Ansys

Powering Innovation That Drives Human Advancement

Ask the Expert 3: Motor NVH

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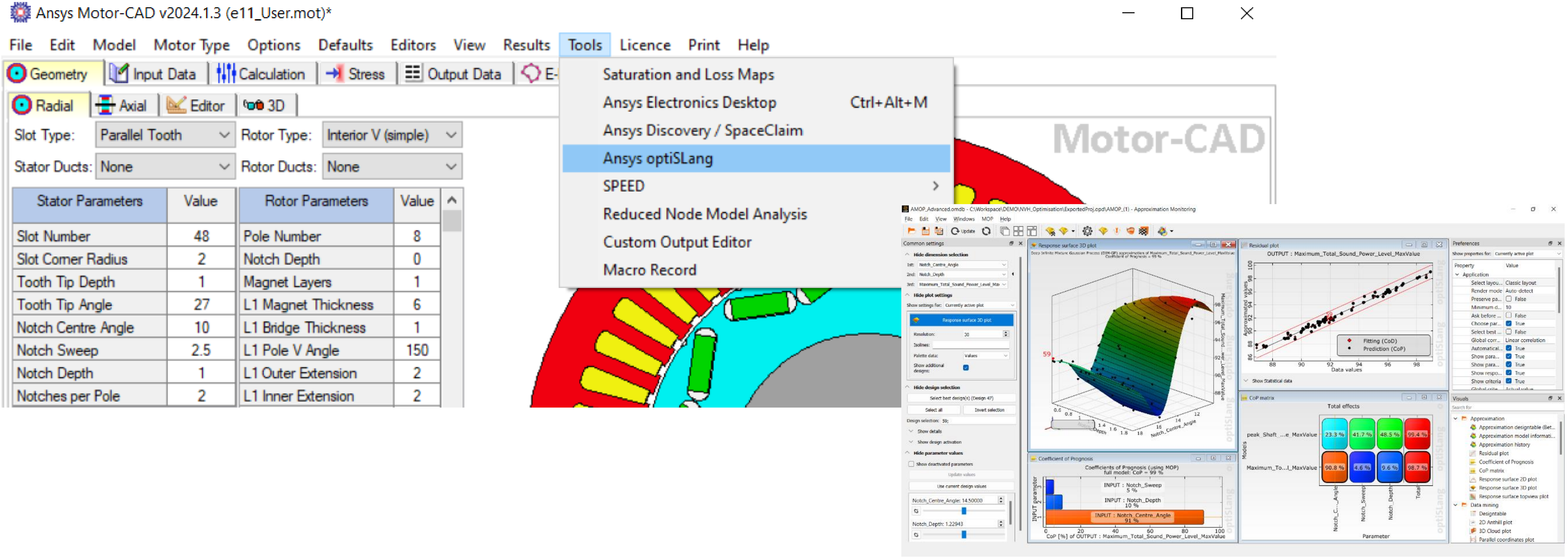
Motor-CAD to optiSLang link including NVH parameters

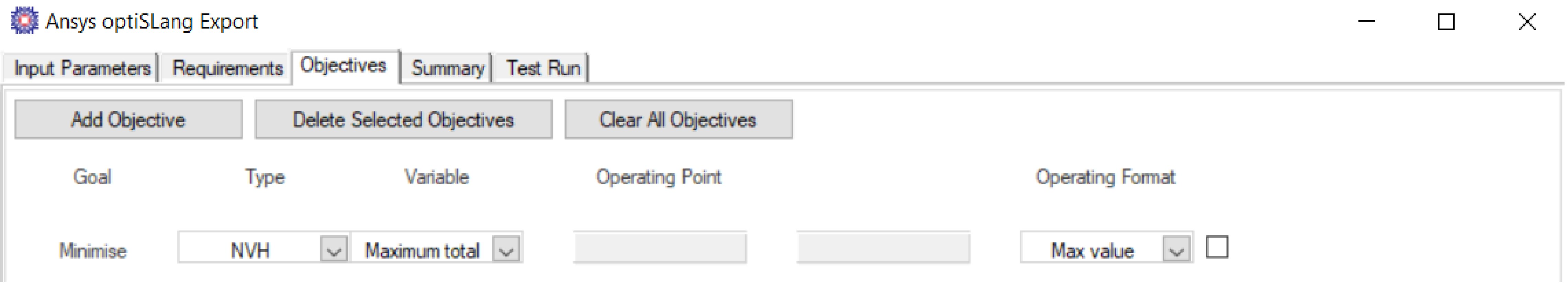
- Motor-CAD has an automated link with Ansys optiSLang
  - In 2024 R1, this has been enabled for NVH calculations



Ansys

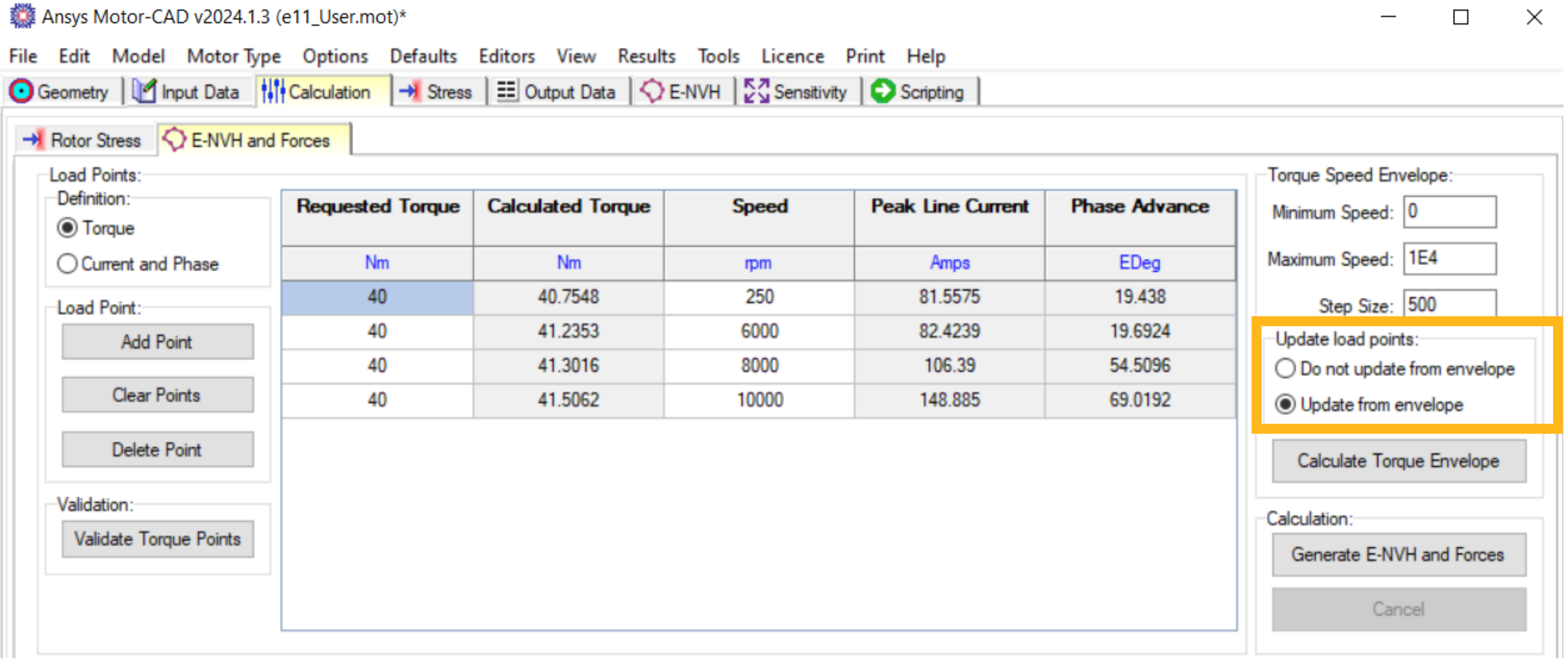
Motor-CAD to optiSLang link including NVH parameters

- Set NVH metric as a requirement or objective
  - Maximum total sound power level (over speed sweep)



Motor-CAD to optiSLang link including NVH parameters

- If ‘Update from envelope’ is chosen for ‘Update load points’, then operating points will be re-calculated from maximum torque curve, using lab model build for each candidate model
  - Uses Minimum Speed, Maximum Speed and Step size to set speed points. Duplicated E-magnetic points are removed

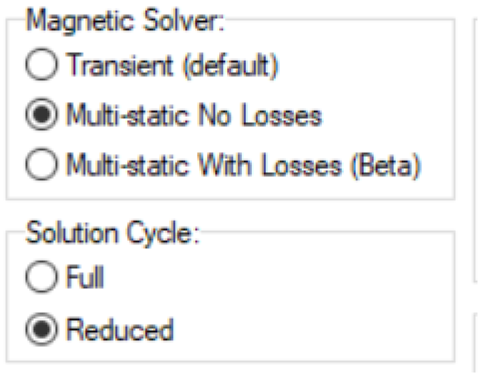


Motor-CAD to optiSLang link including NVH parameters

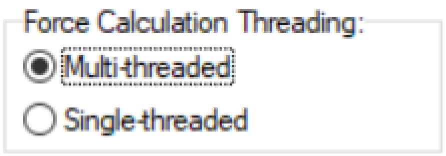
- **Troubleshooting**: Always worth running small optimization study first (for example sensitivity calculation with one or two points):
  - If no NVH results are generated (Sound power level results all 0), try moving optiSLang project to a shorter path
  - Both Motor-CAD and optiSLang use nested folder structure, can end up with very long paths, causing calculations to fail
- Example:
  - Original file at
    - `C:\Workspace\Scratch\Optimisation\optiSlang_NVH_Demo_e11_30Points\NVH_osl_Demo\e11_user.mot`
  - Working file generated by sensitivity study at
    - `C:\Workspace\Scratch\Optimisation\optiSlang_NVH_Demo_e11_30Points\NVH_osl_Demo\e11_User\optiSLangExport\ExportedProj.opd\Sensitivity\Design0001\Design0001.mot`

Solver options for speed

- Techniques available to enhance NVH solution speed



- Consider using reduced multi-static solver
  - (E-Magnetic context, Input Data->Settings->Calculation)



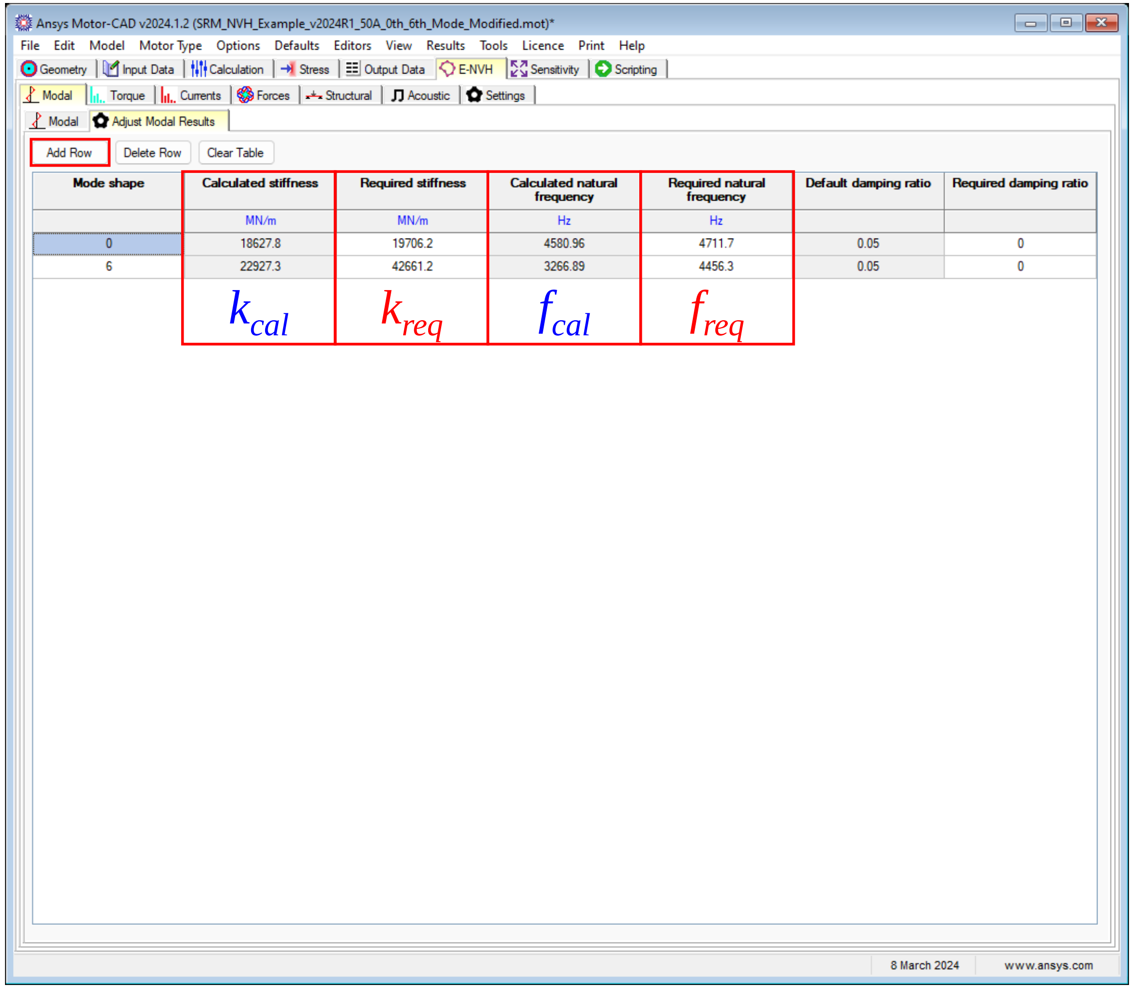
- Consider using Force Calculation Multi-Threading
  - (Mechanical context, Input Data->Settings->Calculation)

- Enough points per cycle to capture required harmonics, but not excessive
  - 90 points per cycle is often enough (Harmonics up to 45th electrical)

Structural model tuning

- As a new feature in Motor-CAD 2024 R1, users can adjust the analytical structural model, for one or more mode shapes
  - Natural frequency
  - Stiffness
  - Damping ratio
- For example, if natural frequency is known from modal testing or structural FEA modal analysis, the natural frequency can be tuned
  - Recommended to tune stiffness and natural frequency together.
  - If stiffness factor isn't known, remember that natural frequency is proportional to square root of stiffness.

Structural model tuning



Mode shape

Add mode numbers that we need to tune.

Required natural frequency

Input the natural frequencies calculated from Modal analysis corresponding to each mode.

Required stiffness

To tune the Motor-CAD NVH model, we can use a simple relation as follows:

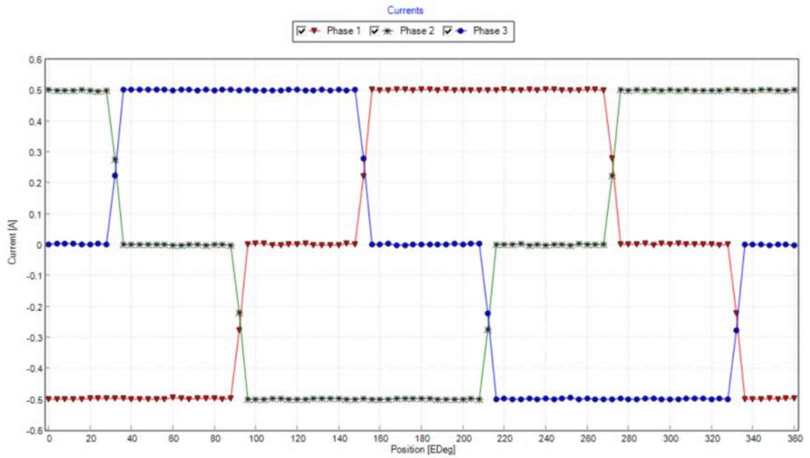
$$f = \sqrt{\frac{k}{m}} \quad f: \text{natural frequency}, \; k: \text{stiffness}, \; m: \text{mass}$$

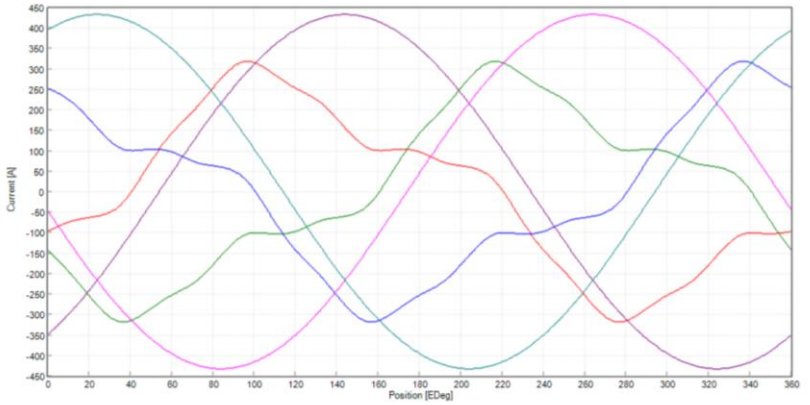
From the equation above, k_{req} can be calculated as follows:

$$k_{req} = k_{cal} \times \left(\frac{f_{req}}{f_{cal}}\right)^2$$

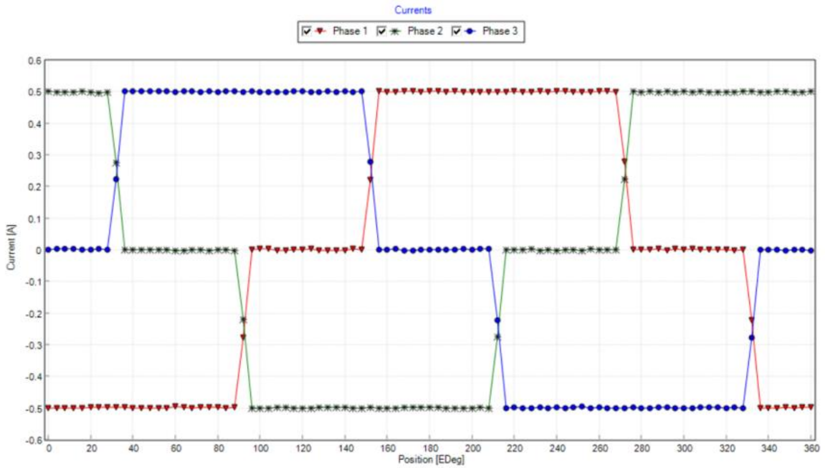
Square wave current drive and delta connected circulating currents

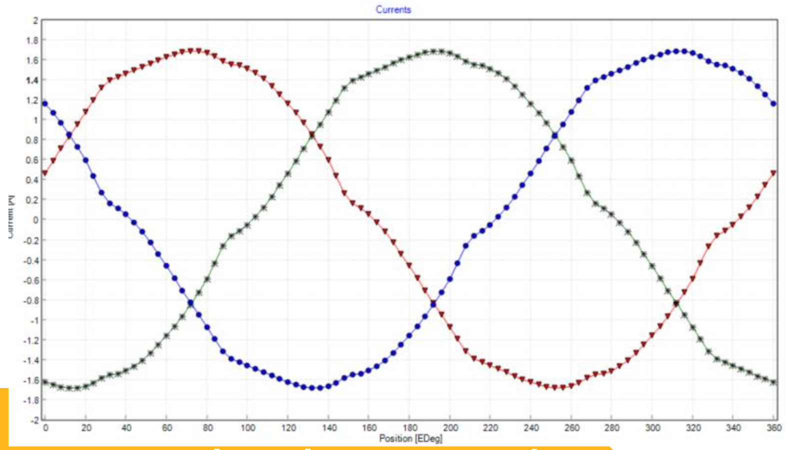
- For many motors, the current is largely sinusoidal
  - Non-sinusoidal current can have a significant effect on motor noise
  - Square wave drive ('Brushless DC motor') will add significant additional harmonics due to switching transients
  - Delta connection of windings can introduce significant harmonics at 3rd electrical order and higher multiples in phase currents, even if line currents are sinusoidal
- Both can be considered in Motor-CAD NVH analysis





Square-wave current

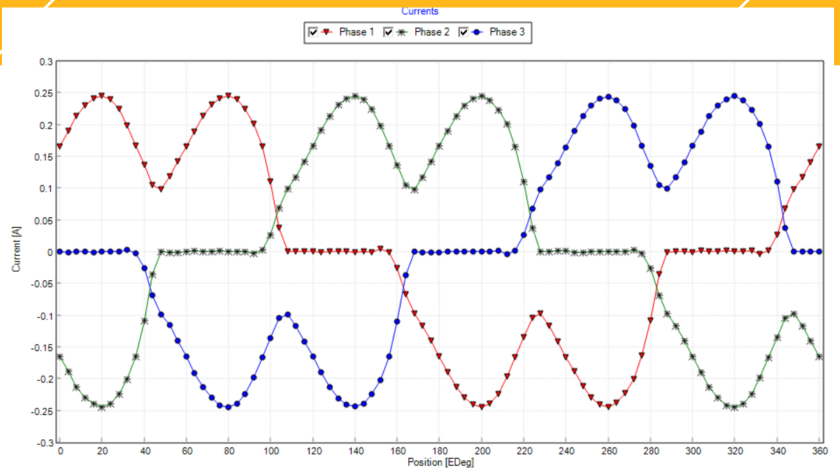




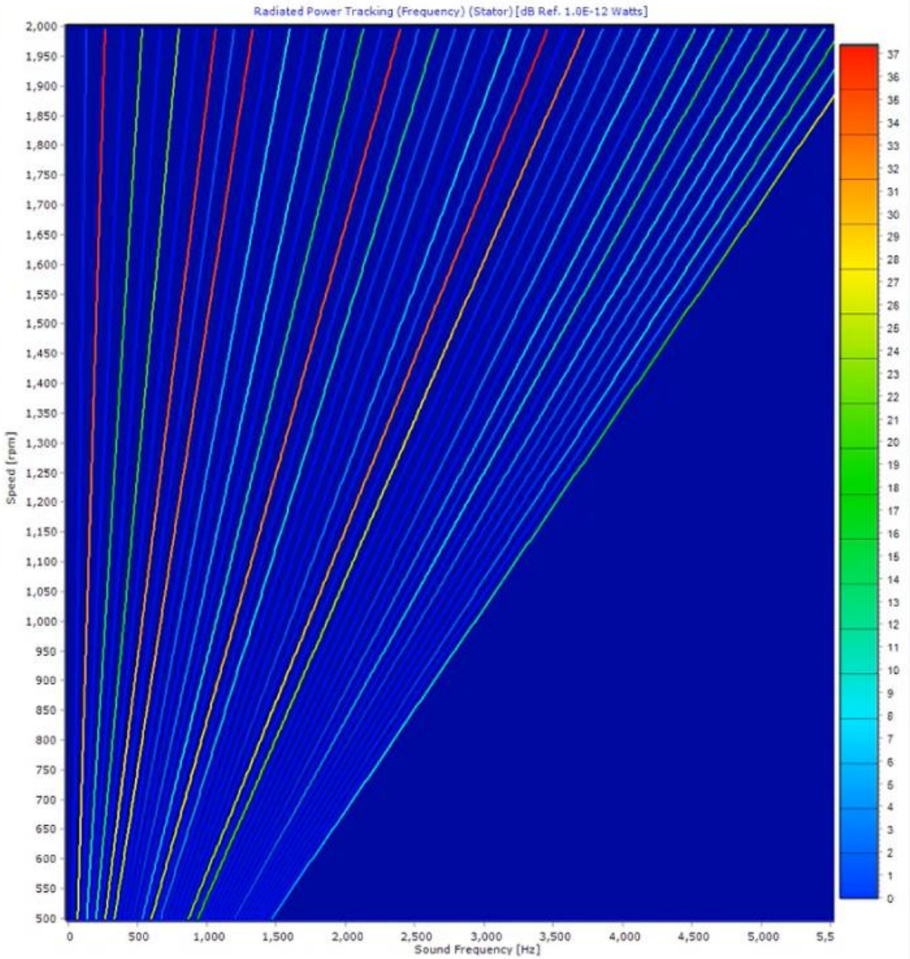
Constant torque region

Constant power region

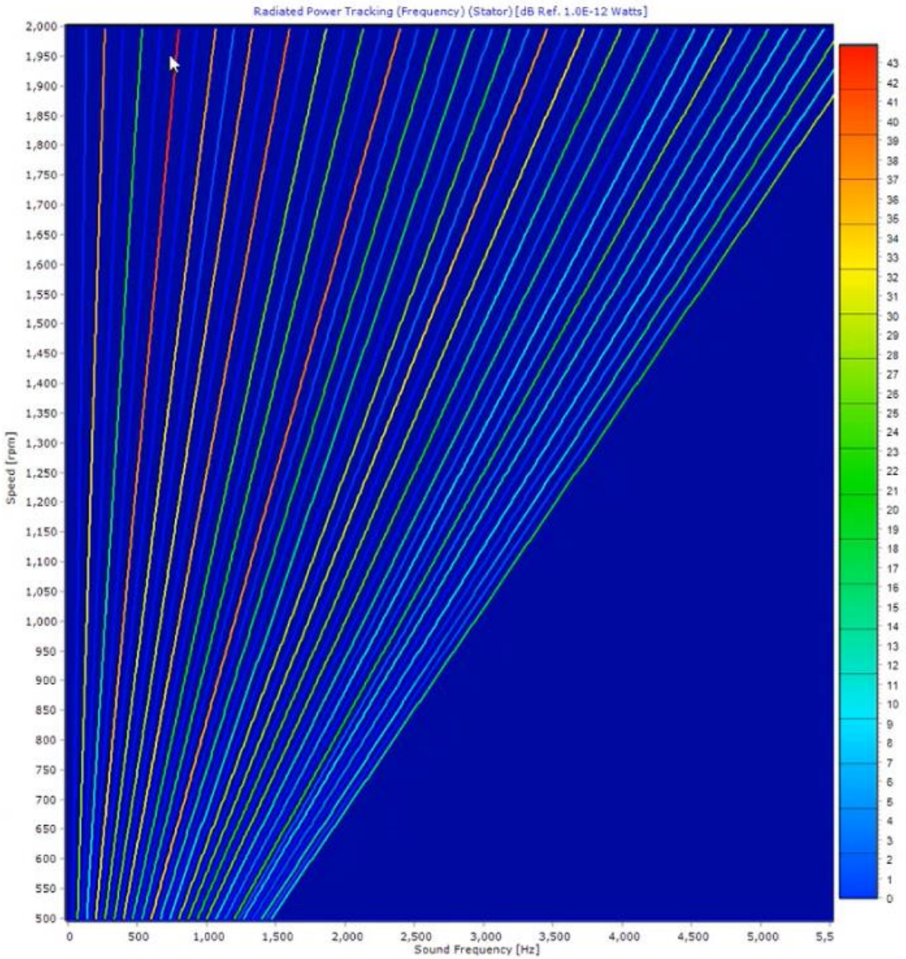
Very high-speed operating conditions



Spectrogram effects of square-wave drive current



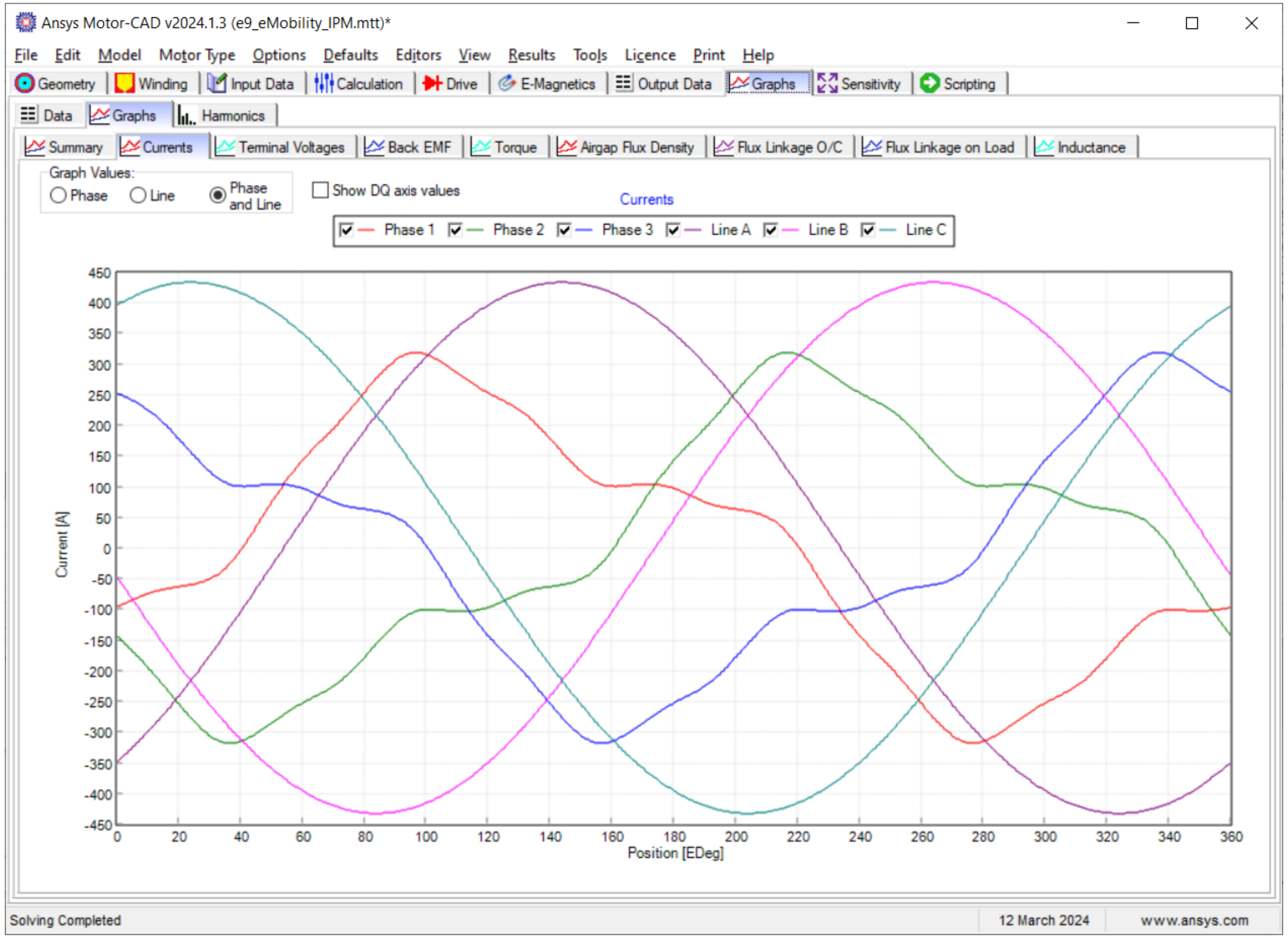
Sinusoidal current



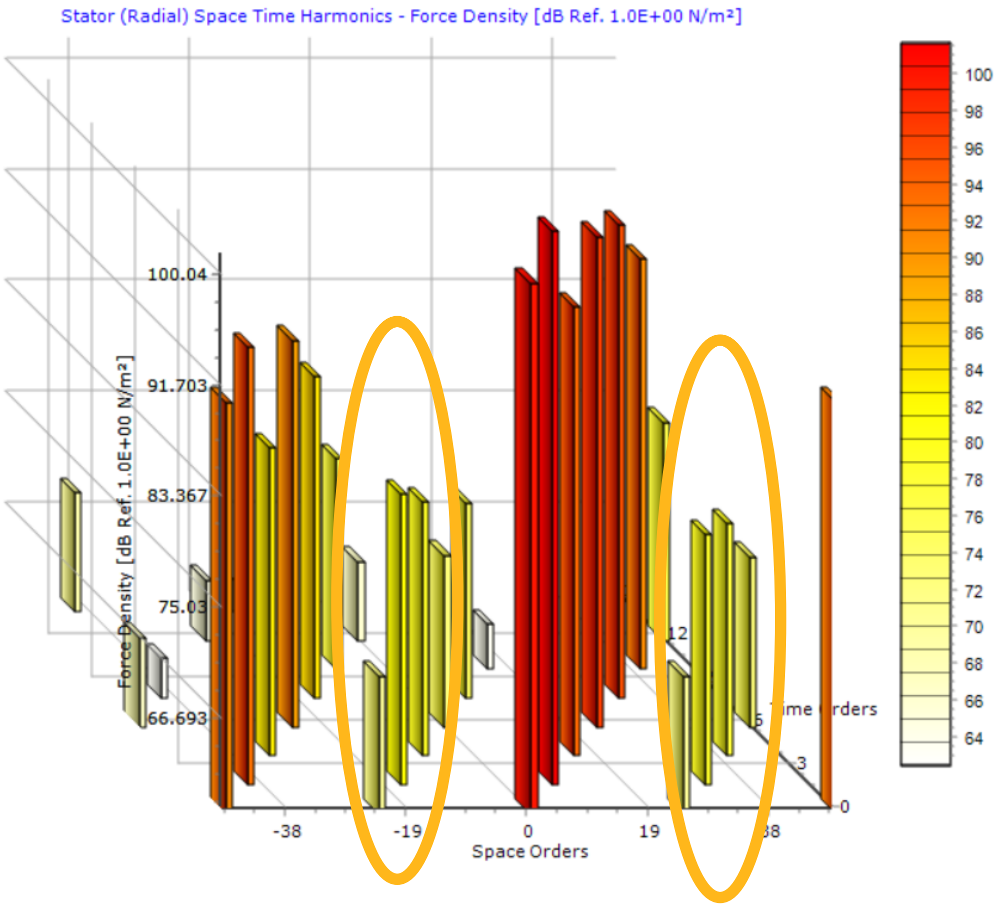
Square wave drive current:
Additional orders and higher amplitude

Delta circulating current

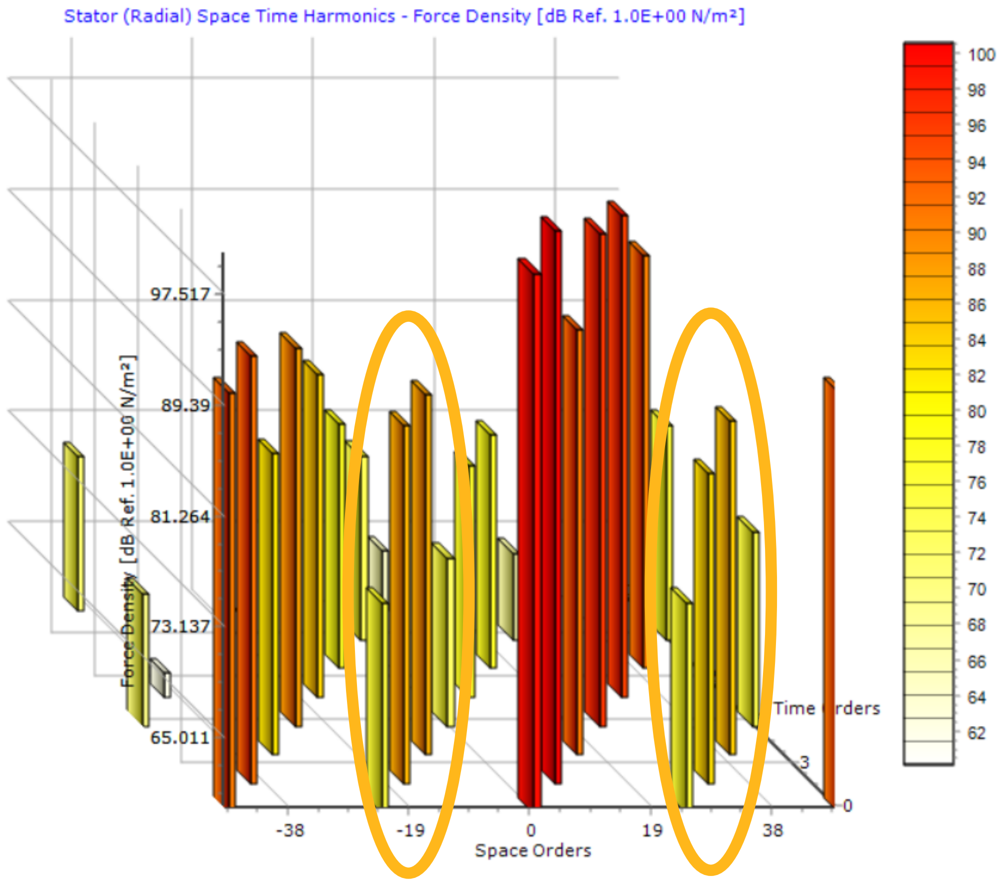
- Sinusoidal line currents with space vector drive
- Estimated on load back EMF calculated from an initial sinusoidally driven calculation
- Additional 3rd harmonic and multiples present in current, will affect force harmonics
  - Not currently recommended for PWM studies, as the general assumption is that the PWM frequency is significantly higher than the Motor-CAD timestep



Delta circulating current



Sinusoidal phase current



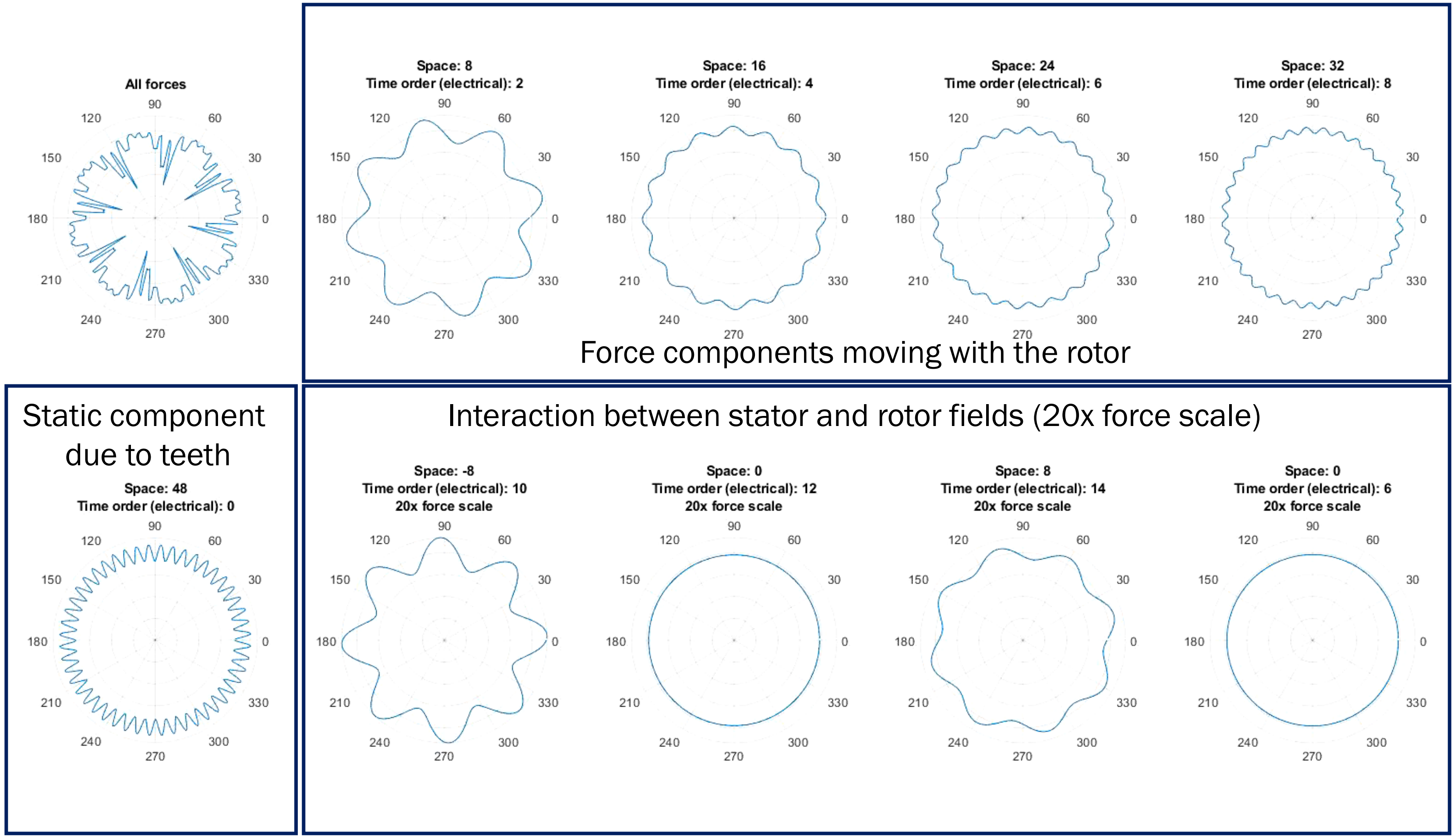
Calculated phase current

Additional material

What do 2d FFT components mean?

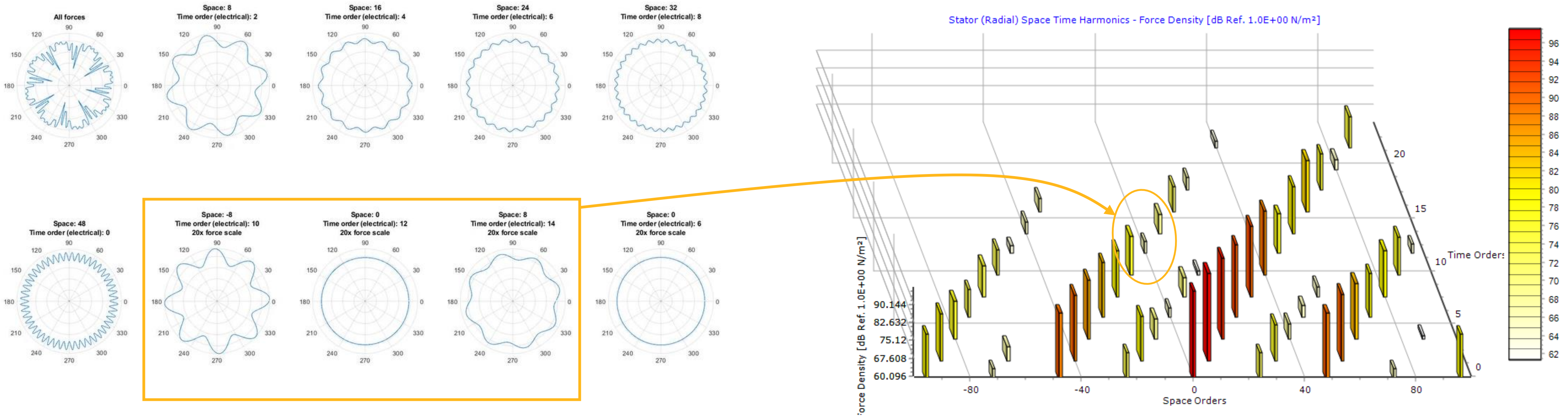
Force analysis

- The magnetic force can be visualized as the sum of waves with given:
  - shape (space order)
  - frequency (time order).
- They result from interactions in the airgap magnetic field between stator and rotor fields



Example of 2D FFT components

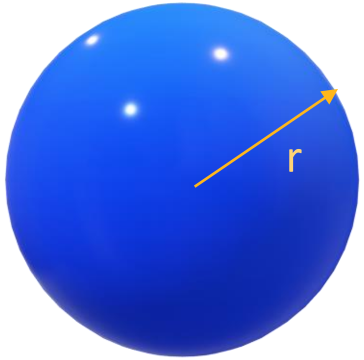
- Some components directly from rotating field from rotor
- Other components from stator teeth and windings
- Interactions between these



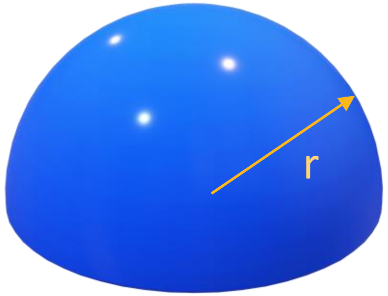
Acoustic aspects

Sound power and sound pressure

- Motor-CAD produces results in Sound Power
  - dB results referred to 1pW. Often referred to as $\mathbf{L_W}$
- Microphones measure Sound Pressure
  - dB results referred to 20 μPa. Often referred to as $\mathbf{L_p}$ or **SPL**
- Sound power is the total sound power from the machine, sound pressure depends on the distance and surroundings
- If we know the distance, and environment, we can convert between the two dB values:
  - $L_p = L_W + 10\log_{10}\left(\frac{Q}{4\pi r^2}\right)$
  - Example for Q = 1 (full sphere noise radiation), r=1m:
    - $L_p = L_W - 10.99$



Q=1
Full spherical radiation
(free space)



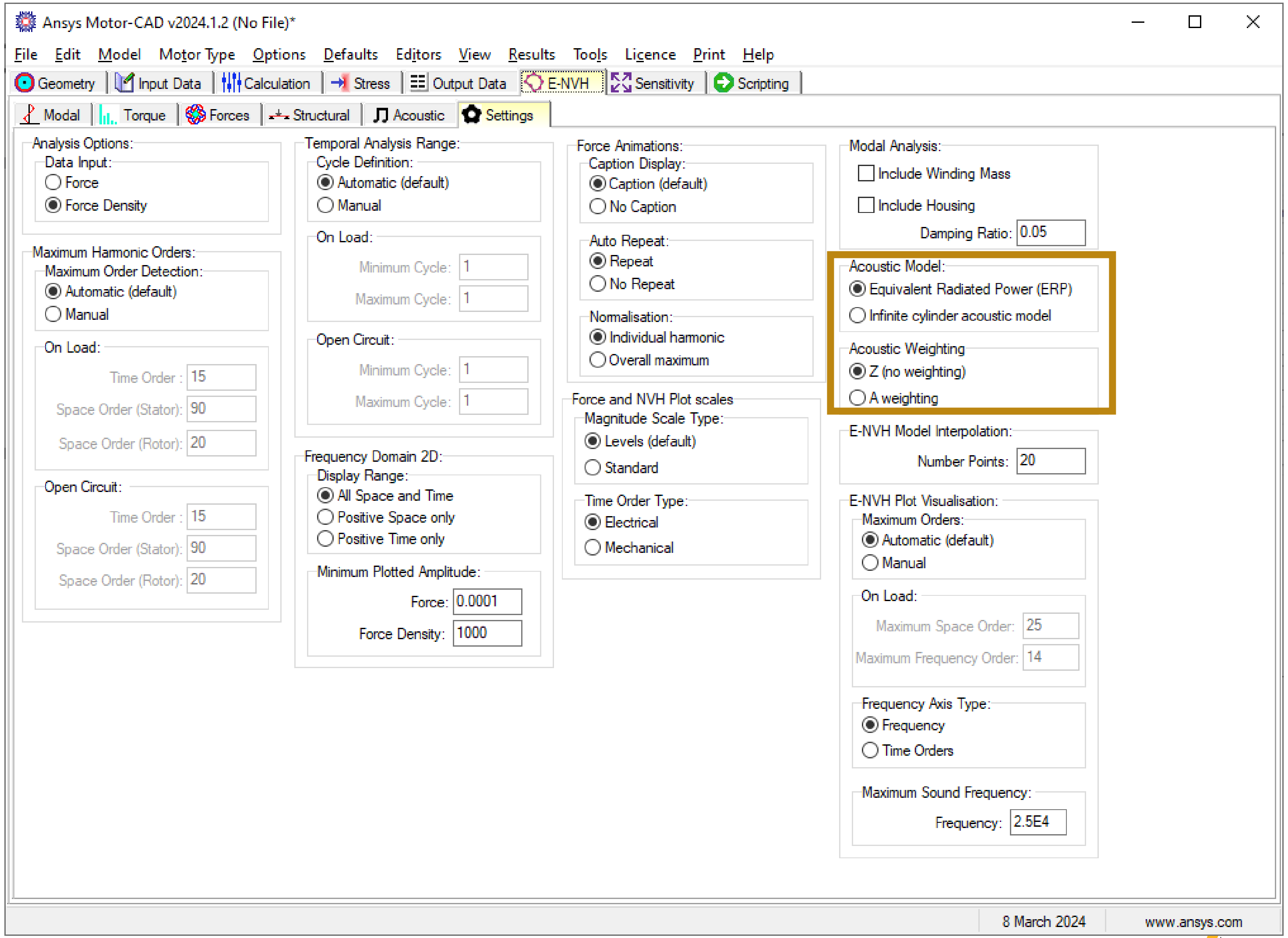
Q=2
Hemispherical radiation
(above reflecting plane)

Q=4 for ¼ sphere, e.g. motor at edge of room with two reflecting surfaces

Q=8 for 1/8 sphere, e.g. motor at corner of room with three reflecting surfaces

Acoustic options

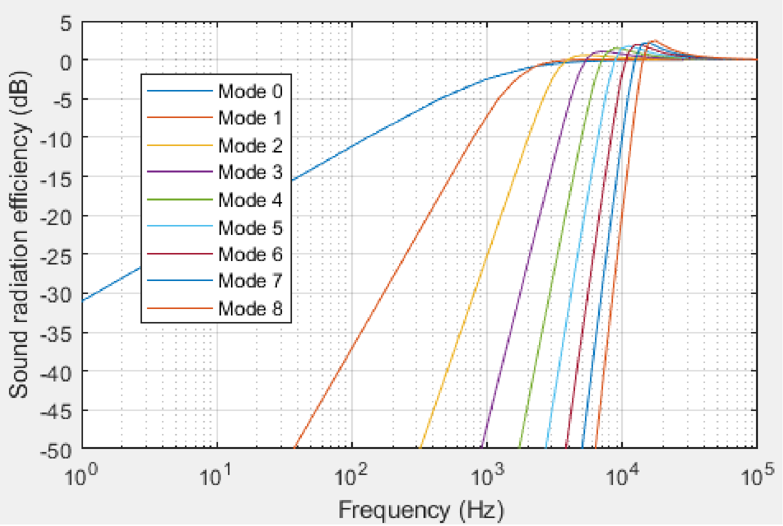
- Acoustic model
  - ERP
  - Infinite cylinder acoustic model
- Acoustic weighting
  - Z (no weighting)
  - A weighting



Acoustic model

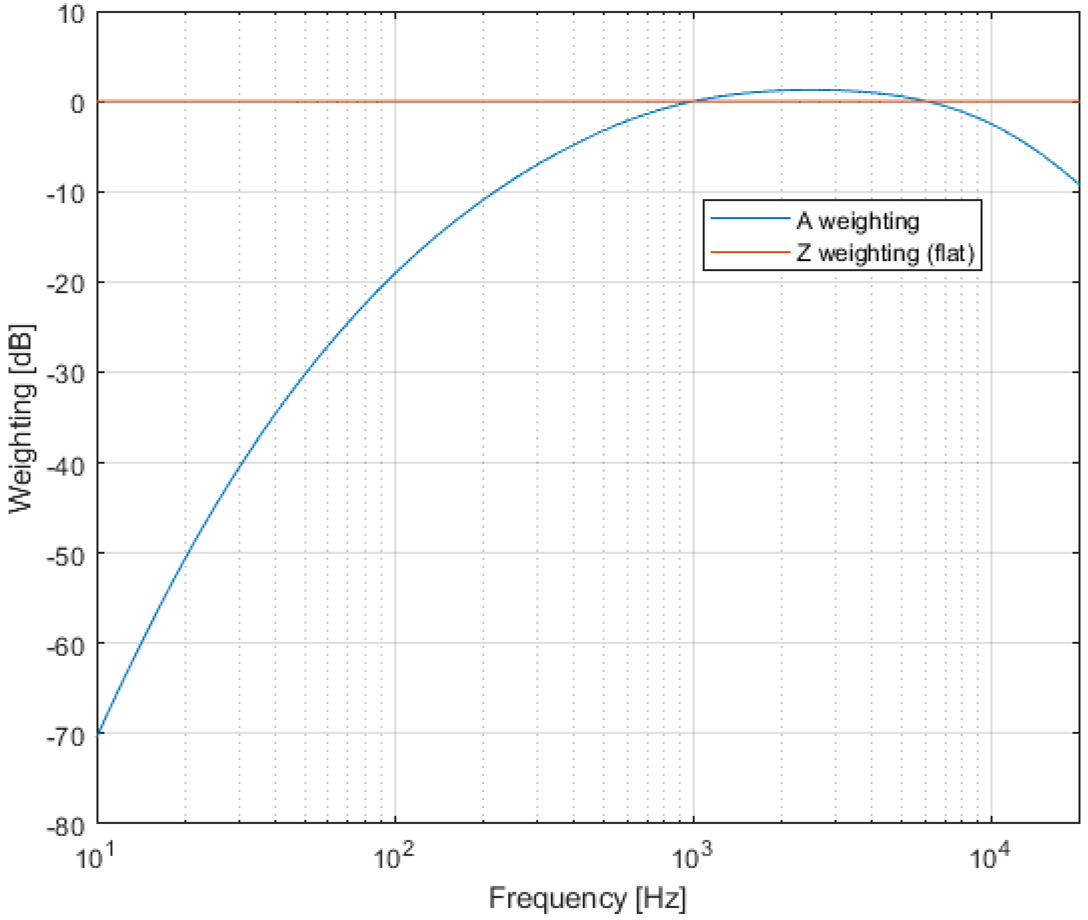
- ERP vs Infinite cylinder acoustic model
  - ERP means equivalent radiated power, and is calculated directly from the surface velocity:
    - $ERP = \frac{1}{2}\rho c v^2 S,$
    - ρ is the air density, c is the speed of sound in air, v is the surface velocity amplitude, and S is the surface area.
  - This is simple to calculate, and a useful value for comparison.

- ERP does not consider the shape of the radiating surface, or the wavelength of the sound
  - This means that it substantially overestimates the sound radiated at low frequencies, particularly for small motors, and high vibration space orders.
  - To improve this estimate, we can use the 'Infinite cylinder acoustic model', which adds a radiation efficiency term to the equation. This is 1 at high frequency, but drops substantially at low frequencies.
  - The higher the space order of the vibration, the more the efficiency drops at low frequency



Acoustic weighting

- The human ear does not respond equally to different frequencies
  - It is hard to hear sounds at very low frequencies, or at very high frequencies
- The 'A weighting' curve is one standard curve used to adjust sound measurements to take this into account
- 'Z weighting' just means no adjustment of the sound results



Feature timeline

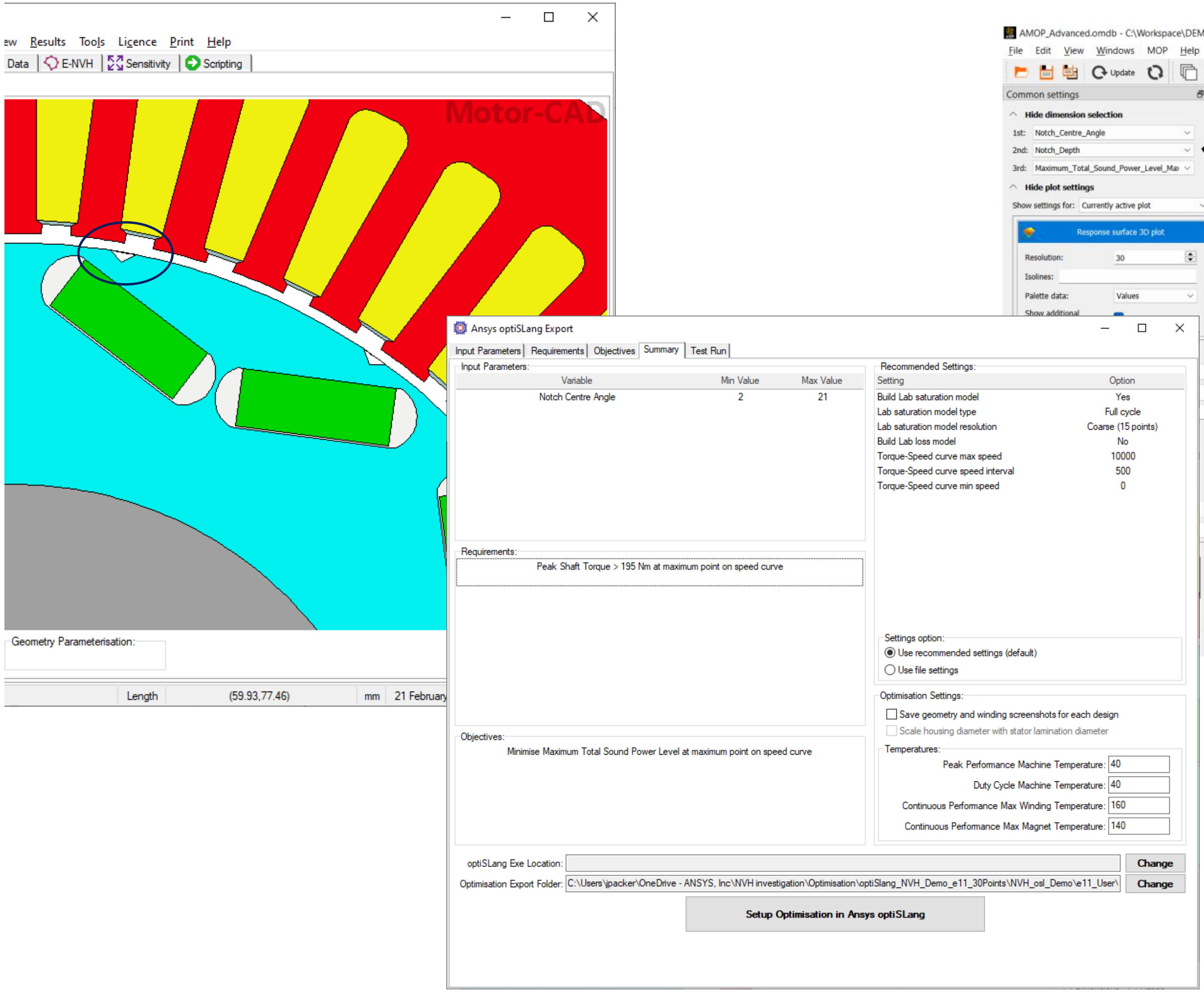
Updates for NVH analysis by release version

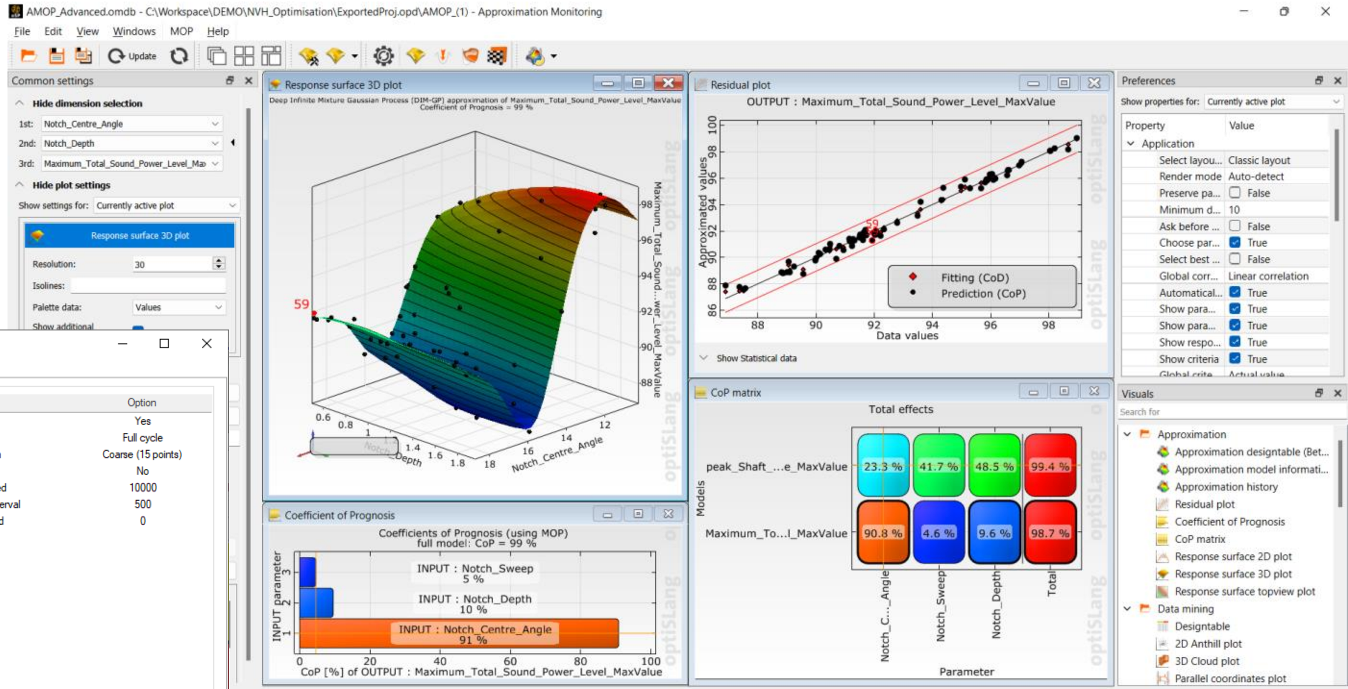
- Overview:
  - 2022 R1 (15.1.2/15.1.3):
    - First release with NVH features.
    - 15.1.3 included link to Ansys sound, and acoustic model in addition to simple ‘ERP’ output
  - 2022 R2 (15.1.7):
    - A range of performance and speed improvements
    - More modal model options
  - 2023 R1 (2023.1.1/2023.1.2):
    - NVH analysis for induction machines
    - Option to include housing in modal model
    - Multi-slice skew averaging for forces
    - Force export to Ansys Mechanical
    - Scripting improvements
    - 2023.1.2 includes support for square wave drive BPM NVH calculations

Updates for NVH analysis in previous releases

- Motor-CAD 2023 R2:
  - Save and reload NVH results
  - Change modal, structural and acoustic options rapidly
  - Synchronous (wound field) machines supported for NVH analysis
  - Speed enhancement when using 'Reduced Multi-static solver'
- Motor-CAD 2024 R1:
  - Integration of NVH with optiSLang automated optimisation link
  - Allow users to tune modal and structural results for correlation with FEA or test data
  - Improved display of harmonic force animations
  - Option to re-calculate operating points along torque envelope
  - Display of torque for each NVH operating point (and current if non-sinusoidal)
  - Improved mechanical order display for induction motors
  - **This version also includes adaptive template functionality, which is likely to be very useful for improving NVH design**

Motor-CAD 2024 R1: NVH optimization link with optiSLang





- Using Adaptive template alongside automated optiSLang link