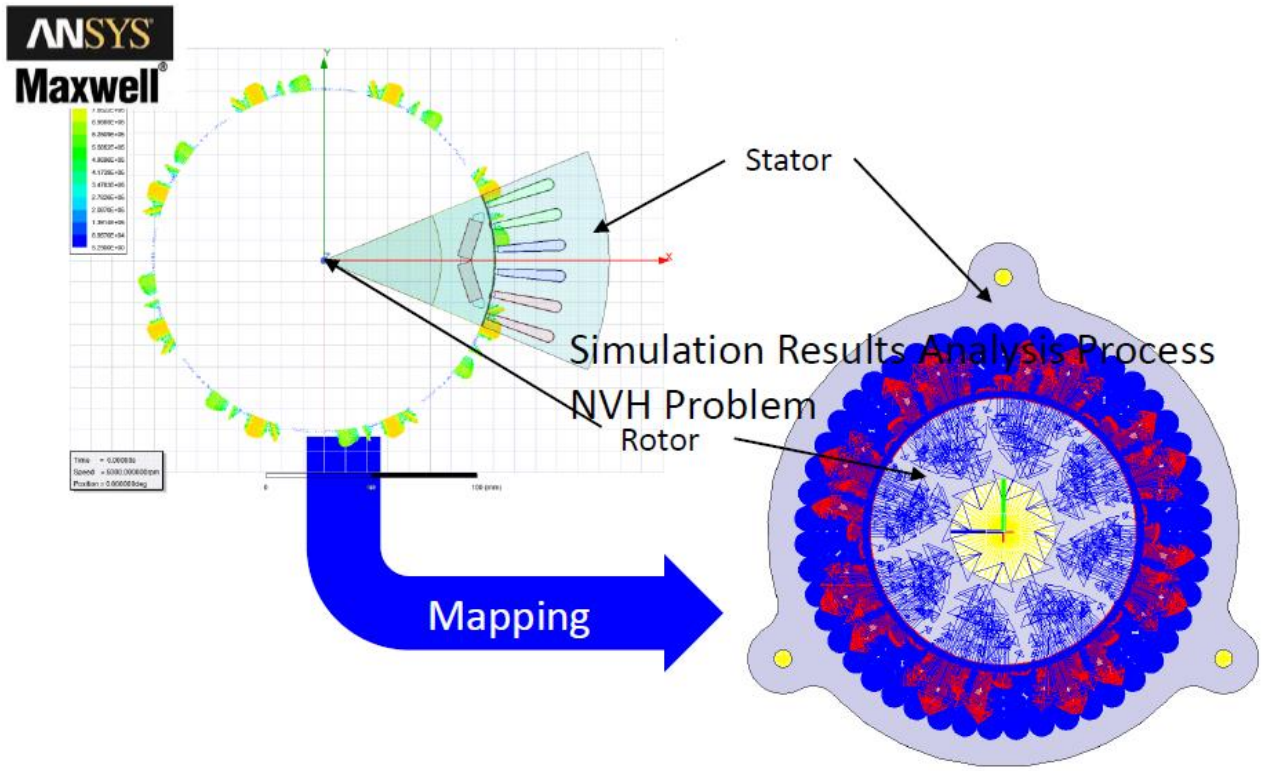
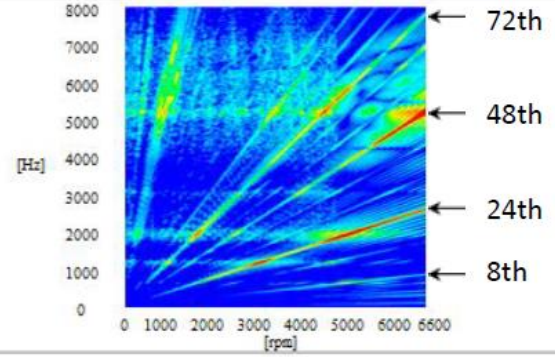
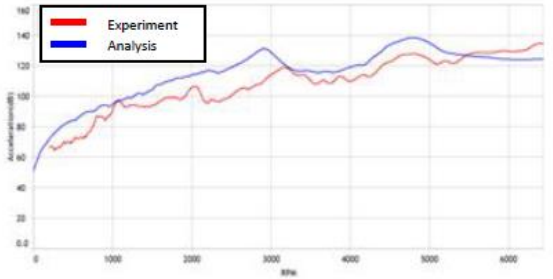
Types of NVH problems(EM force)

- Additional excitation force coming from electromagnetic force needs to be considered as it can cause system resonance.



	Results
STFT	
	24th
Order Tracking	

How can improve?

- Design plan to reduce electromagnetic excitation (Skew condition, etc.)
- System mode change to avoid problem areas

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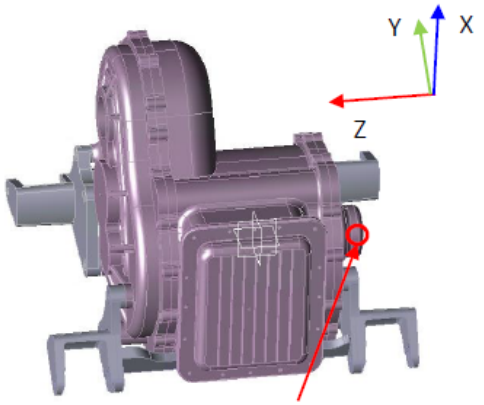
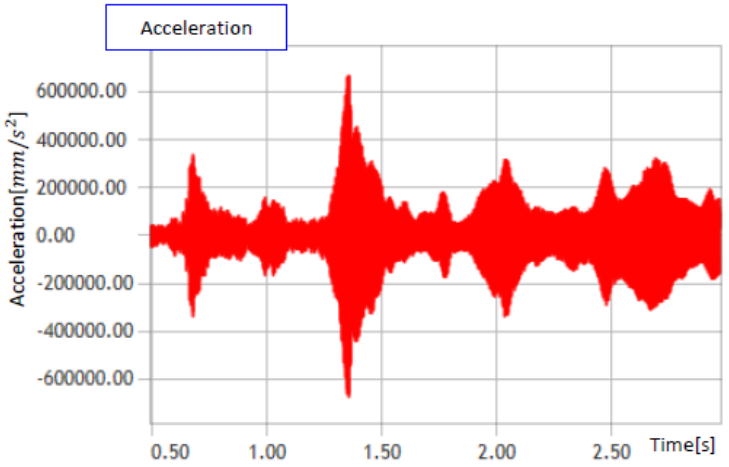
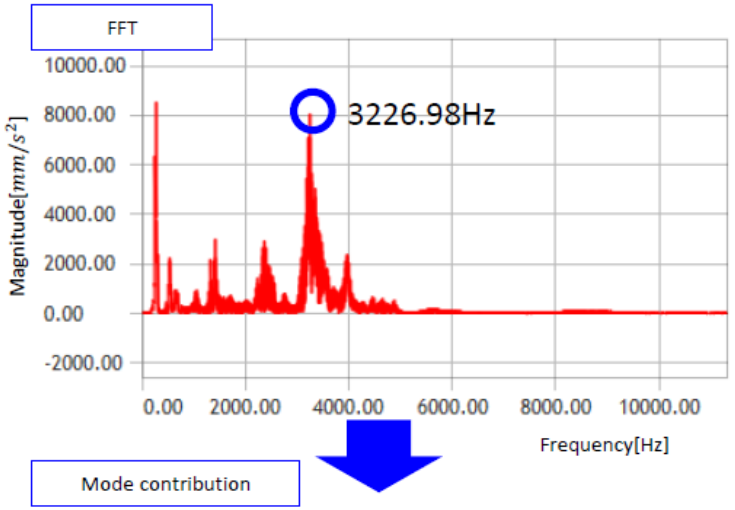
Types of NVH problems(EM force)

- To improve NVH performance, check the deformation mode at the resonant frequency and find the part that needs reinforcement.



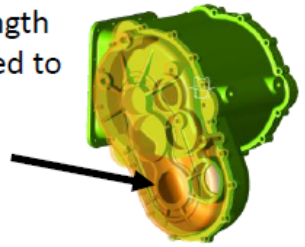
Sensing Point
→ Measure the X-axis acceleration

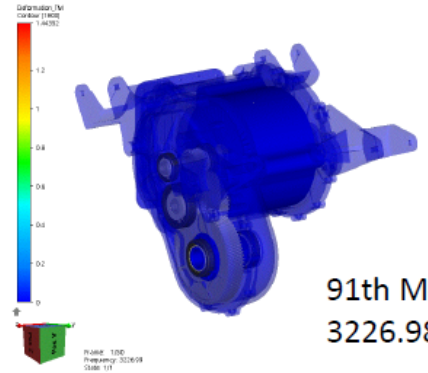




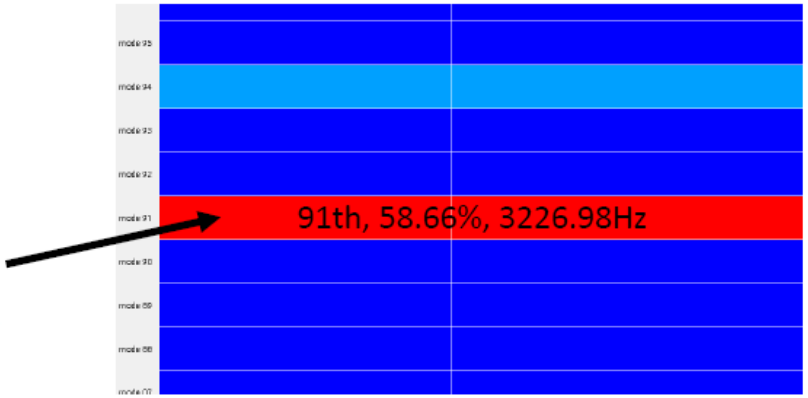
How to improve?

- Reinforcement of the structural strength of the housing (mode 91th) is required to reduce noise.





91th Mode
3226.98Hz



Mode check affecting resonance frequency(3226.98Hz)

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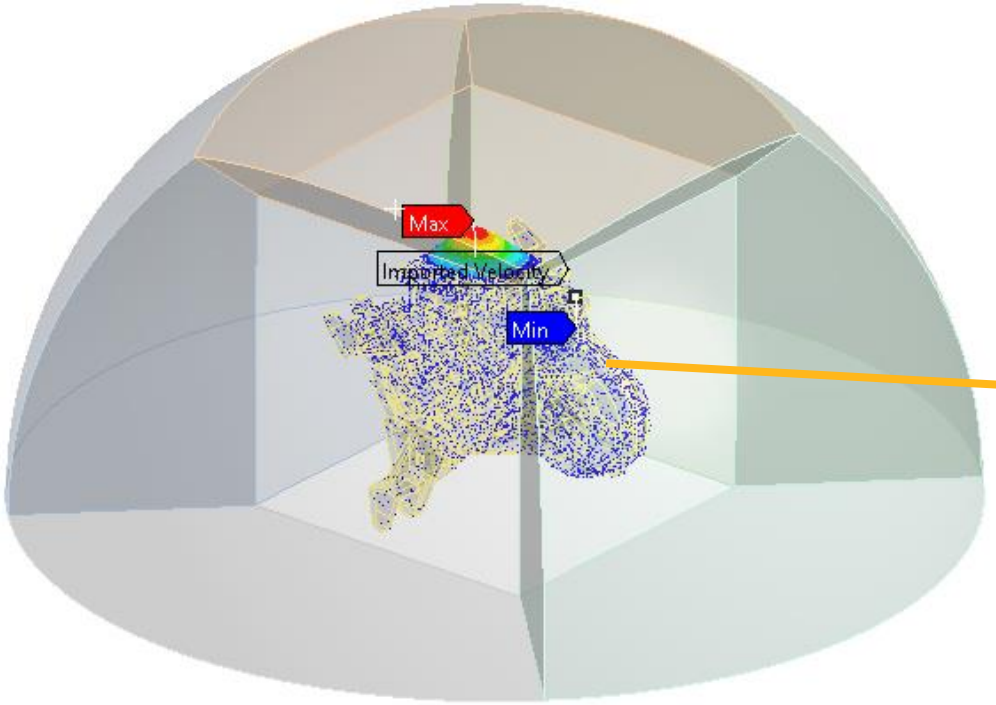
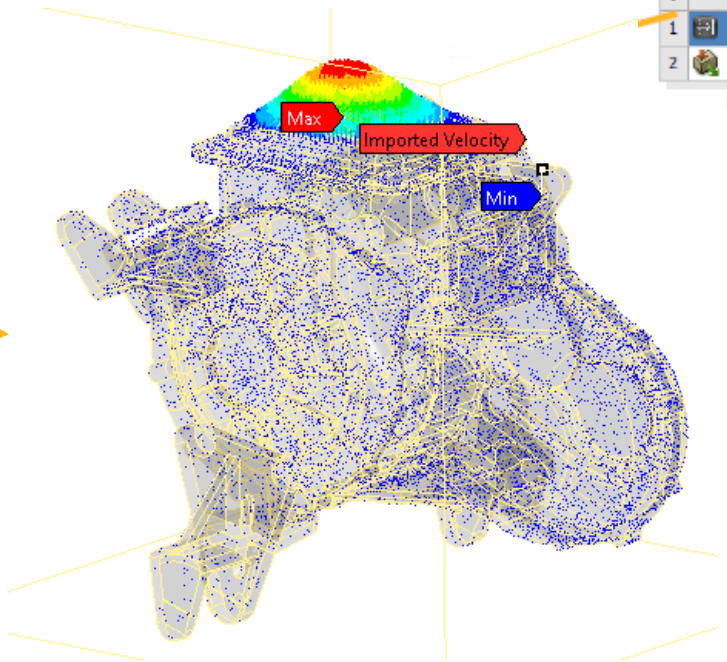
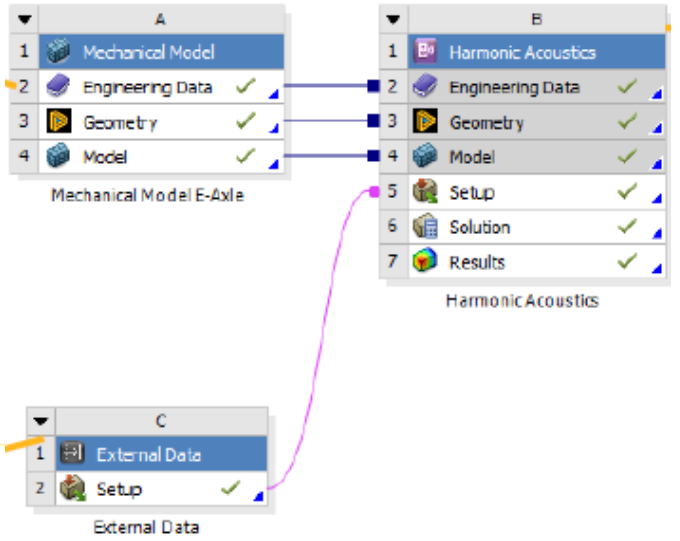
E-Drivetrain NVH Workflow: Velocity Mapping

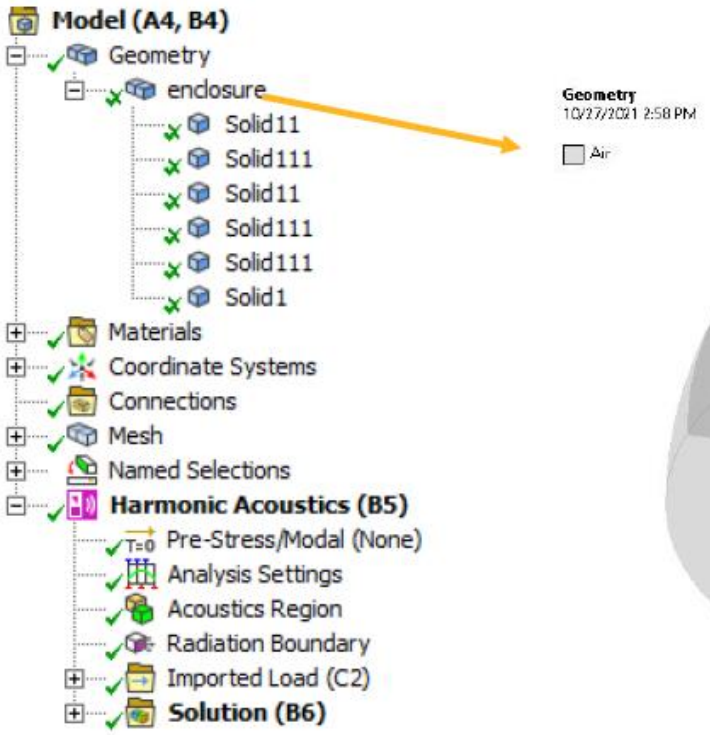
- The velocity of the outer surface of the housing is mapped to the acoustics domain
- Automatic data transfer from Ansys Motion to Ansys Mechanical in Workbench

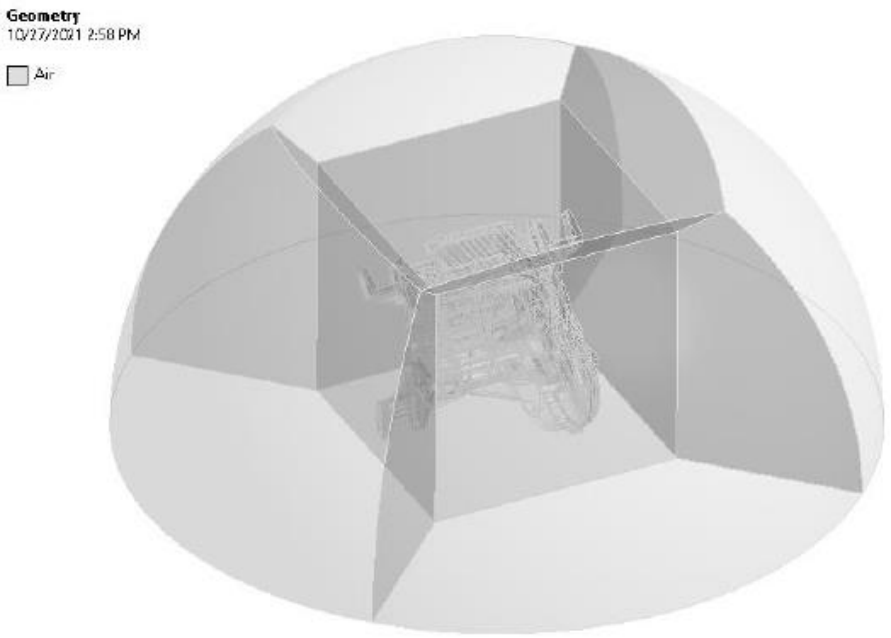






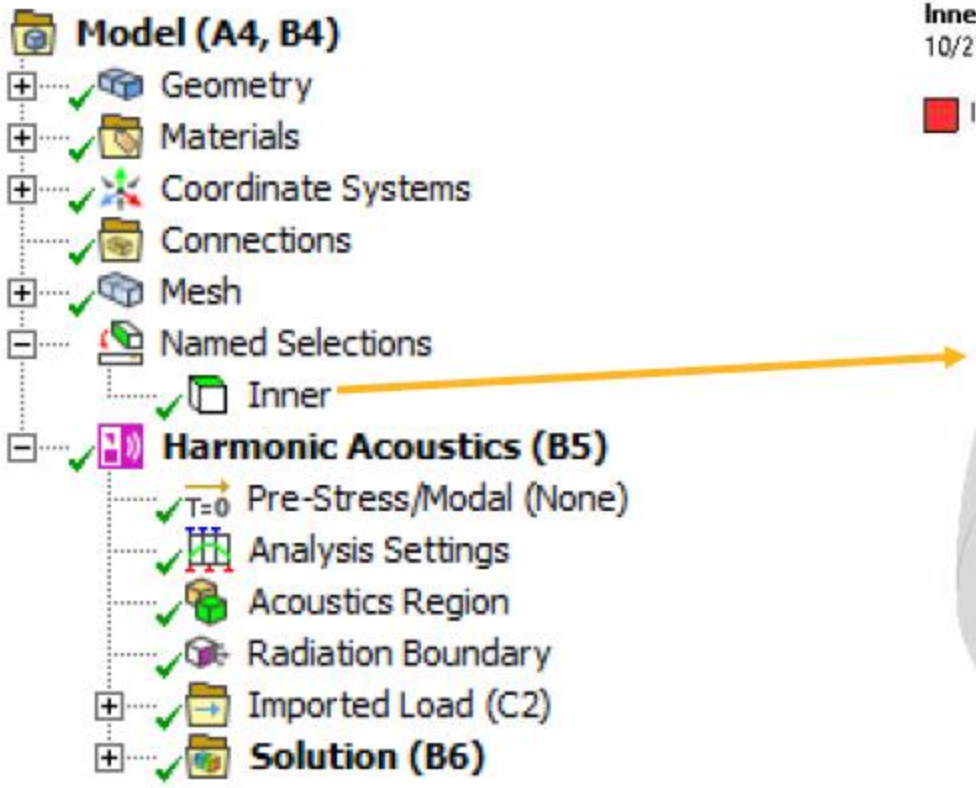
Setting enclosure

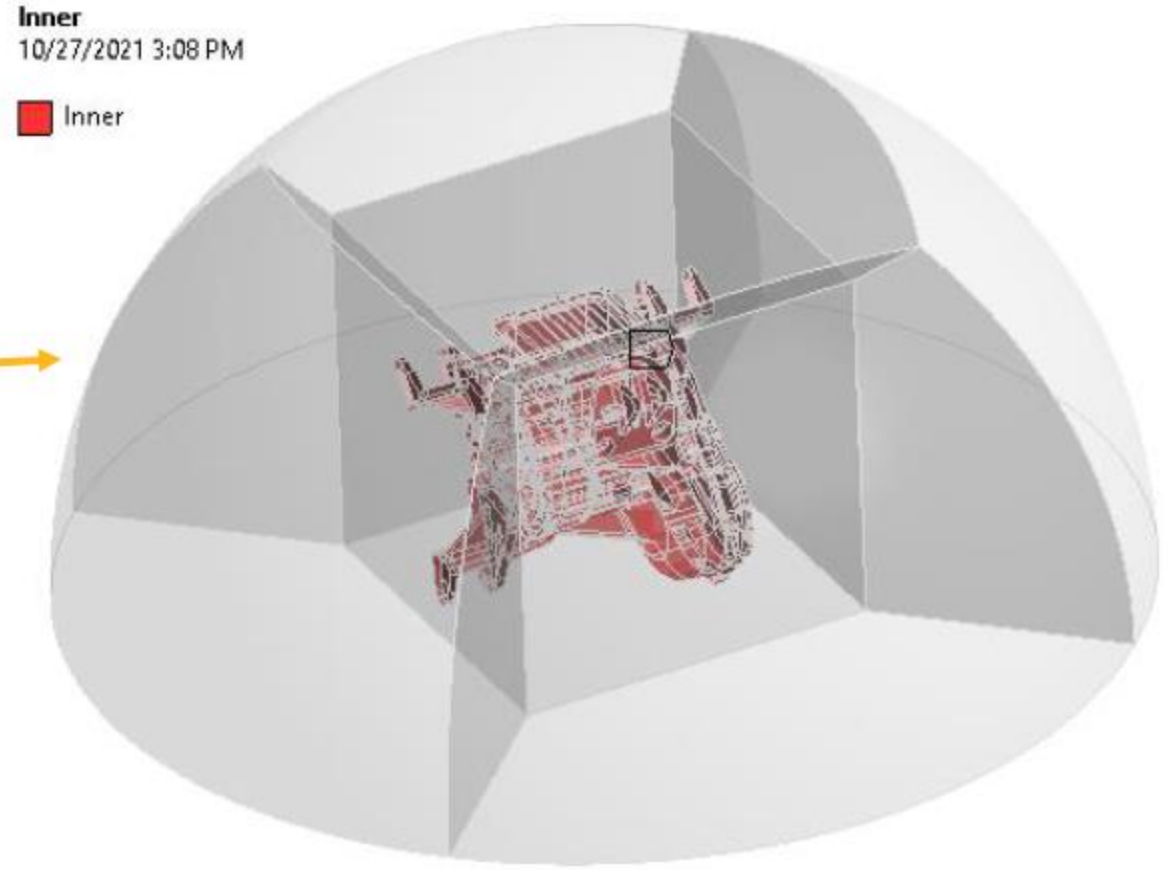




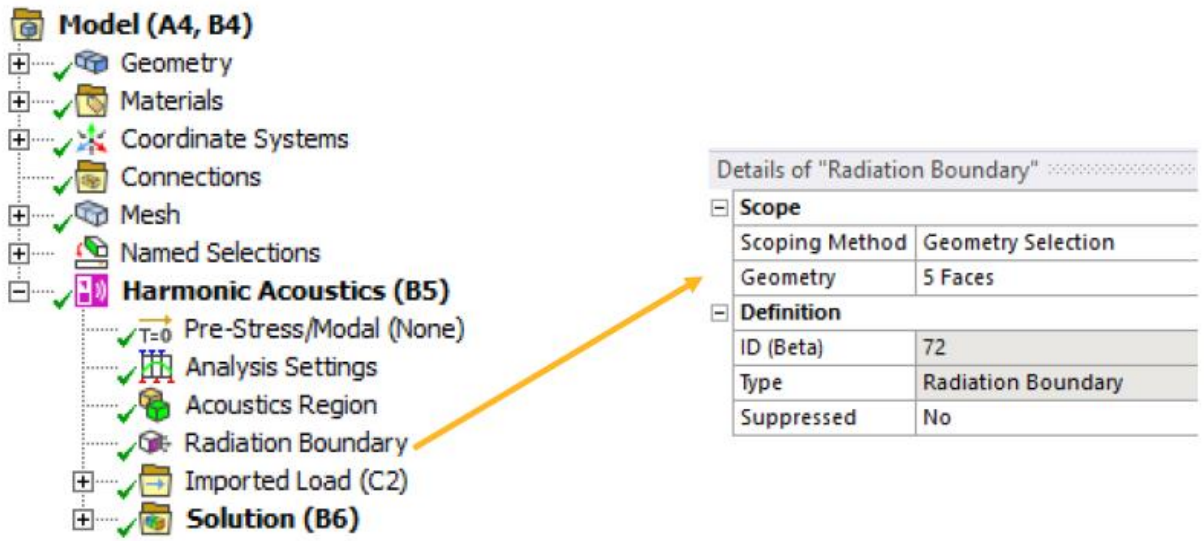
Details of "Multiple Selection"	
Graphics Properties	
Visible	Yes
Glow	0
Shininess	1
Transparency	0.2
Color	
Specularity	1
Definition	
Suppressed	No
ID (Beta)	
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Treatment	None
Material	
Assignment	Air
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Properties	
Statistics	

Named selection on the interface



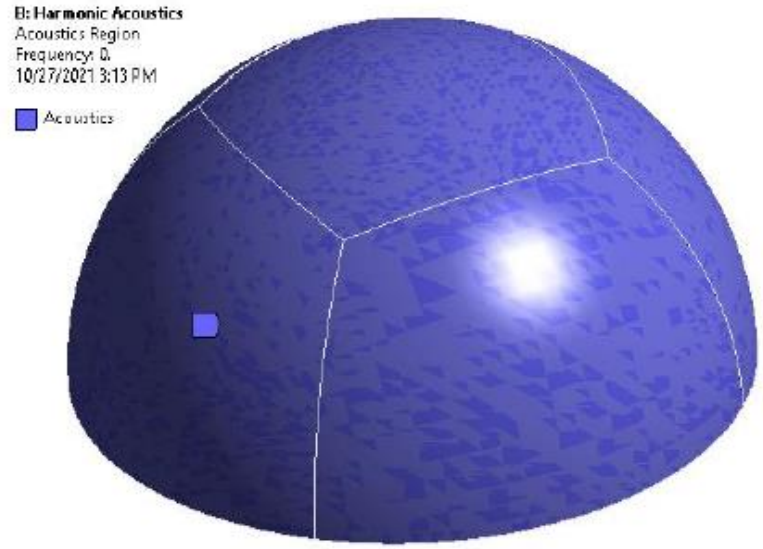


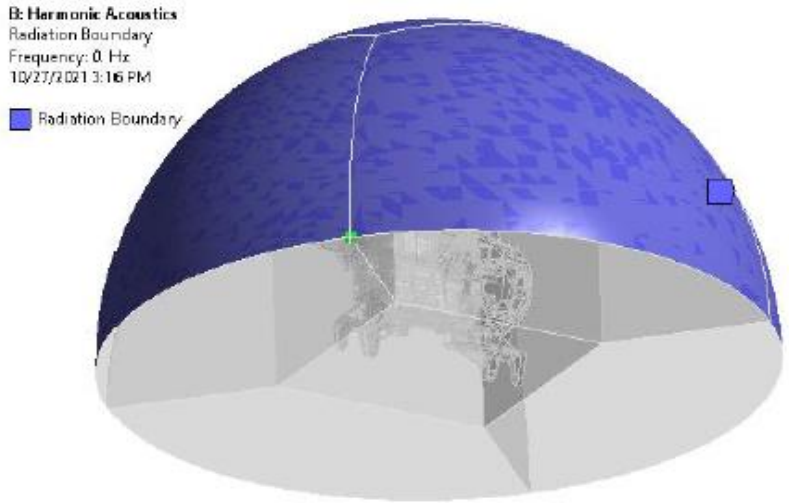
Radiation boundary



Details of "Radiation Boundary"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Faces
Definition	
ID (Beta)	72
Type	Radiation Boundary
Suppressed	No





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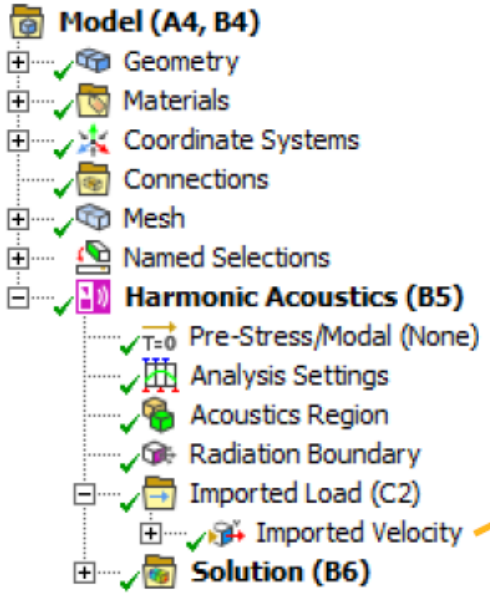
Import velocity



Details of "Imported Velocity"

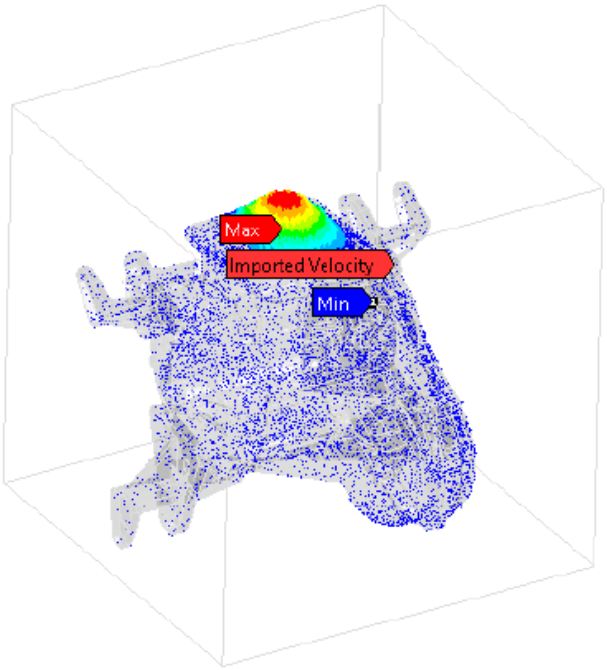
Scope	
Scoping Method	Named Selection
Named Selection	Inner
Definition	
Type	Imported Velocity
Tabular Loading	Program Controlled
Suppressed	No
Coordinate System	Source Coordinate System
Graphics Controls	
By	Active Row
Active Row	1
Complex Component	Real
Component	All
Display Source Points	Off
Display Source Point Ids	Off
Beta Options (Beta)	
Show Body Wireframe (Beta)	No
Settings	
Mapping Control	Program Controlled
Mapping	Profile Preserving
Weighting	Triangulation
Transfer Type	Surface

Imported Velocity

	X Component [Real] (mm/s)	X Component [Imag] (mm/s)	Y Component [Real] (mm/s)	Y Component [Imag] (mm/s)	Z Component [Real] (mm/s)	Z Component [Imag] (mm/s)	Analysis Frequency (Hz)
1	File1:Velocity1	File1:Velocity2	File1:Velocity3	File1:Velocity4	File1:Velocity5	File1:Velocity6	1000
2	File2:Velocity1	File2:Velocity2	File2:Velocity3	File2:Velocity4	File2:Velocity5	File2:Velocity6	1500
3	File3:Velocity1	File3:Velocity2	File3:Velocity3	File3:Velocity4	File3:Velocity5	File3:Velocity6	2000
4	File4:Velocity1	File4:Velocity2	File4:Velocity3	File4:Velocity4	File4:Velocity5	File4:Velocity6	2500
5	File5:Velocity1	File5:Velocity2	File5:Velocity3	File5:Velocity4	File5:Velocity5	File5:Velocity6	3000
6	File6:Velocity1	File6:Velocity2	File6:Velocity3	File6:Velocity4	File6:Velocity5	File6:Velocity6	3500
7	File7:Velocity1	File7:Velocity2	File7:Velocity3	File7:Velocity4	File7:Velocity5	File7:Velocity6	4000
8	File8:Velocity1	File8:Velocity2	File8:Velocity3	File8:Velocity4	File8:Velocity5	File8:Velocity6	4500
9	File9:Velocity1	File9:Velocity2	File9:Velocity3	File9:Velocity4	File9:Velocity5	File9:Velocity6	5000
*							

B: Harmonic Acoustics
Imported Velocity
Frequency: 1000. Hz
All
Complex Component: Real
Unit: mm/s
Max: 2.8635
Min: 0.00030838
10/27/2021 3:18 PM

2.8635
2.5453
2.2272
1.9091
1.591
1.2728
0.9547
0.63657
0.31844
0.00030838



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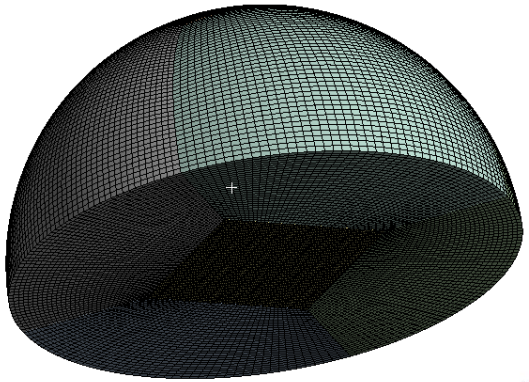
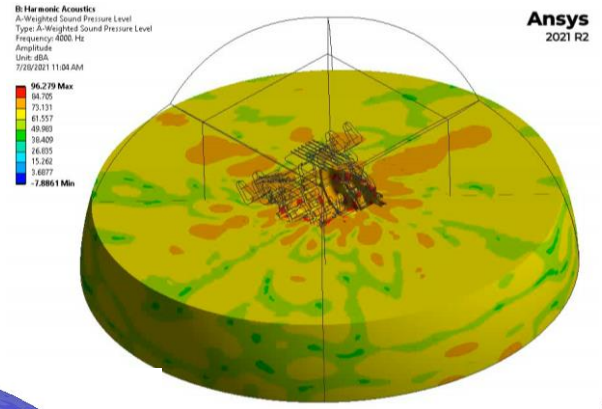
E-Drivetrain NVH Workflow: Harmonic Acoustics Analysis

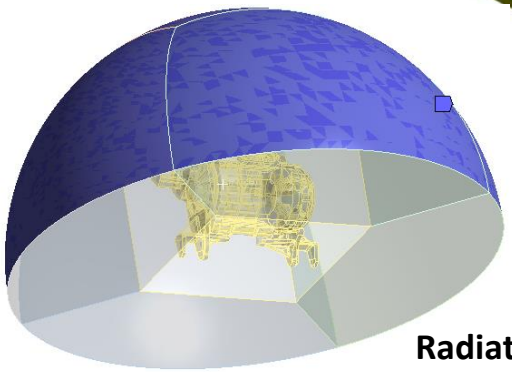
- Ansys Mechanical provides high-fidelity acoustics solver in frequency domain
- Estimation of the noise radiated from the vibrating housing of the E-drivetrain
- SPL, SWL and directivity patterns can be calculated



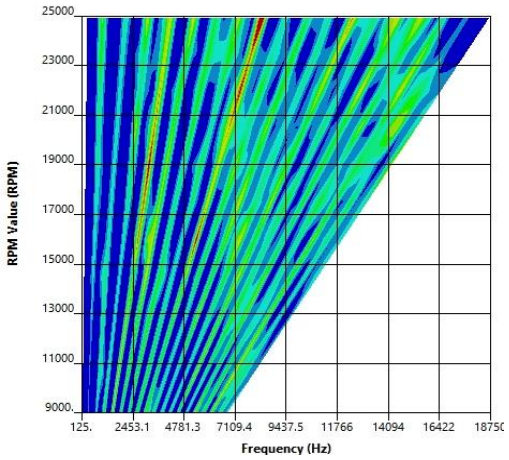
Acoustic Mesh



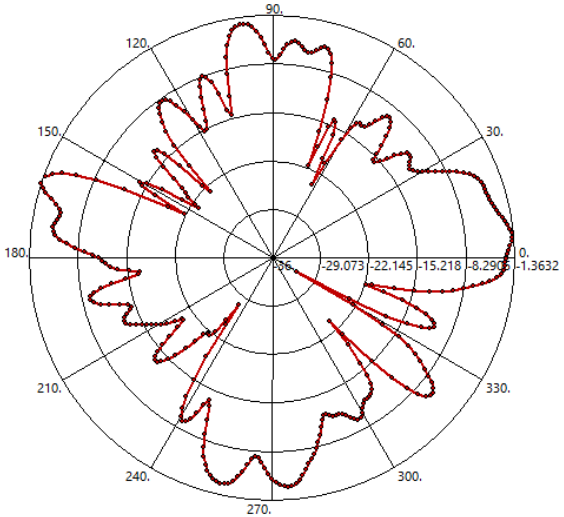
SPL



Radiation BC



SPL vs Frequency & RPM



Directivity

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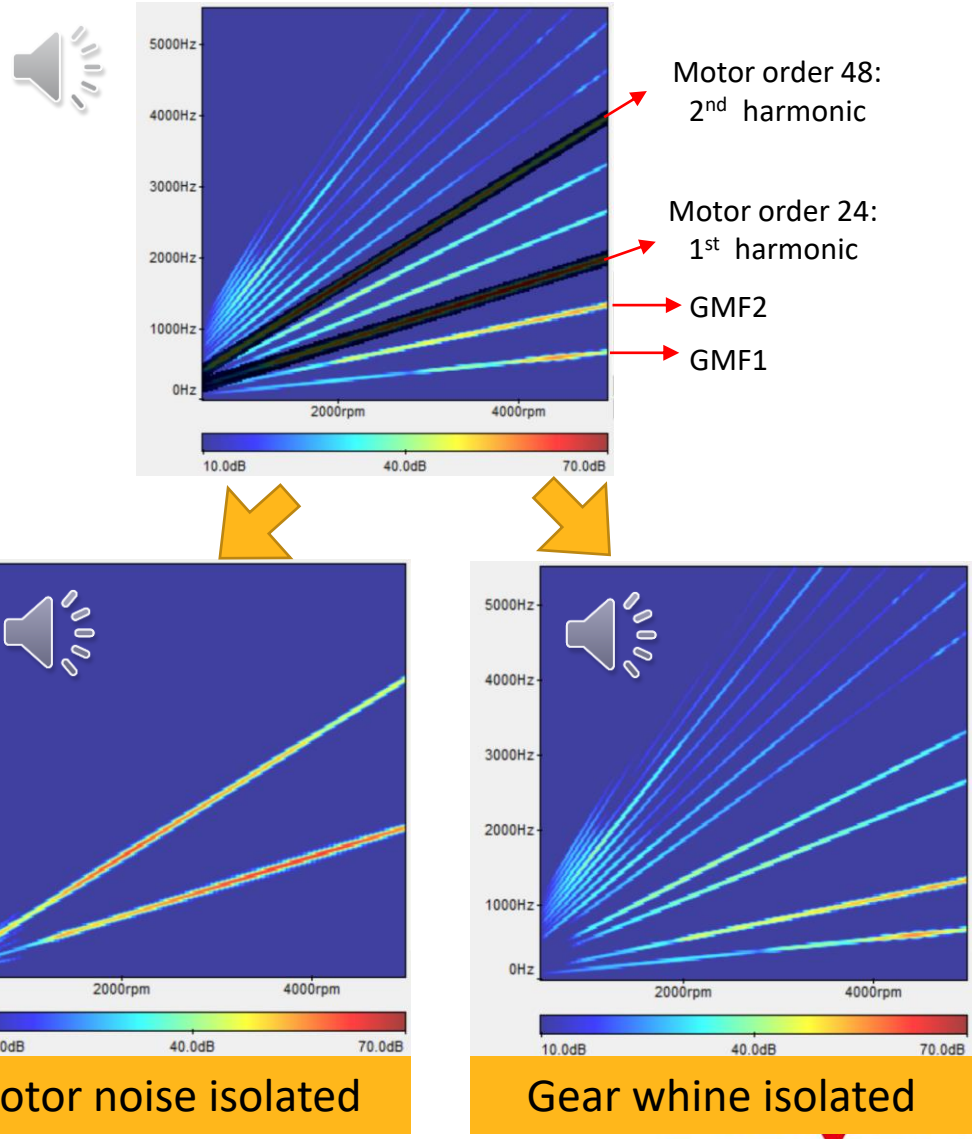
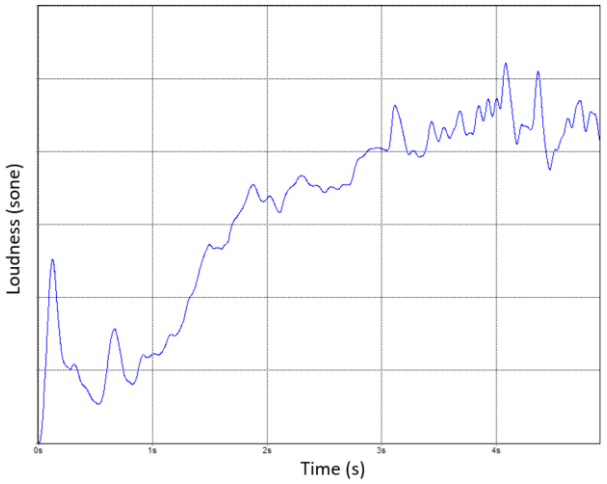
E-Drivetrain NVH Workflow: Postprocessing of Simulated Noise

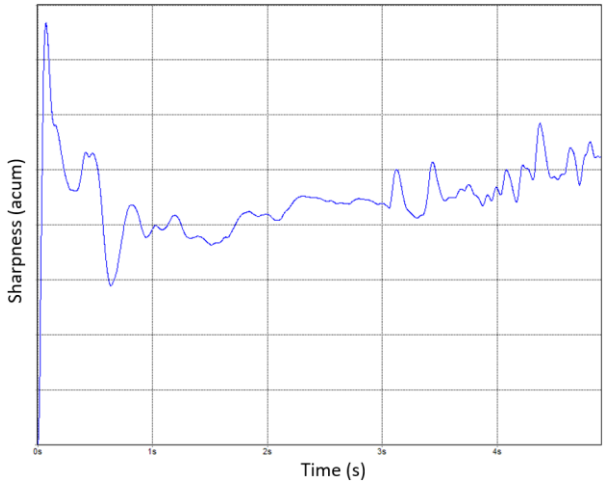
- Ansys VRX Sound enables further analysis of the simulated noise from Ansys Mechanical
  - Listen to the simulated noise
  - Order analysis
  - Psychoacoustics analysis
  - Noise isolation



Loudness



Sharpness



Summary

- The integrated, Multiphysics workflow for the E-Drivetrain NVH analysis
  - Electromagnetic simulation to calculate the EM forces of a motor
  - Multi-body dynamics simulation to calculate structural response considering the motor and gear excitation
  - Acoustics simulation to predict the noise
  - Listen to the simulated noise
  - Psychoacoustic analysis to quantify human perception of noise

- Orders related to gear mesh and motor captured accurately in vibration and noise generated from the E-Drivetrain

- Such a workflow demonstrated enables engineers;
  - To reflect motor design, gear design, selection of bearings and housing design
  - To evaluate the NVH performance of E-powertrain in early design stage
  - To expedite design iterations to reduce noise

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