



Forward. For all.

**MNOISE eMotor NVH Simulation Process –
Efficient Evaluation of an Entire Load Spectrum**

Anton Plank

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Motivation



- Support development process with reliable NVH simulation results during short development cycles
- Why to use FE approach instead of MBS?
 - Focus on harmonic content
 - Frequency domain approach enables efficient handling of loads in frequency domain
 - Process with high automation grade
- Goal and tasks
 - Capture resonance behavior and detect critical areas to derive design proposals
 - Capture excitation characteristics
 - Enable cycle times of 2 weeks

Content

01 NVH Simulation Process

02 Process Details – Post-Processing

03 Example Results

04 Correlation to Measurements



01

NVH Simulation Process

Process Overview



MNOISE Software

Multi-Body Dynamics

- Gear run-up simulation
- Evaluation of meshing forces



Pre-Processing Software

- Transform forces to frequency domain for rpm steps
- Define loading and evaluation surfaces

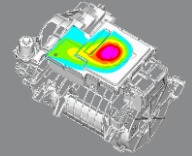


FE-modal
response

MNOISE Software

Post-Processing Software

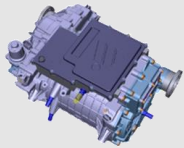
- Collect all simulation results: gear and EMAG
- Post processing:
Structure borne noise
Surface noise



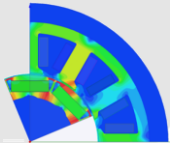
Process Overview

Pre-Processing for EMAG

FE-model



EMAG analysis



EMAG
process
input

MNOISE Software

Multi-Body Dynamics

- Gear run-up simulation
- Evaluation of meshing forces

Pre-Processing Software

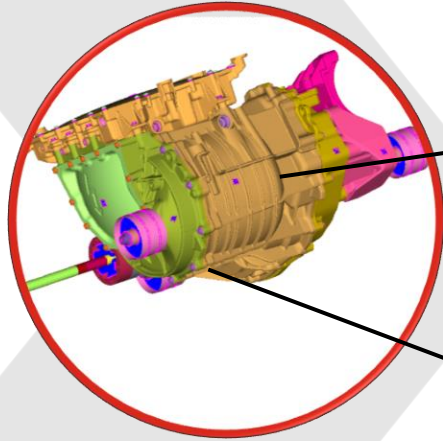
- Transform forces to frequency domain for rpm steps
- Define loading and evaluation surfaces

- Preprocessing combining finite element structural model with excitation provided by electromagnetic (EMAG) analyses
- Load distribution in airgap used as excitation mechanism
- ➔ automated model adaption, preparation and application of excitation forces

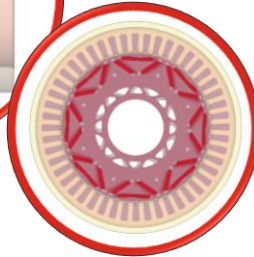
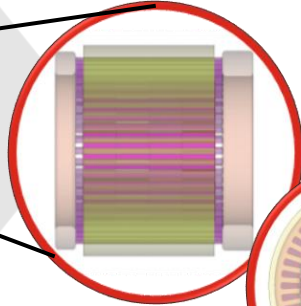
Process Details

Preparing the Structural Model

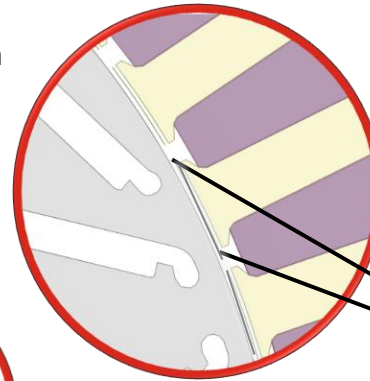
Structural system
solid model



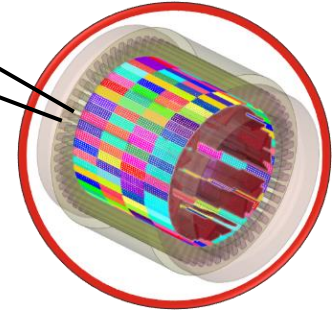
Structural motor solid model with
orthotropic material definition



Two layer of shells for load application
One layer connected to stator, and one to rotor



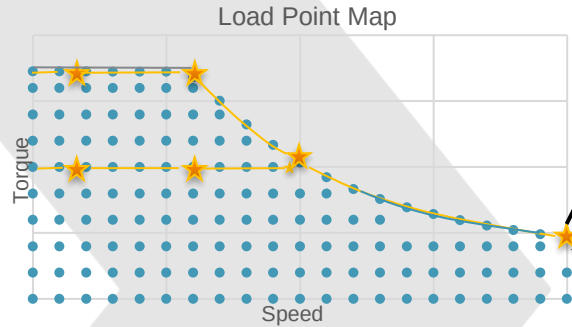
Shell element sets for force
application, created script
based



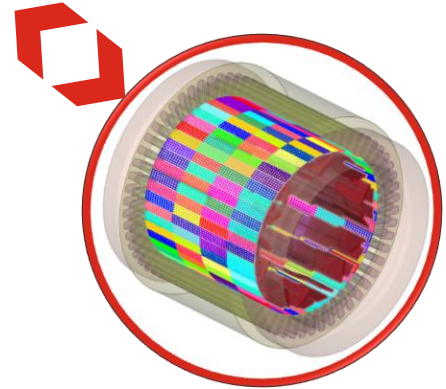
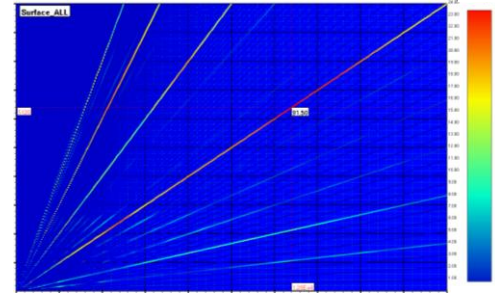
- Automated generation of elements and set for airgap force application using ANSA scripting
- Referring excitations generated based on EMAG data

Process Details

Processing Airgap Loads



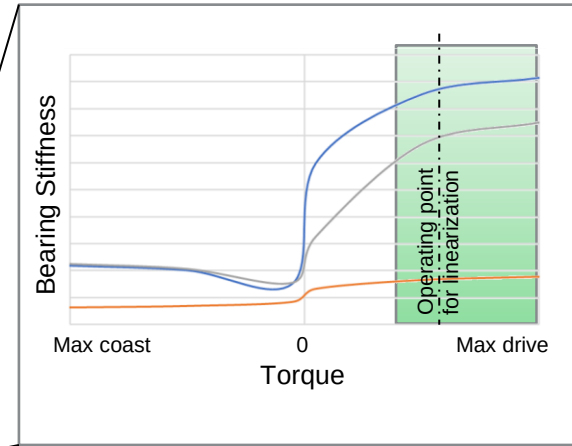
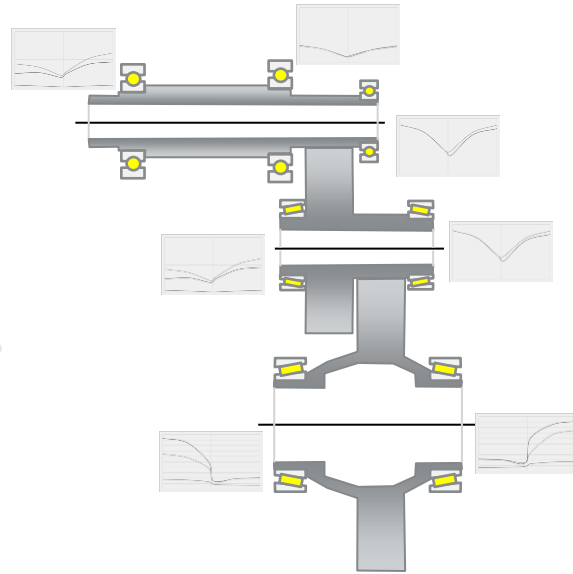
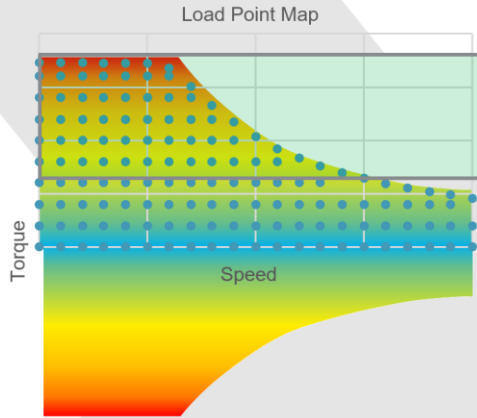
- ★ Minimum input data set
- Detailed load spectrum input data set



- Airgap forces provided for suitable amount of interpolation points (4-10)
- Standardized Excel exchange format and script control file used
- Scripted setup of excitation tables for frequency response analysis
- Interpolation in-between load points in complex domain
- Setup of excitation data in Abaqus format

Process Details

Definition of Operating Point



- Typical Load Map of eDrive system
- Nonlinear structural effects mainly torque dependent

Nonlinearities in eDrives:

- Roller bearing stiffness
- Gear contact
- Aggregate mount stiffness

- Bearing characteristics linear over wide range
- Different behavior in drive and coast due to change of load direction
- ➔ Linearization at 75% load is suitable for a wide range of the drive load spectrum
- ➔ To capture coast load cases, a separate linearization needed

Process Details

FE Simulation Definition

```

*RESTART, READ, STEP=2
**
**
** STEP 3
**
*STEP, NAME= runup_rpm_100
*STEADY STATE DYNAMICS, FREQUENCY SCALE=LINEAR, INTERVAL=RANGE
1.666667,8000.000000,4800
*RESTART, WRITE, FREQUENCY=0
**
**----load definition generated by MNOISE--
**
*include, INPUT=Excitation_0100.inp
**
*DLOAD, REAL,AMPLITUDE=AMP_TAN_RE_RPM_100_1_1, ORIENTATION=RotorCoord
stat_ex set 1 1, TRVEC, 1, 0., 1., 0.
*DLOAD, IMAGINARY,AMPLITUDE=AMP_TAN_IM_RPM_100_1_1, ORIENTATION=RotorCoord
stat_ex set 1 1, TRVEC, 1, 0., 1., 0.
*DLOAD, REAL,AMPLITUDE=AMP_NOR_RE_RPM_100_1_1
stat_ex set 1 1, P, 1
*DLOAD, IMAGINARY,AMPLITUDE=AMP_NOR_IM_RPM_100_1_1
stat_ex set 1 1, P, 1
**
*DLOAD, REAL,AMPLITUDE=AMP_TAN_RE_RPM_100_1_2, ORIENTATION=RotorCoord
stat_ex set 1 2, TRVEC, 1, 0., 1., 0.
*DLOAD, IMAGINARY,AMPLITUDE=AMP_TAN_IM_RPM_100_1_2, ORIENTATION=RotorCoord
stat_ex set 1 2, TRVEC, 1, 0., 1., 0.
**
**
*MODAL DAMPING, MODAL=DIRECT, DEFINITION=FREQUENCY RANGE
0., 0.03
8000, 0.03
**
*OUTPUT, FIELD
*NODE OUTPUT, NSET = Surface_Nodes_OUTPUT
J
*OUTPUT, HISTORY
*NODE OUTPUT, NSET=Monitoring_OUTPUT
RM,
RF,
U,
A,
V,
**
*END STEP
*STEP, NAME= runup_rpm_200
*STEADY STATE DYNAMICS, FREQUENCY SCALE=LINEAR, INTERVAL=RANGE
3.333333,8000.000000,2400

```

- Set up as restart on modal analysis and preceding static loadcase on demand

- Subcase definitions are generated by MNOISE for speed Run-up at variated loads
- One subcase per speed or order

- Include of excitation tables – real/imaginary force content along frequency

- Radial and tangential force definitions at each tooth referring excitation table

- Damping definition and output request added to the subcase



02

Process Details

Post-Processing

Process Overview



MNOISE Software

Multi-Body Dynamics

- Gear run-up simulation
- Evaluation of meshing forces



Pre-Processing Software

- Transform forces to frequency domain for rpm steps
- Define loading and evaluation surfaces

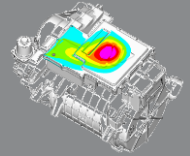


FE-modal
response

MNOISE Software

Post-Processing Software

- Collect all simulation results: gear and EMAG
- Post processing:
Structure borne noise
Surface noise



Process Overview

Post-Processing

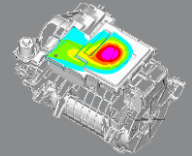
The frequency response analyses of the prepared model with applied loads for the entire load map yields a huge amount of result data, which is handled by MNOISE:

- Result files are processed by MNOISE postprocessing
- Based on nodal results, surface noise quantities are computed and stored in MNOISE data format, as well as nodal results for particular structure borne noise evaluations
- Based on this compressed data set, MNOISE can efficiently perform evaluations at various levels of detail

MNOISE Software

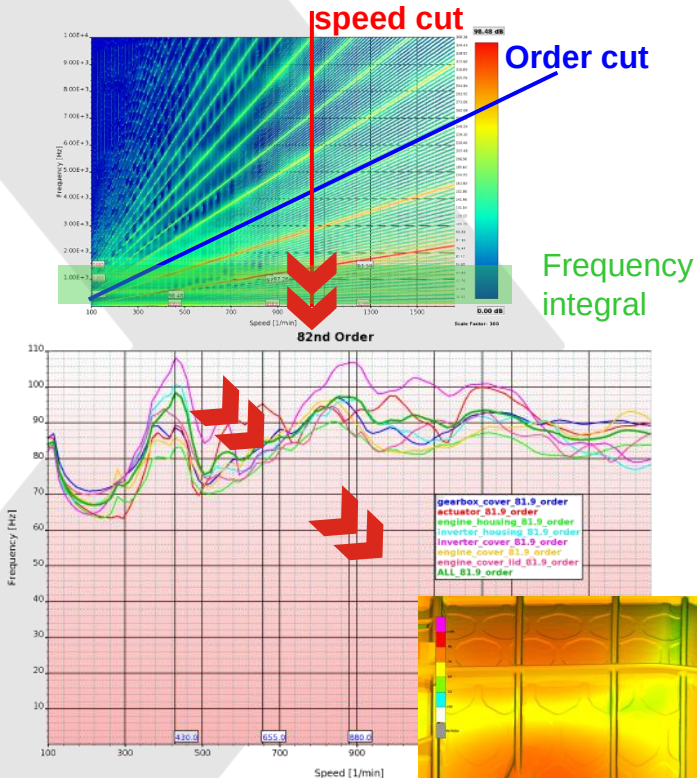
Post-Processing Software

- Collect all simulation results:
gear and EMAG
- Post processing:
Structure borne noise
Surface noise



Process Details

Post-Processing Output



- Campbell diagram
 - Common view known from measurement evaluations
 - Result overview, for structure borne noise and surface noise quantities as integral over the radiating surface
- 2d excerpts
 - Speed cuts, order cuts, frequency integrals
 - Provide a more detailed view on structural response
 - Base for correlation investigations
- Surface noise quantities on 3d structure
 - For specific loads/resonances of interest
- Results suitable for correlation
 - Structure borne noise quantities directly
 - Simulated acoustic power vs. radiated sound power measurements
 - Surface noise distributions vs. acoustic camera measurements

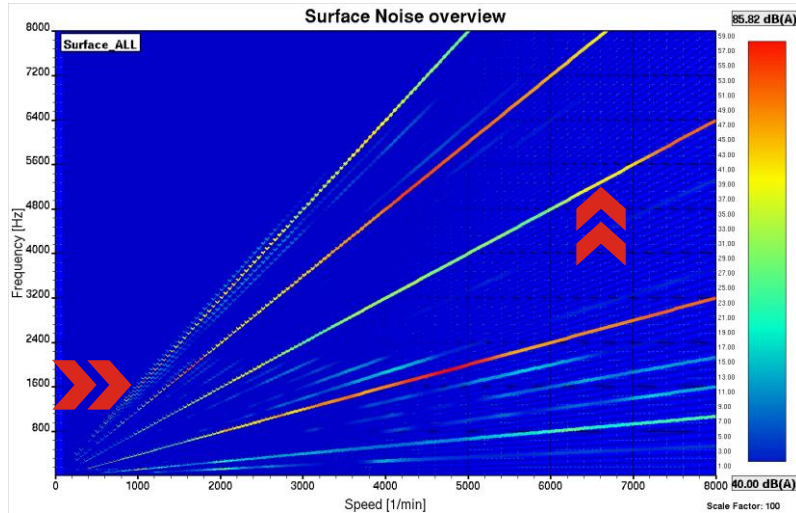
A long-exposure photograph of a road at sunset. The sky is a mix of dark blue, purple, and orange. The road is dark, and the light trails from cars are visible as bright red and orange streaks. The number '03' is overlaid in large white font on the left side of the image.

03

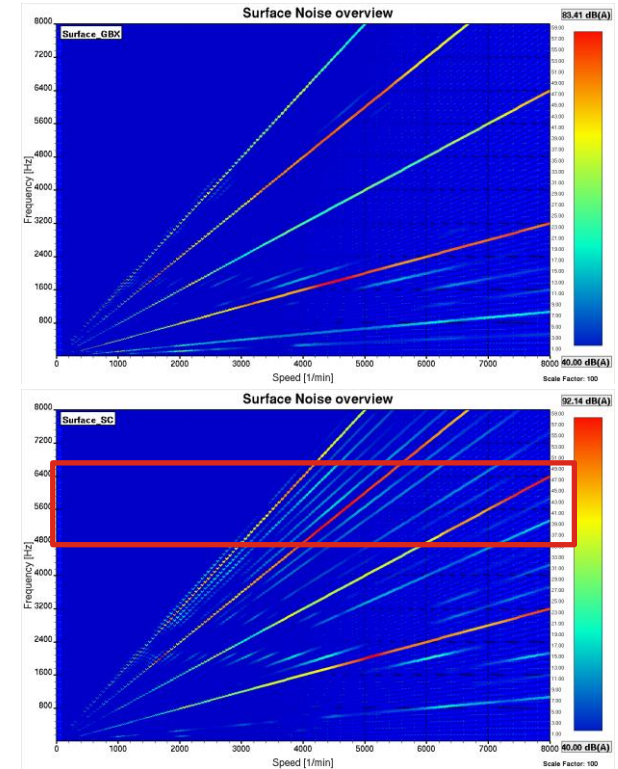
Example Results

Example Results

Campbell Diagram – First Overview

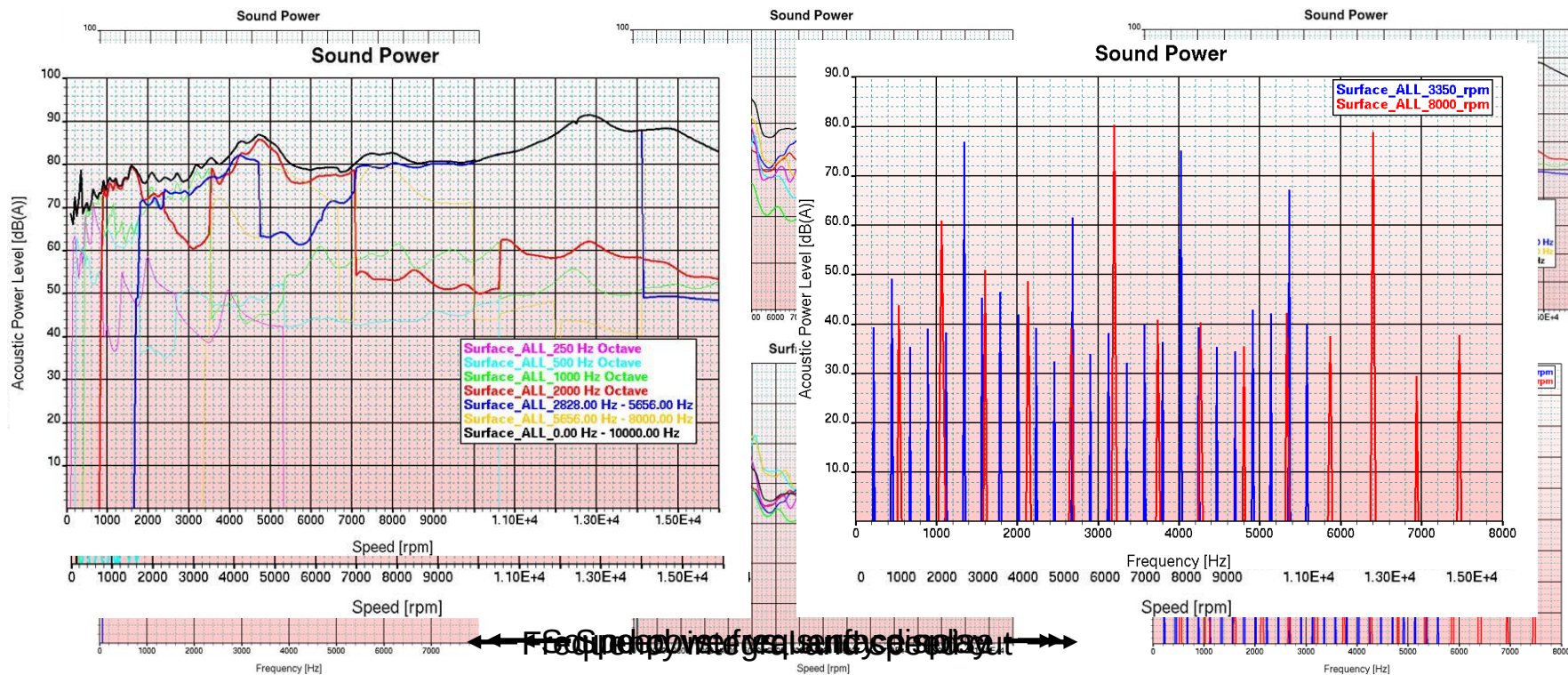


- Campbell diagram of whole aggregates surface noise level showing main excitation orders and resonance behavior at 1800Hz
- Similar behavior present at partial surface GBX Cover
- High sensitivity at higher frequencies additionally to global resonance at 1800Hz in other partial evaluation surface
- ➔ First indication on critical speeds, frequencies and critical regions too



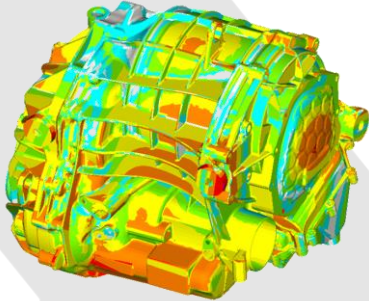
Example Results

Surface Noise Order Cuts



Example Results

Surface Noise Distribution

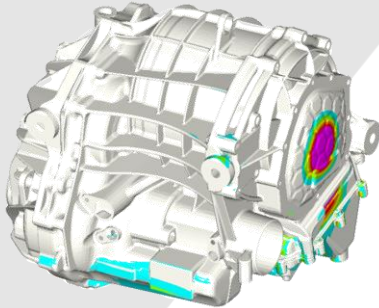


2000rpm 0-8000Hz



Surface noise level

- Evaluation of particular load points/frequencies as well as integral over frequency ranges
- Sound radiation at service cover, oil tank and front housing structure detected



2000Hz 48th order



Mobility distribution

- Acoustic hotspots are pointed out, looking at specific frequencies
- Local membrane vibration of cover detected

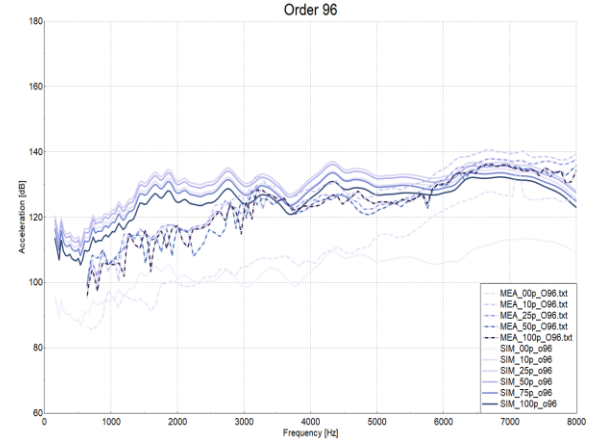
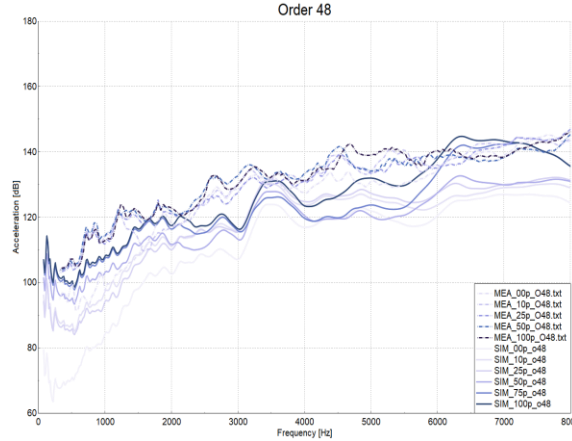
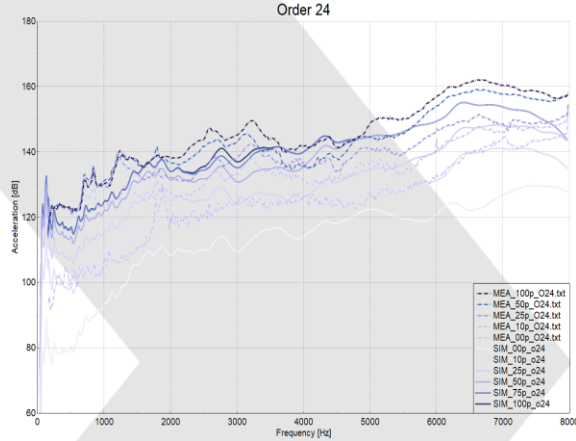


04

Correlation to Measurements

Simulation vs. Measurement

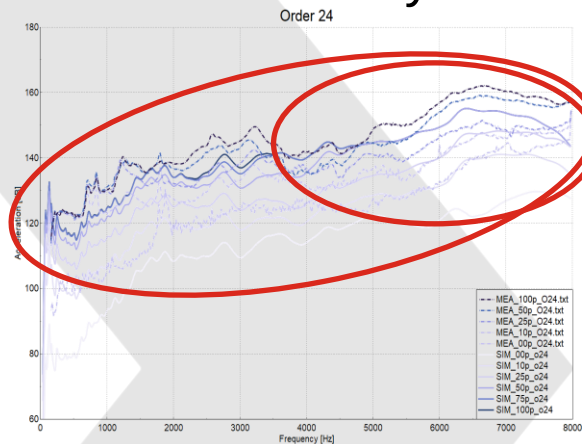
Order Cuts



- Comparison of main orders
- Each order has its own characteristic
- Different modes are excited with each mode
- Load dependency differs from order to order
- ➔ Effects are captured by simulation

Simulation vs. Measurement

Correlation Study



High load dependency in 24th order

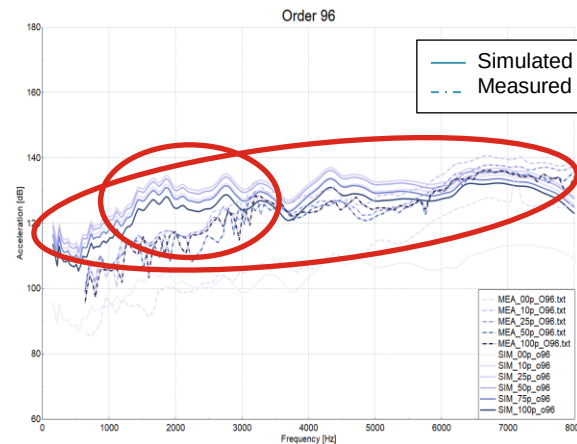
Good correlation between measurement and simulation
CCF > 0.9



Offset between measured and simulated order cuts

Slight frequency shifts with varying load in measurement, which is not covered in simulation

main peaks covered
Load dependency covered



Offset in lower frequency range, test rig influences at low speeds

Inverse load dependency

Summary

- An efficient NVH simulation process for eDrive systems has been established
- Based on a FE frequency response analyses, an environment for handling numerous load cases of an entire load spectrum with high automation grade is introduced
- Evaluation of acoustic quantities for surface noise and structure borne noise assessments using MNOISE are shown
- In a correlation study, the applicability of this procedure has been demonstrated

A long-exposure photograph of a multi-lane highway at night. The road surface is dark asphalt, and a concrete guardrail runs along the left side. In the distance, numerous light trails from cars stretch across the frame, with red trails from taillights and yellow/white trails from headlights. The sky is dark with some clouds. The text "Forward. For all." is overlaid in white on the left side of the image.

Forward. For all.