Even faster: NVH simulated with Motor-CAD

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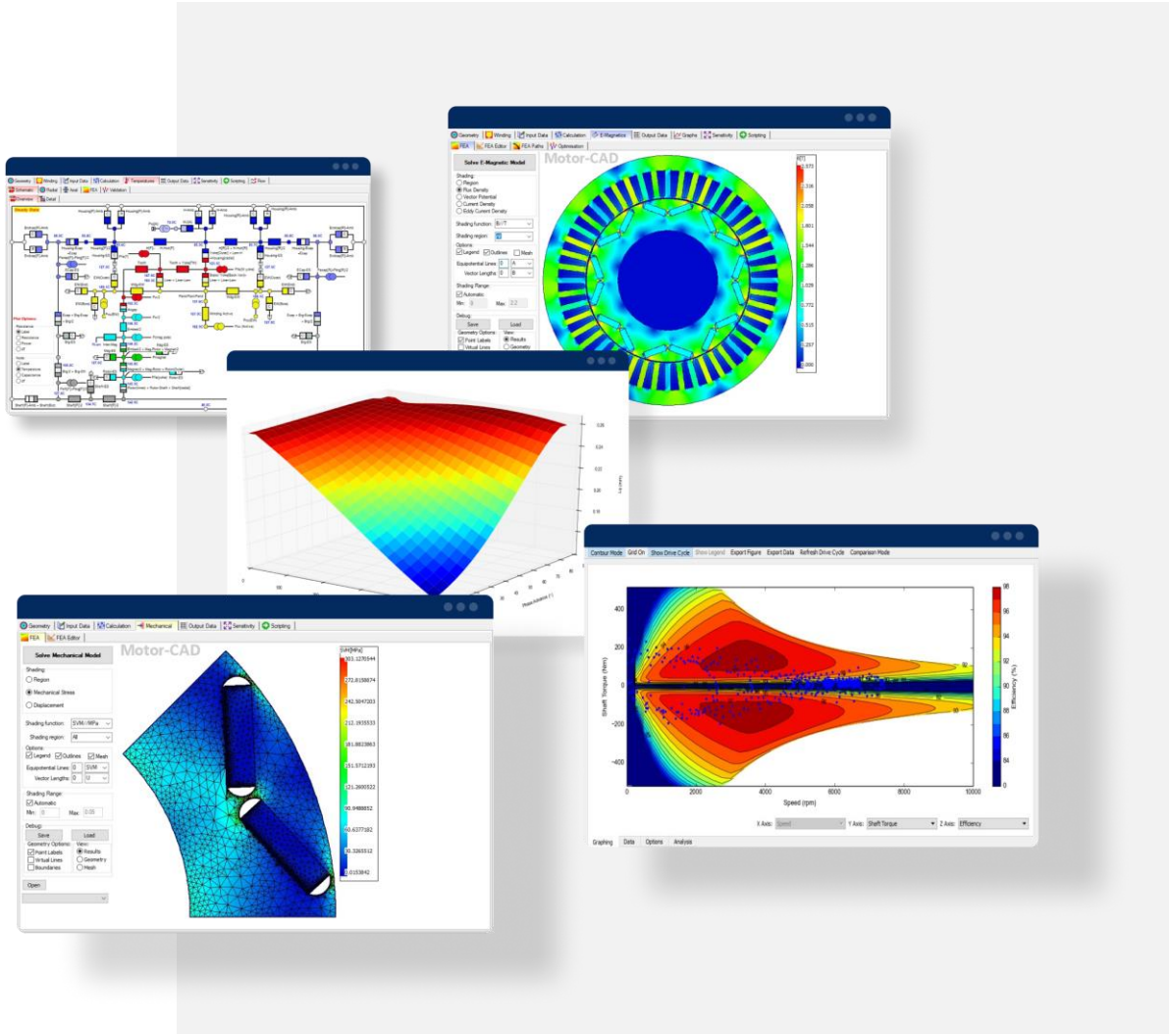
20/07/2021



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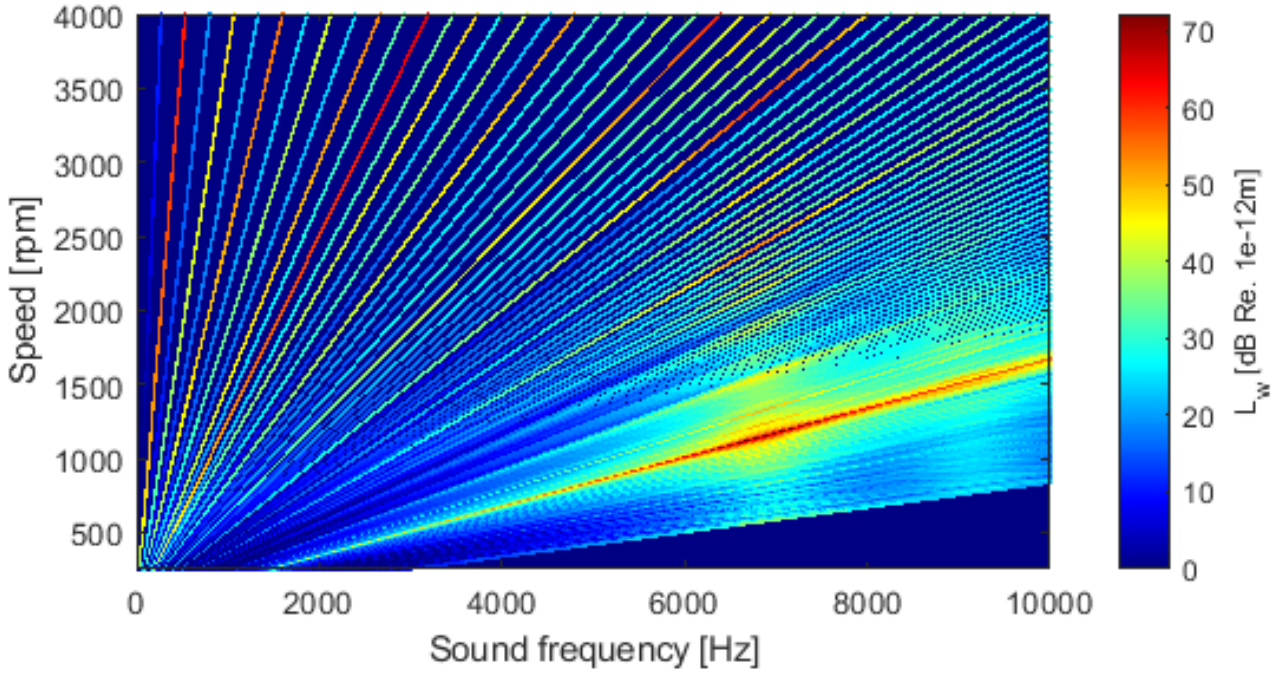
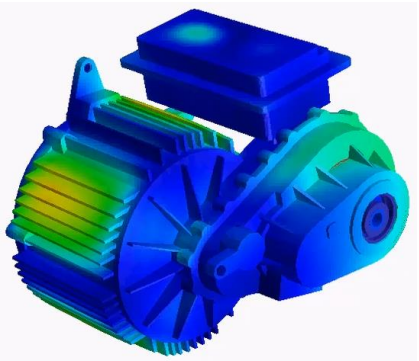
NVH in Electric Powertrains

- NVH (Noise, Vibration and Harshness) analysis is becoming more and more requested during the e-machine design process
- NVH is therefore a complex multi-physics problem, requiring knowledge on excitations and dynamic response of the structure
- NVH is fundamentally a system issue, as the system response to motor and gear excitations needs to be considered

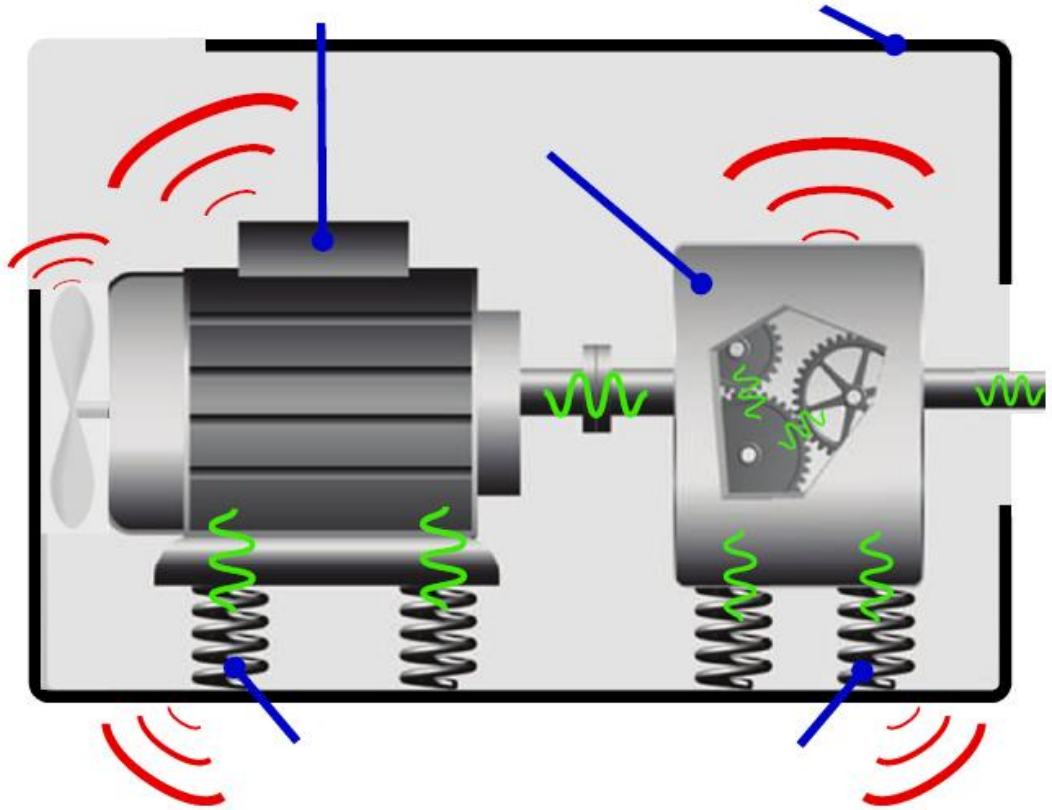




NVH Sources

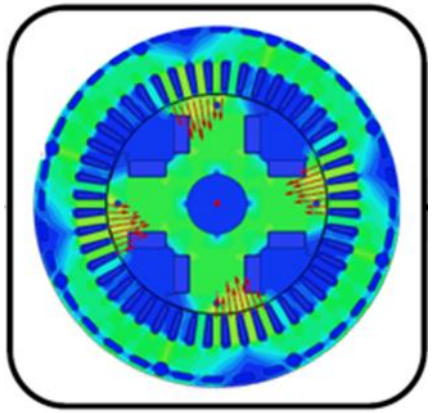
NVH analysis is a key challenge due to sources of different nature:

- Electromagnetic (e.g. magnetic forces)
- Mechanical (e. g. gears, bearings)
- Aerodynamic (e. g. cooling system)

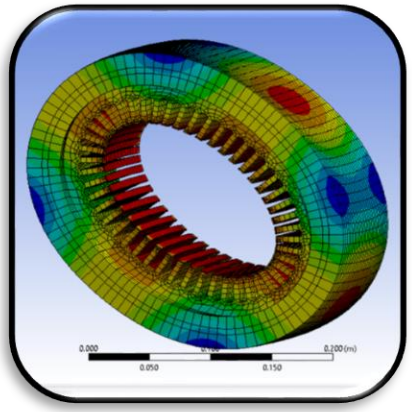


E-NVH Simulation Loop

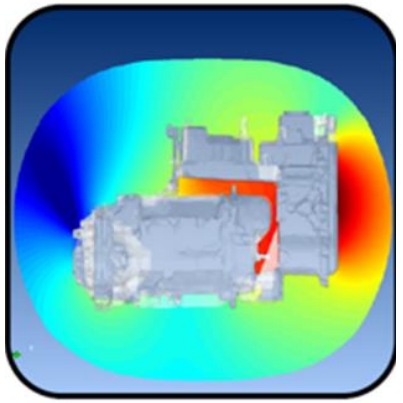
Magnetic System (Forces)



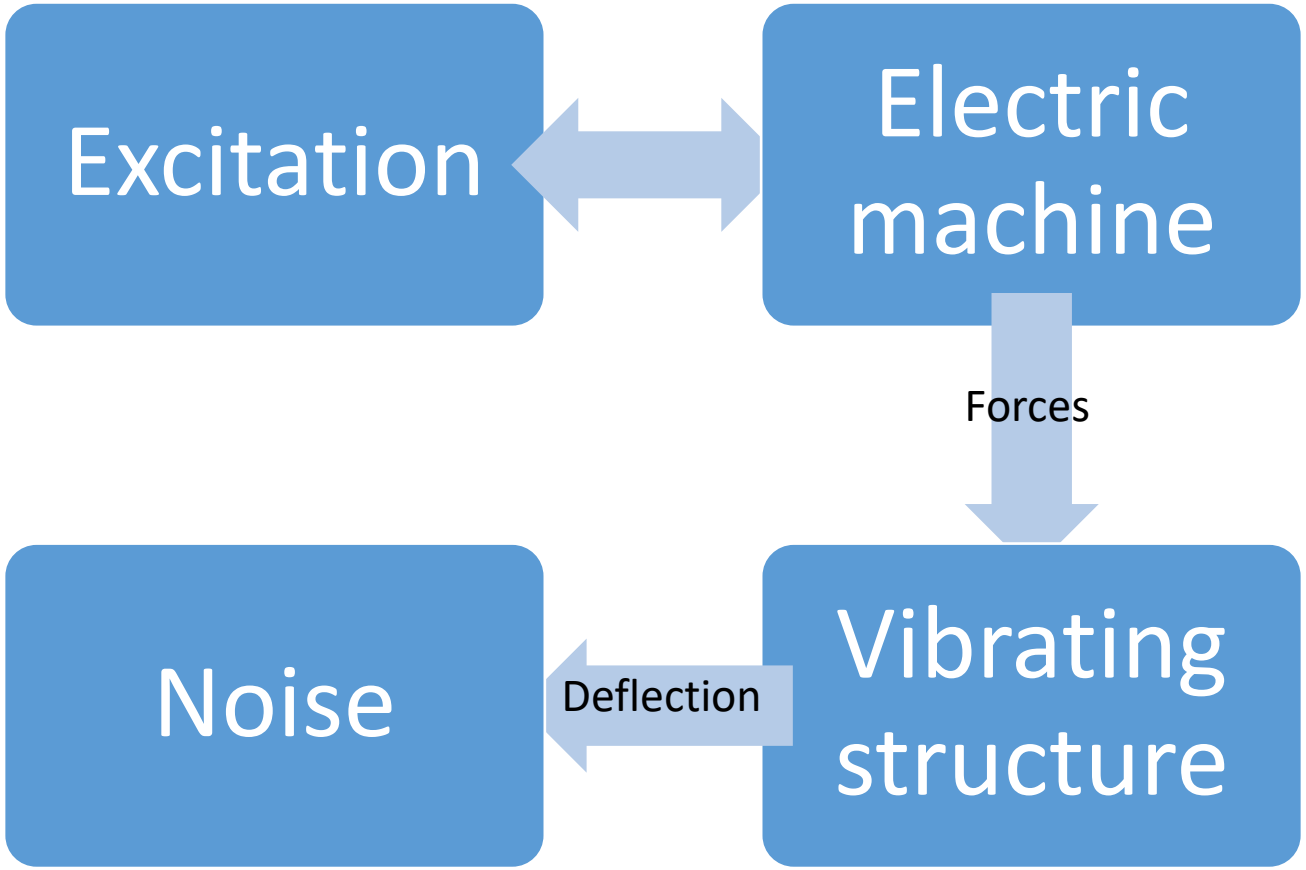
Mechanical system (Deflection)



Acoustic system (Sound)

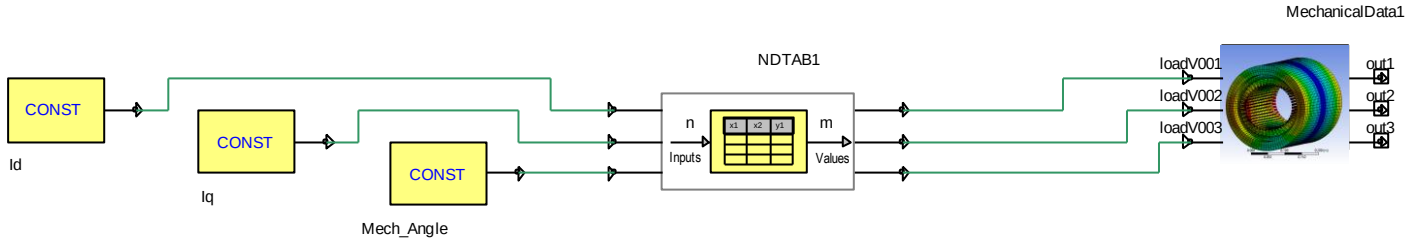


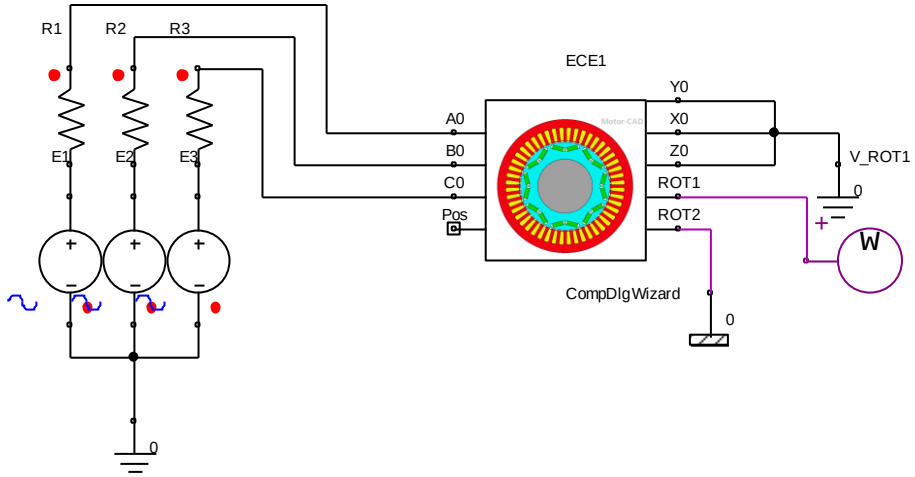
System Simulation for Fast Transient NVH



System Simulation for Fast Transient NVH

- **ROMs**
  - ECE model: reduced order model for the electrical machine based on flux linkages and torque look-up tables
  - Force waves look-up table: force wave coefficients are reported in function of currents and rotor position
  - Vibrating structure: it consists on a state space model with force waves as input and the surface deflection waves as output

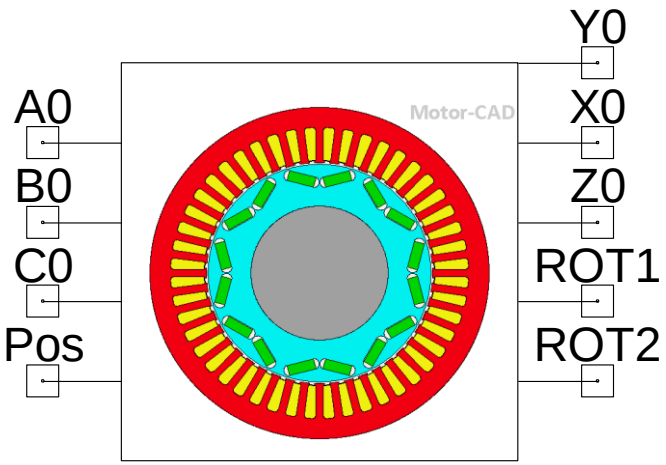


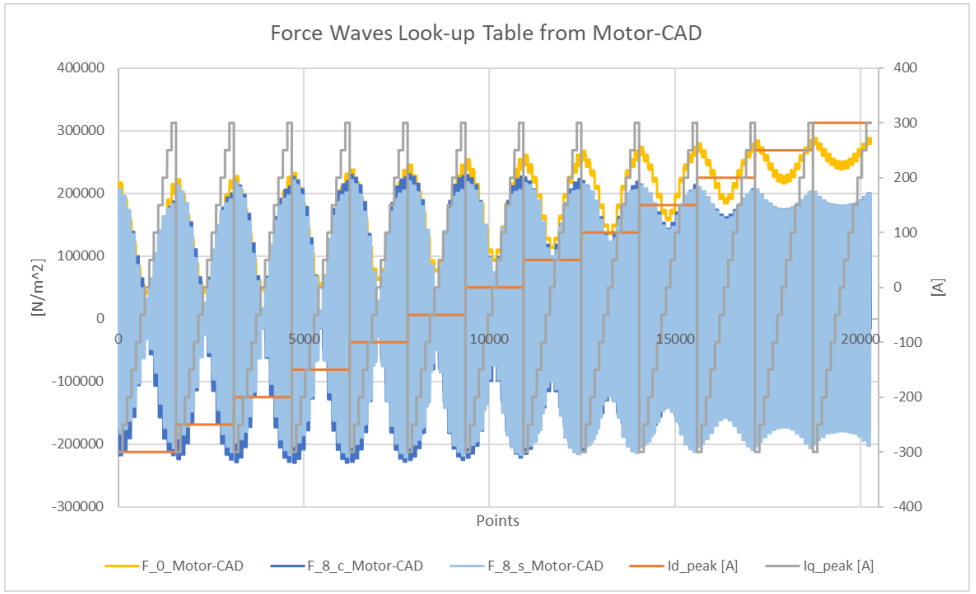


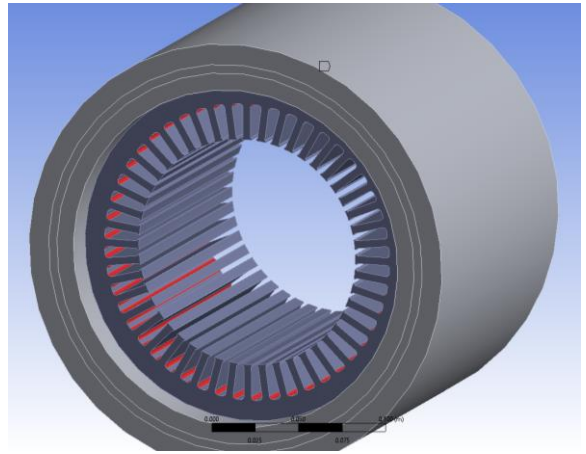
Fast NVH Workflow with Motor-CAD

With Motor-CAD you can:

- Implement a reduced order model for the electric machine
- Calculate the force waves look-up tables
- Export the machine geometry in Ansys Mechanical Workbench for creating the mechanical state space model

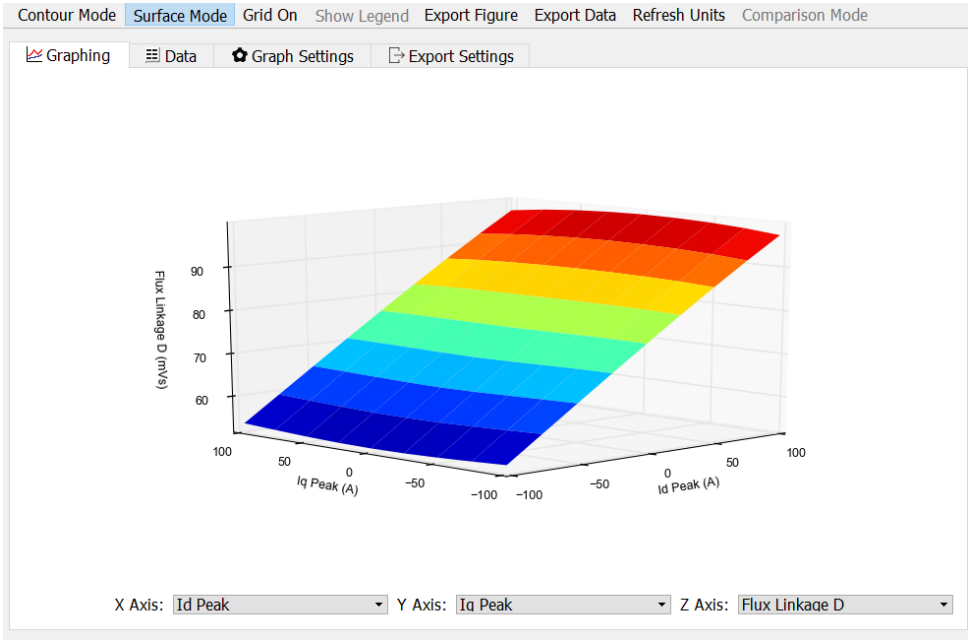


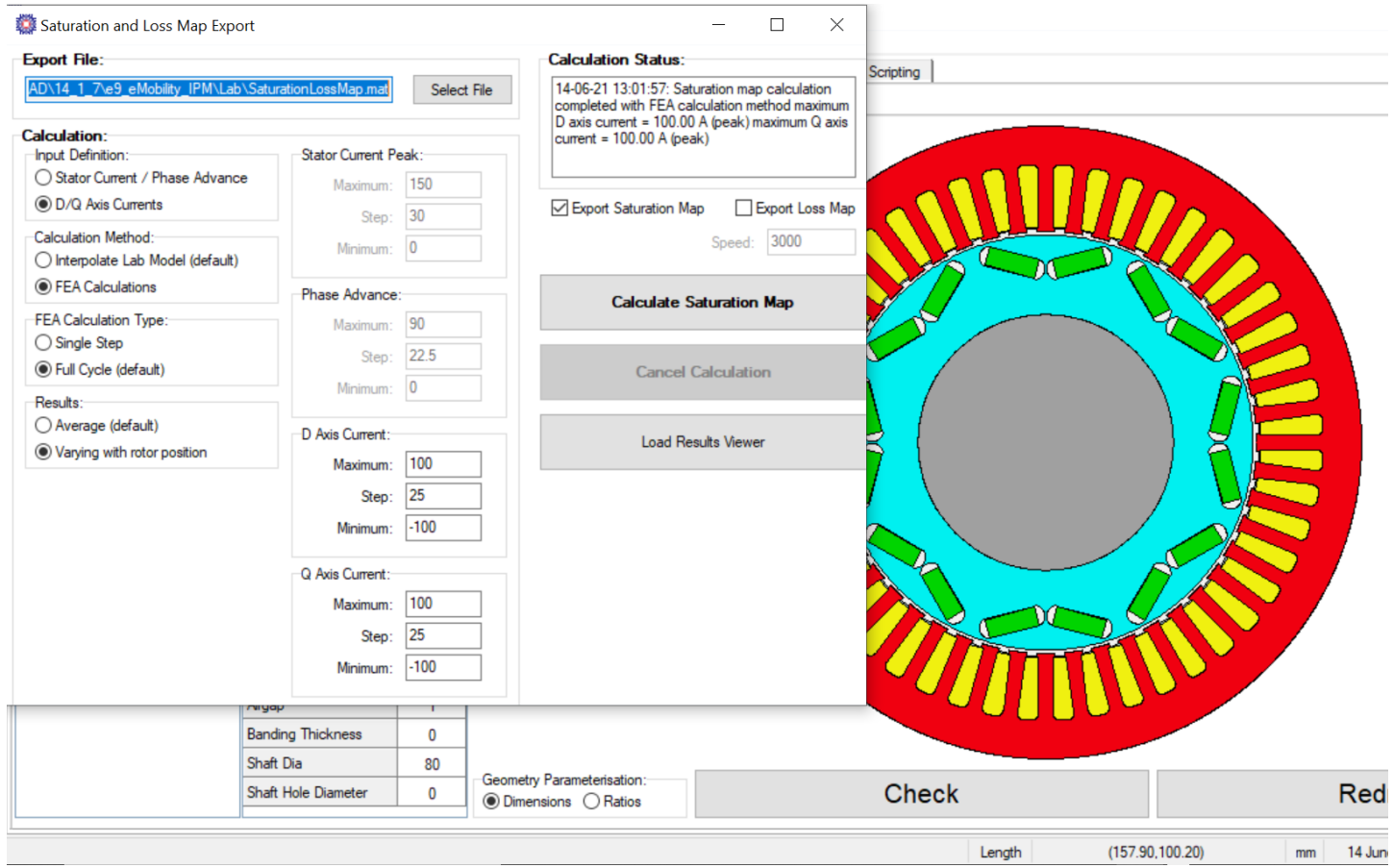




ECE Model Using Motor-CAD

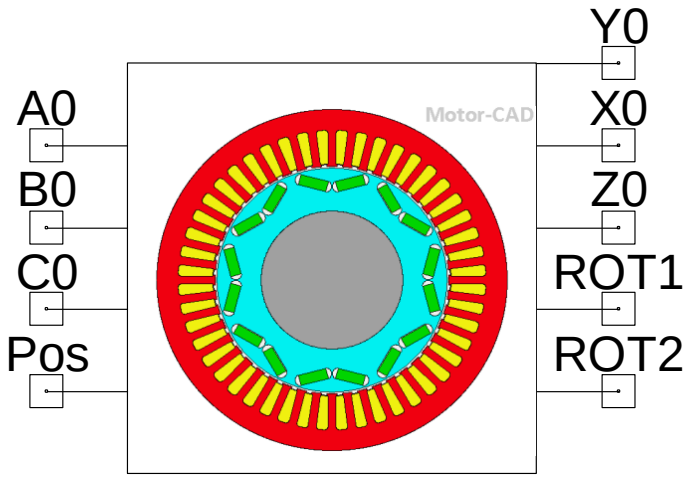
The Saturation and loss map tool generates saturation and loss data for use in other analysis or modelling tools

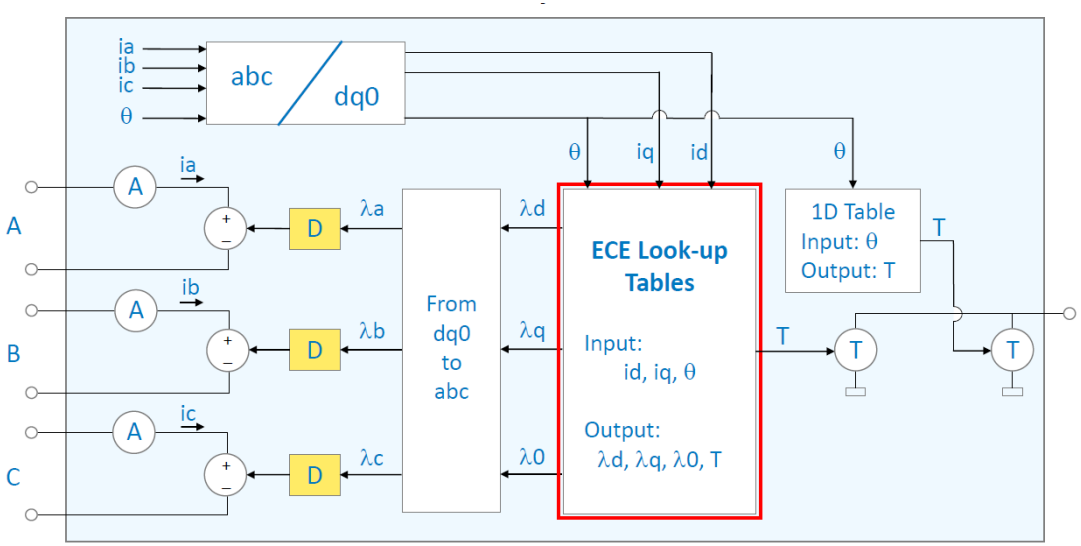




ECE Model Using Motor-CAD

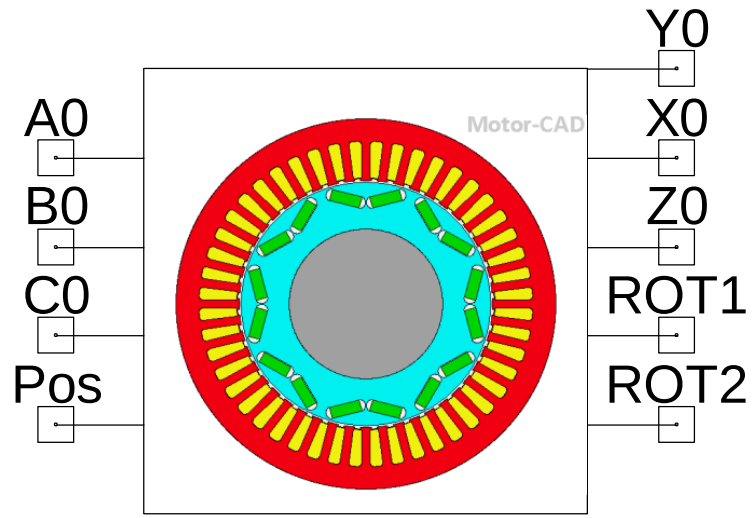
- The ECE Model is a circuit model based on a combination of motor equations/circuit components and look-up tables for flux linkages and torque, obtained from pre-computation of fields results for each variation of all excitation and moving parts via interpolating the input variables of the look-up table
- It can be imported into Twin Builder using a .sml file

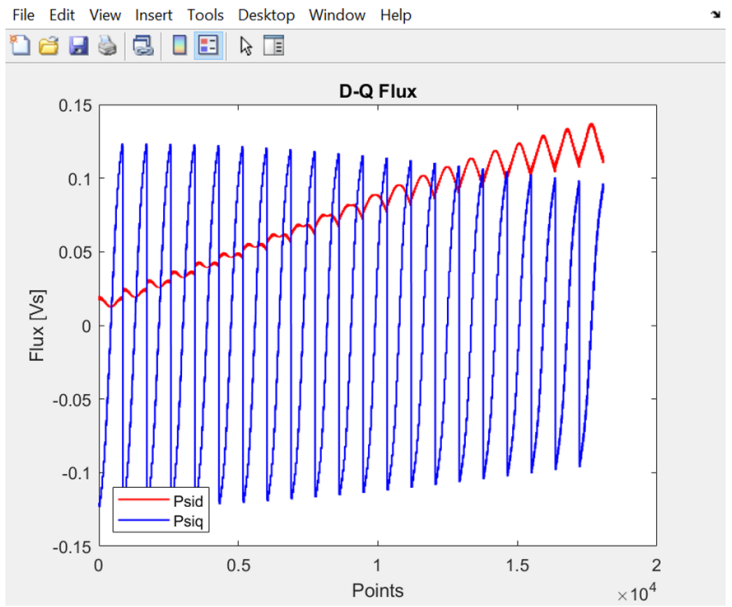


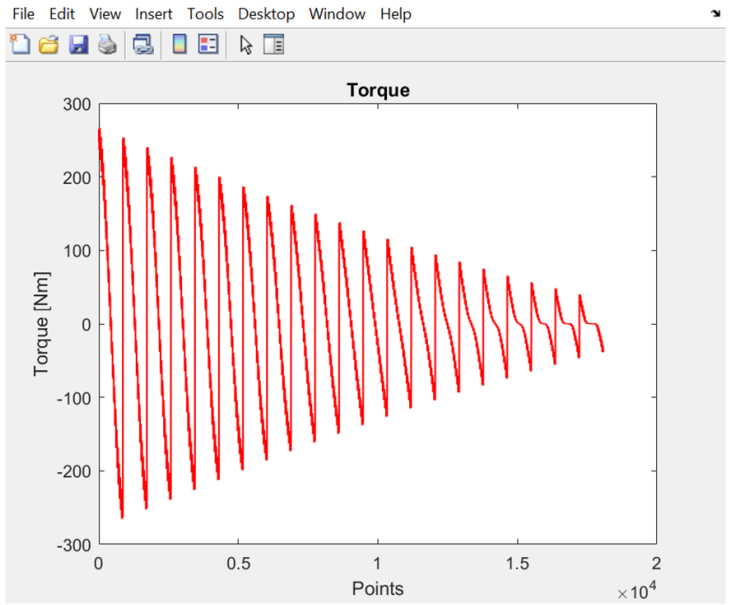


ECE Model Using Motor-CAD

- Flux linkage and torque values are calculated using the Saturation and Loss Map Tool into Motor-CAD
- A script has been implemented in order to realize look-up tables
- OUTPUT -> .sml file

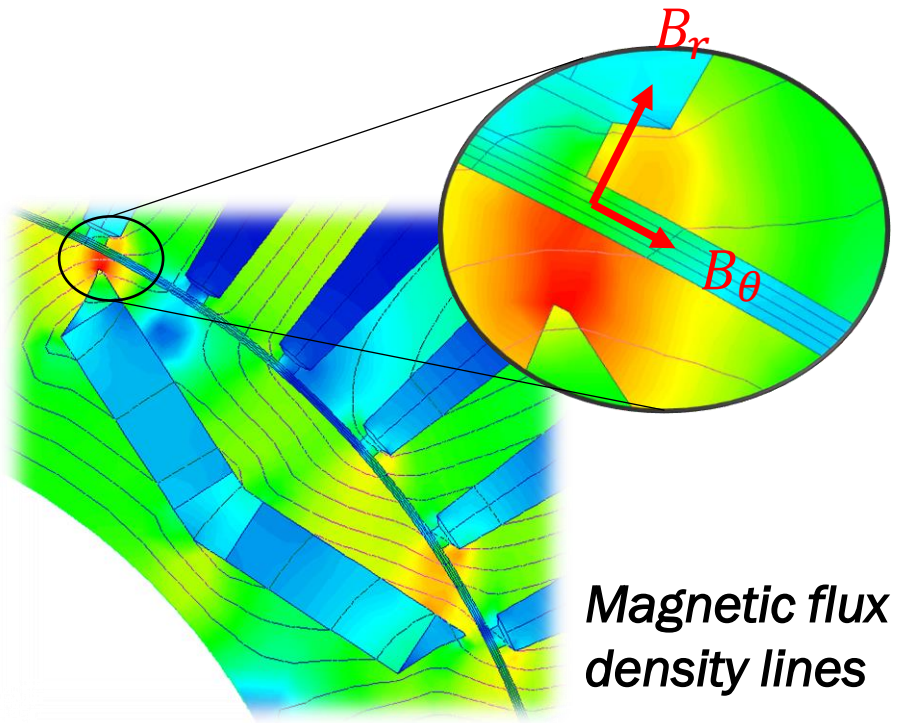






Force Calculation with Motor-CAD

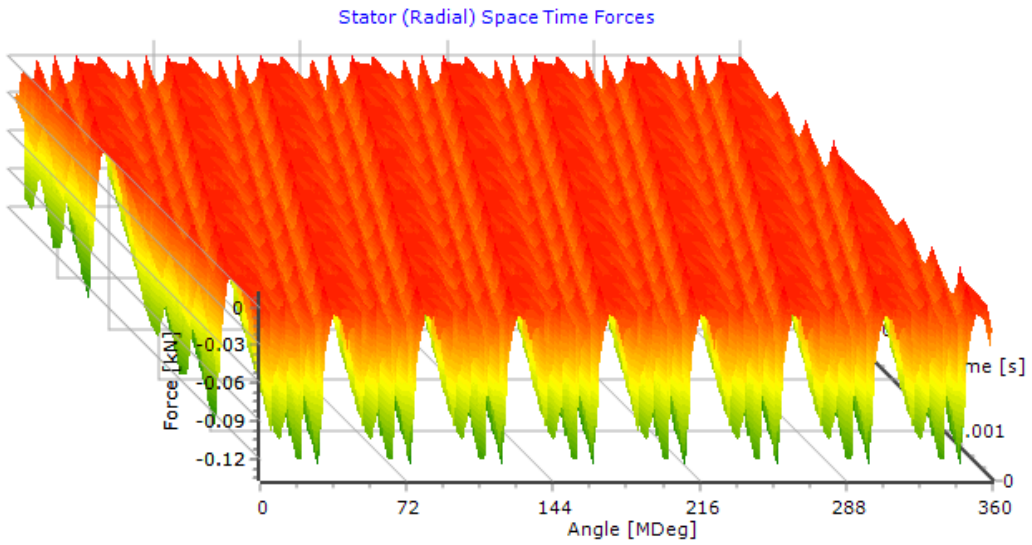
- Forces are calculated from the airgap magnetic pressure applied to the inner stator surface with the Motor-CAD EMag FE solver:
- $\sigma_r = \frac{B_r^2 - B_\theta^2}{2\mu_0} \Rightarrow F_r = \sigma_r S$
- B_r: radial flux density
- B_t: tangential flux density

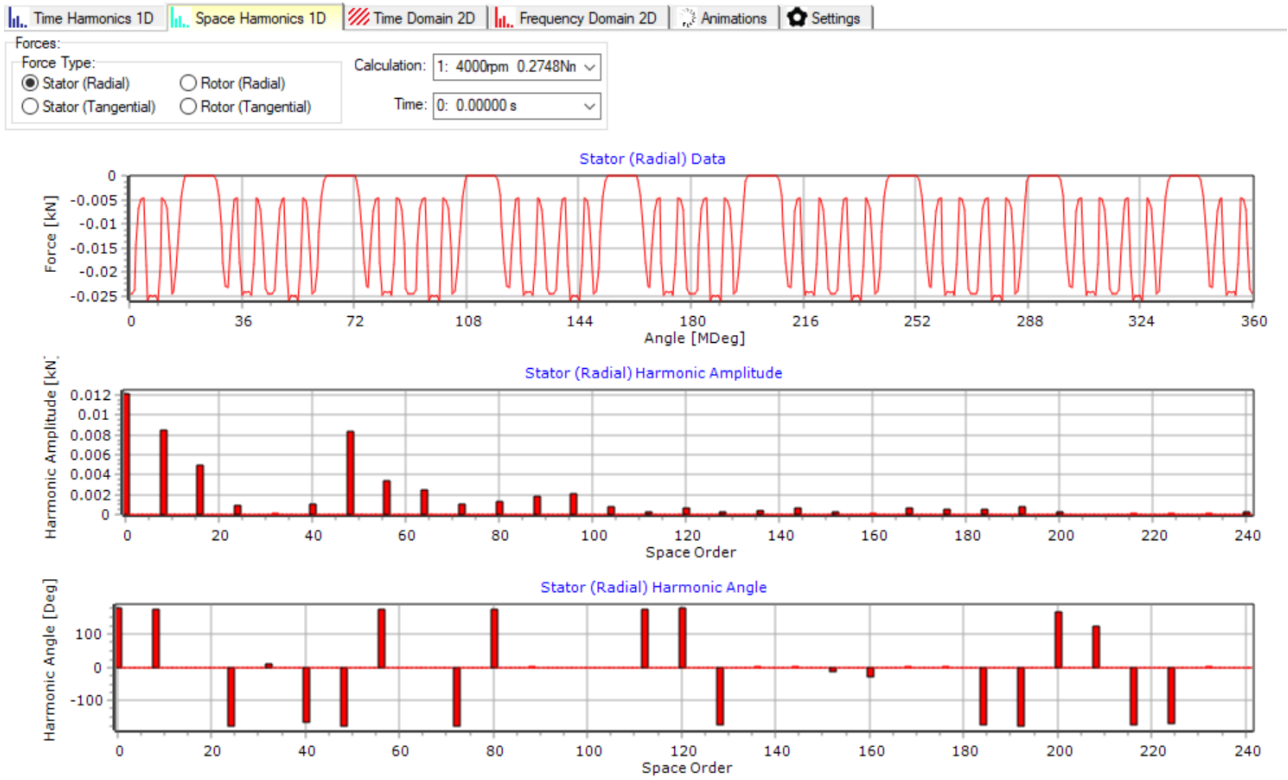


Magnetic flux density lines

Force Calculation with Motor-CAD

- 2D FFT is performed on the force data
  - Space: stator tooth number
  - Time: rotor position





Look-up Table Implementation

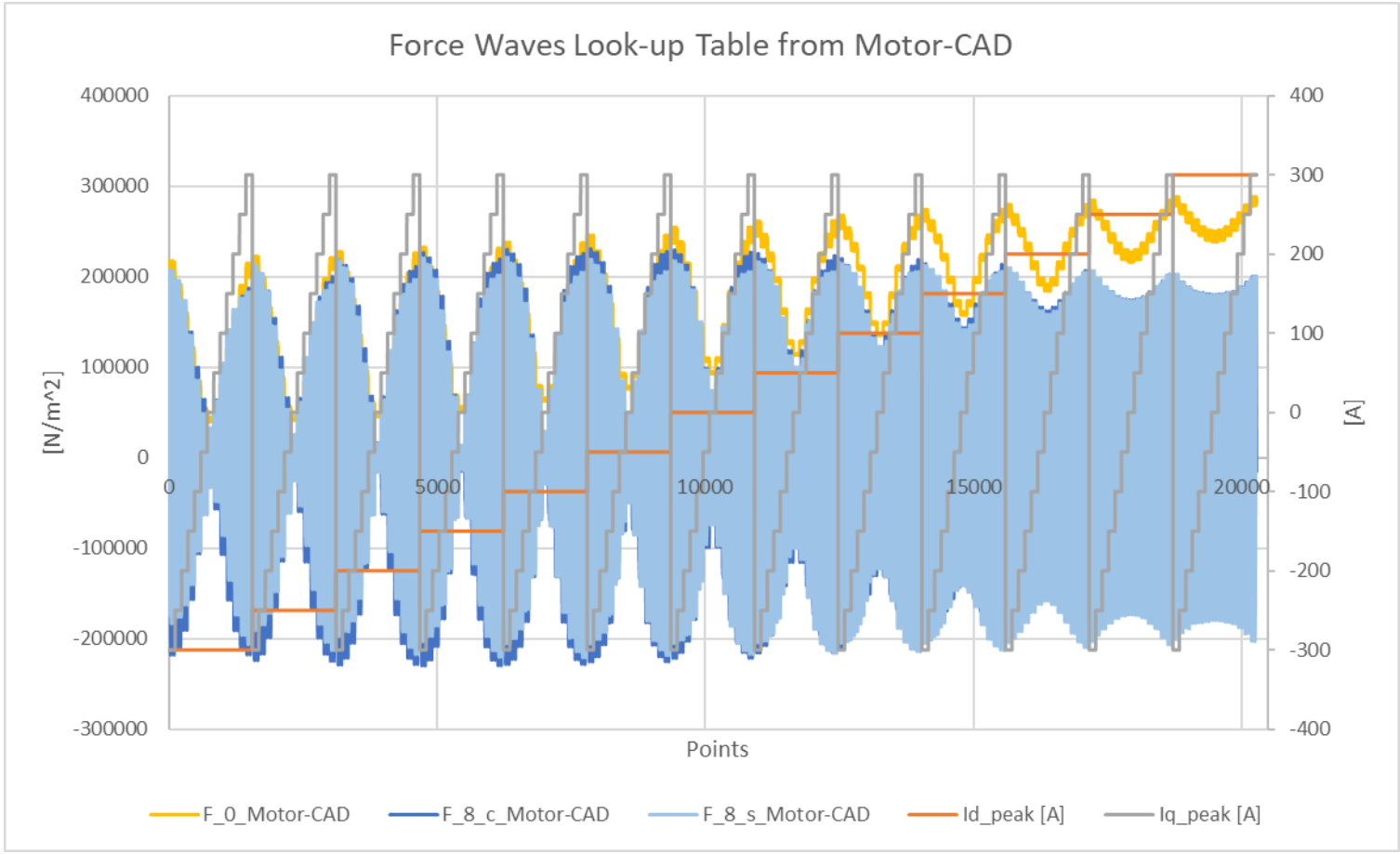
- Force wave coefficients in function of currents and rotor position are calculated using spatial Fourier transformation

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left[a_n \cos\left(\frac{2\pi}{T}nx\right) + b_n \sin\left(\frac{2\pi}{T}nx\right)\right]$$

$$a_0 = \frac{2}{T}\int_{-T/2}^{T/2} f(x)\,\mathrm{d}x$$

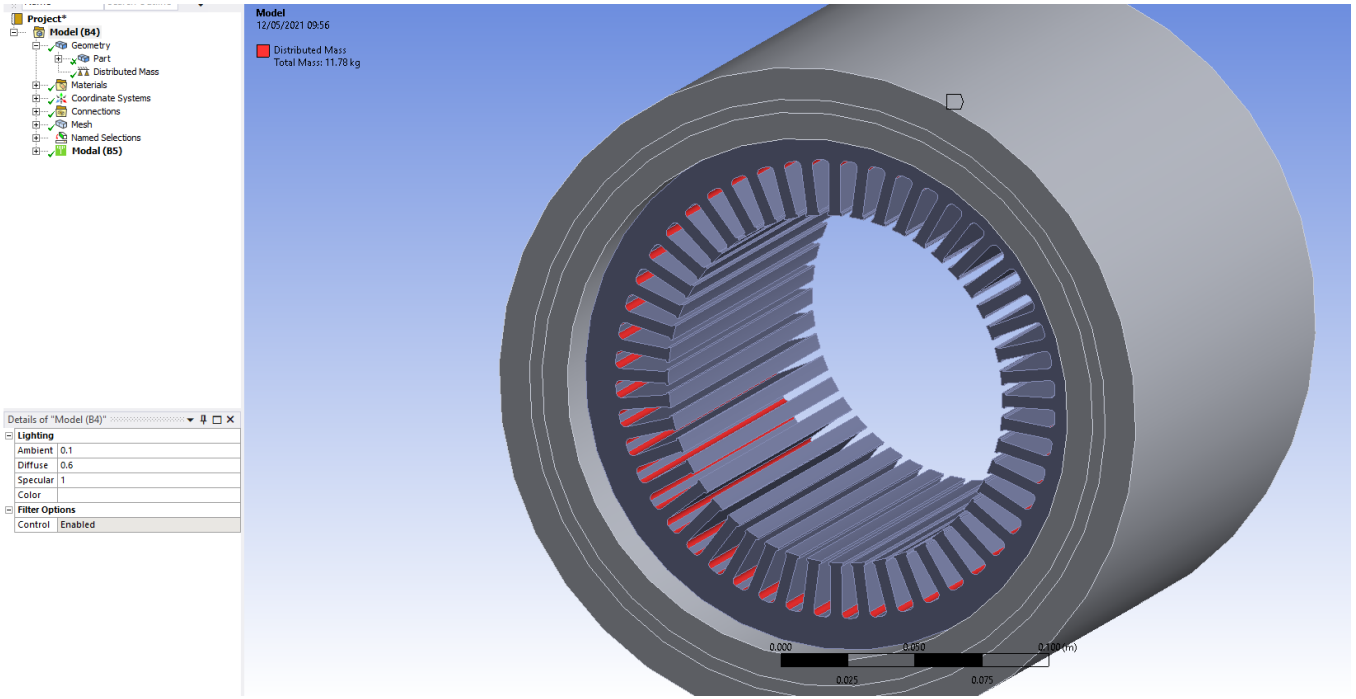
$$a_n = \frac{2}{T}\int_{-T/2}^{T/2} f(x)\cos\left(\frac{2\pi}{T}nx\right)\mathrm{d}x$$

$$b_n = \frac{2}{T}\int_{-T/2}^{T/2} f(x)\sin\left(\frac{2\pi}{T}nx\right)\mathrm{d}x$$



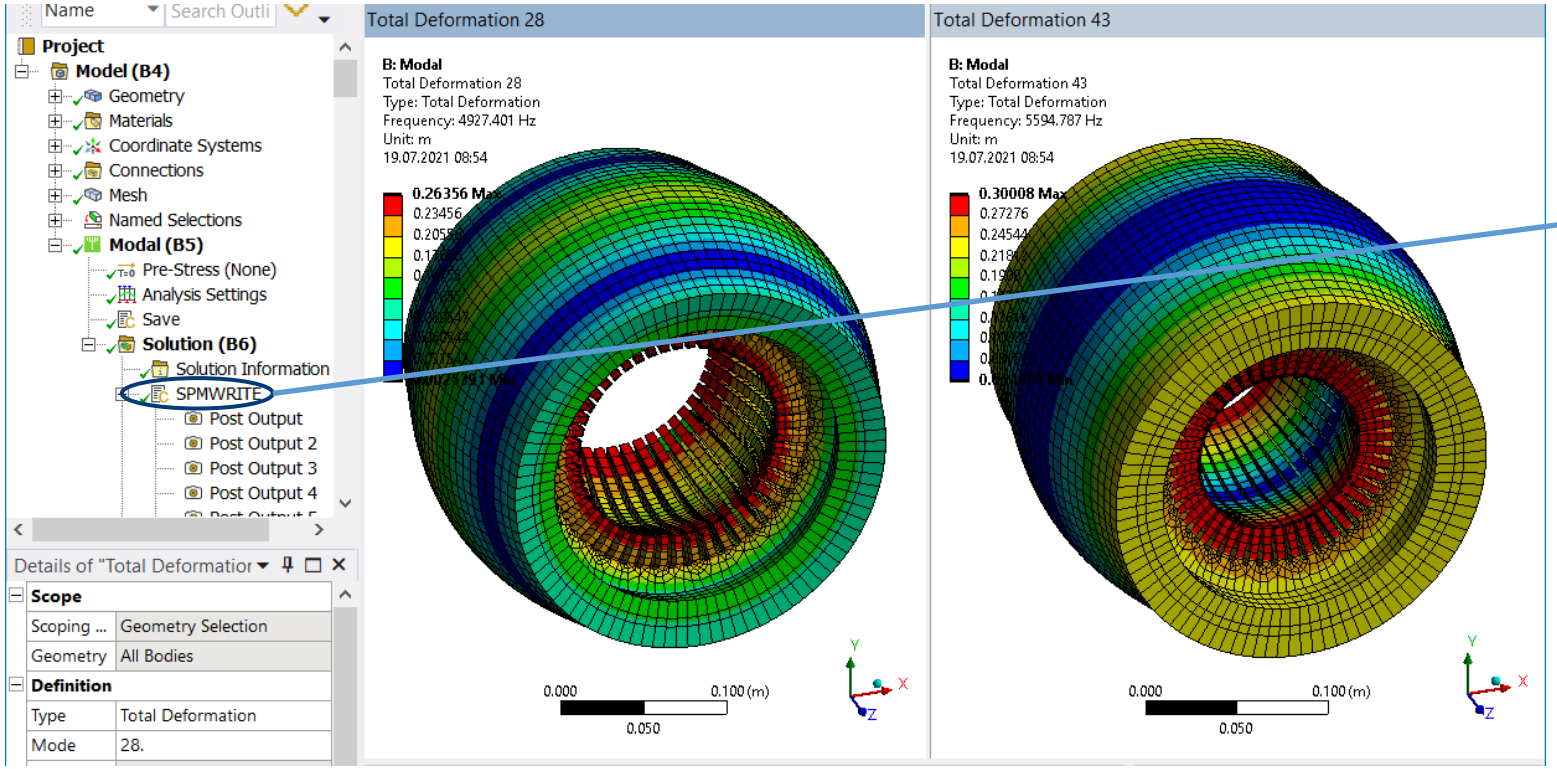
State Space Model

- The geometry can be exported from Motor-CAD into Ansys DesignModeler
- Additional load vectors are applied and state space matrices are exported using SPMWRITE in Ansys Workbench



SPMWRITE to Create Housing ROM

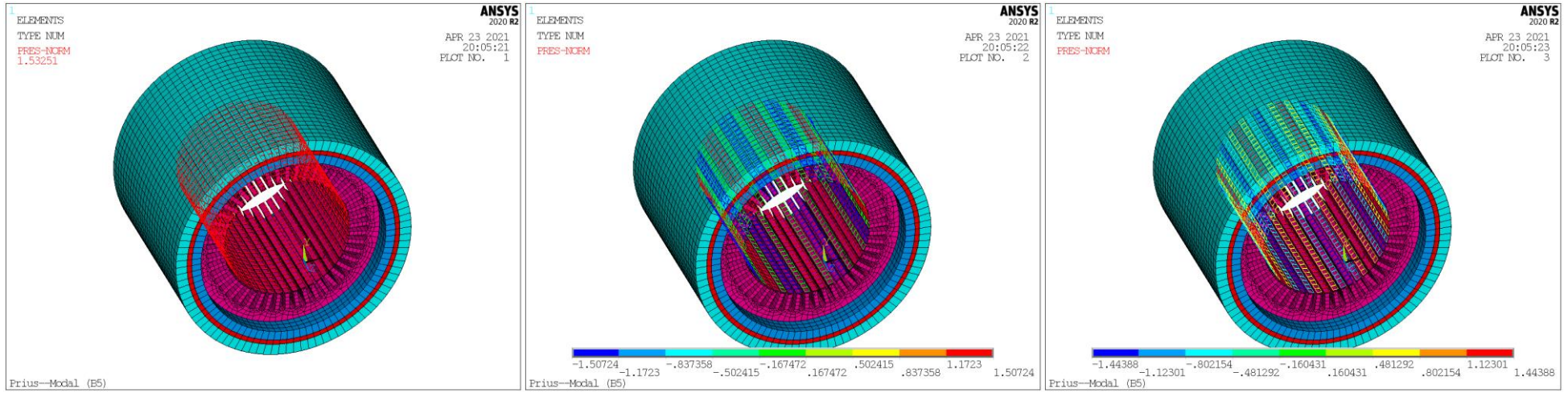
- Apply excitation and radiation force patterns as additional
- load vectors to modal file .mode
- Export state space matrices using SPMWRITE, create SML



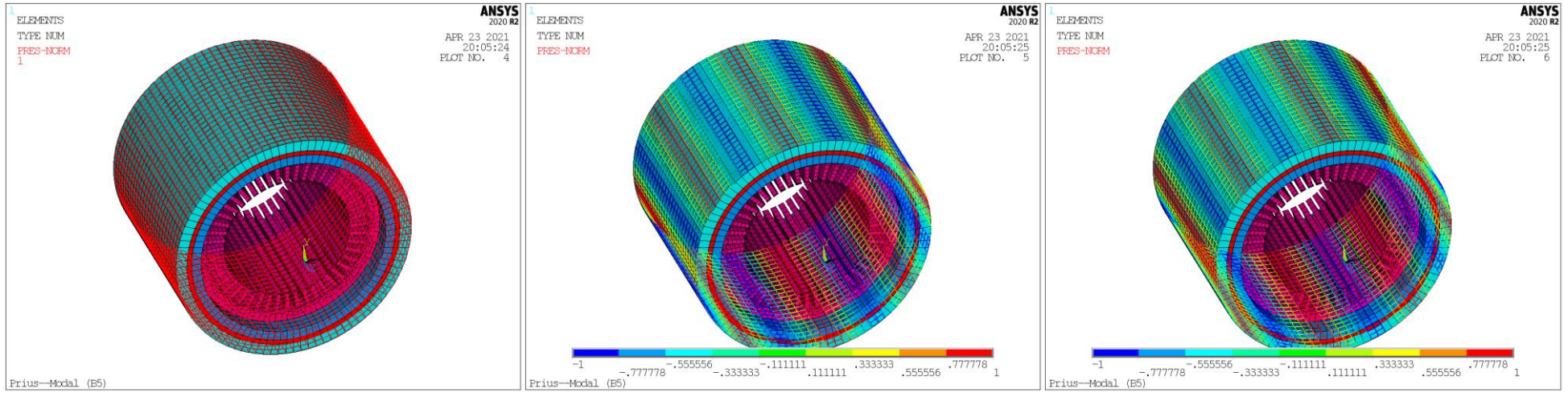

```
/solu
antype,moda
modcont,on
mxpand,,,,yes

fact=1/0.6525   ! fact=tooth_face/cyl_face
*do,i,1,3
  ord=nint(i/2-.25)
  ...           ! fill array nfpress, e.g.:
  csys,1
  *vget,nfpress(1),node,1,loc,y
  *vfact,fact,8*ord*acos(-1)/180
  *vfun,nfpress(1),cos,nfpress(1)
  sffun,pres,nfpress(1)
  sf,force_face,pres,0
  solve
*enddo

*do,i,1,3
  ...           ! fill array nrpress
  sffun,pres,nrpress(1)
  sf,rad_face,pres,0
  solve
*enddo

/post1
spmwrite,,,,,,,,,0
```

Load Vectors

Input load vectors: pressure at teeth heads

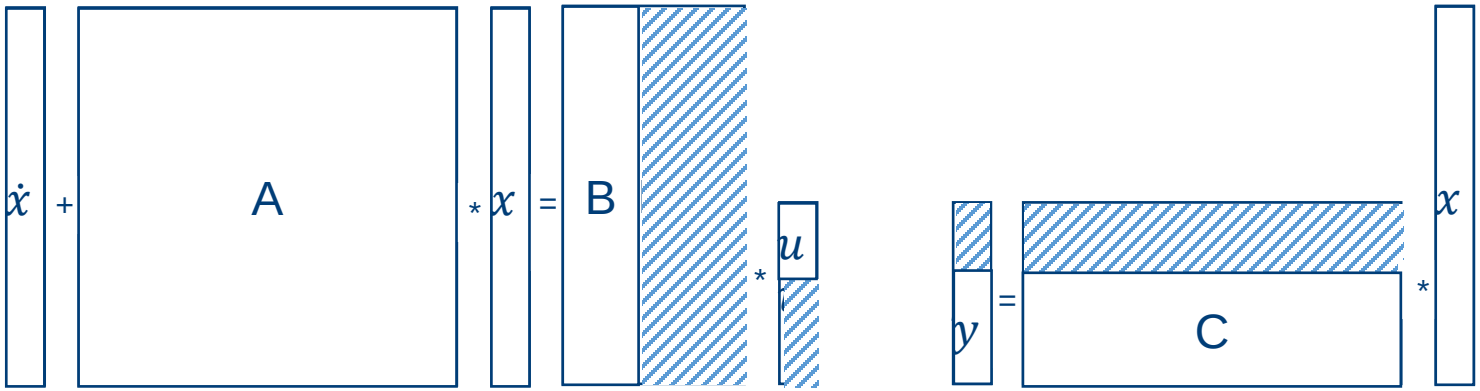


Output load vectors: pressure at outer surface



Load Vectors, Transfer Matrices to SML, Convert to Causal

- Load vectors are applied as spatial pressure distributions
- Allow definition of input loads (force waves onto tooth faces) and output loads (surface modes)
- SPMWRITE creates State Space Model, cut last column from input and first rows from output
- Add header for causal SML-model

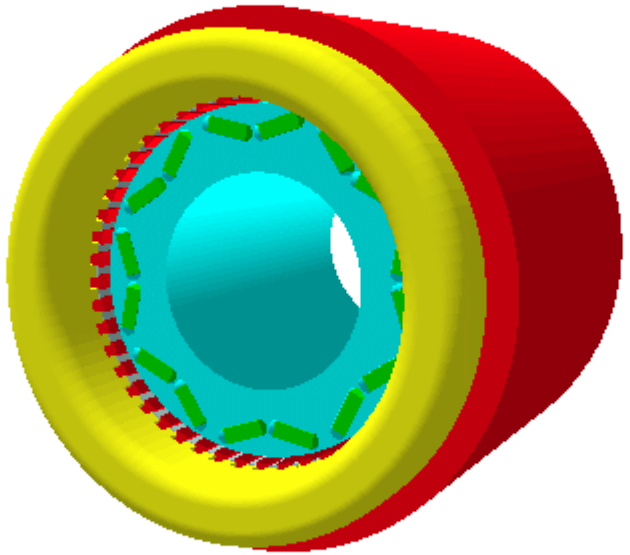


Case study: Fast NVH simulation for a traction machine

Motor-CAD

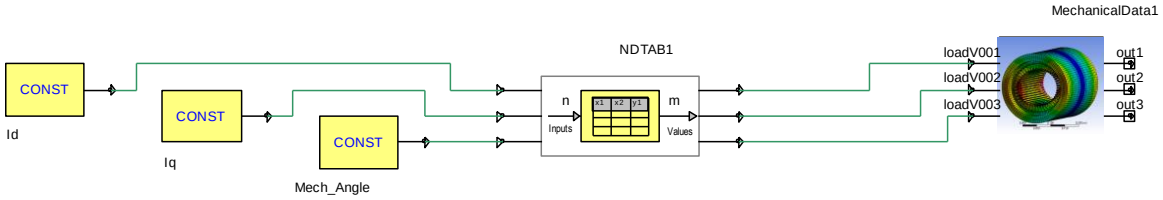
Design Parameters

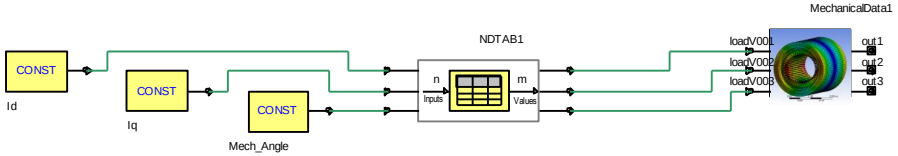
Parameter	Value
Slot number	48
Pole number	8
Stator outer diameter [mm]	198
Rotor outer diameter [mm]	130
Airgap [mm]	1
Active length [mm]	160

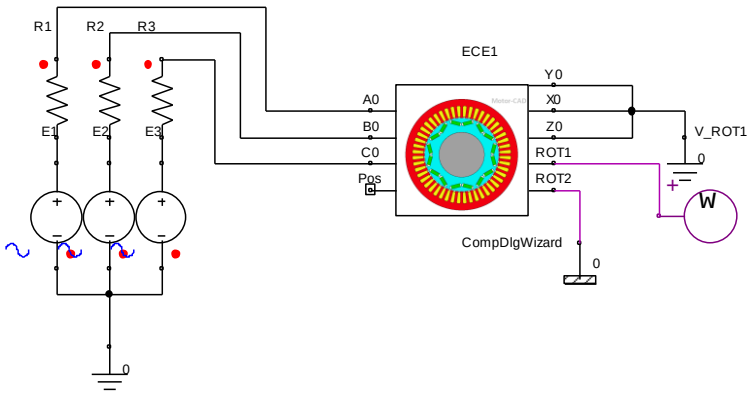


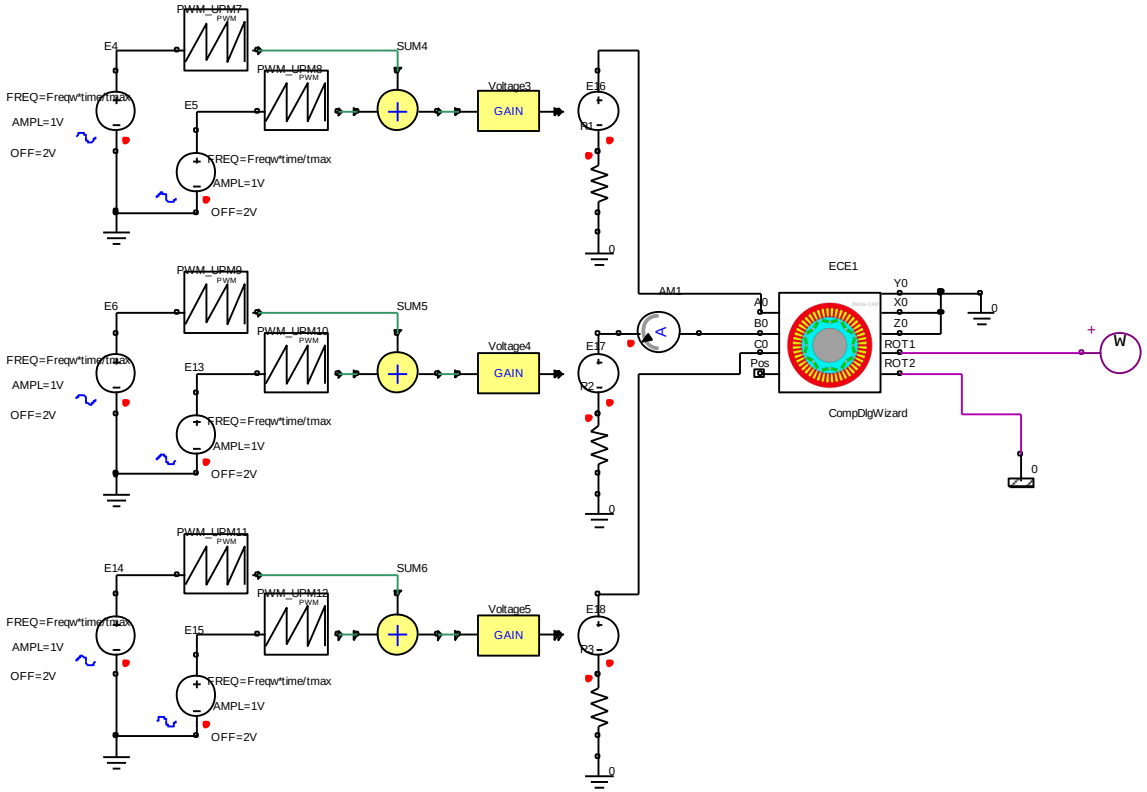
Acoustic response

The machine has been tested with a sinusoidal voltage excitation and a PWM one

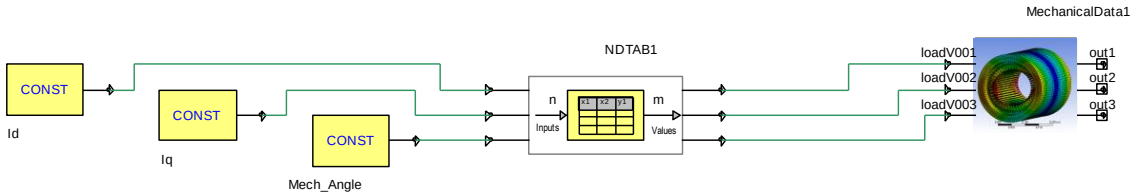


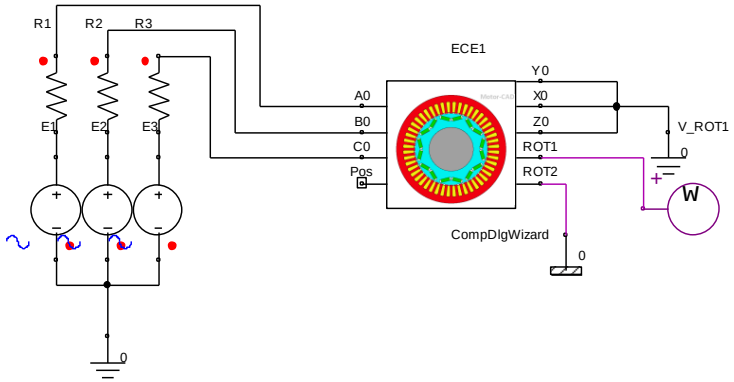


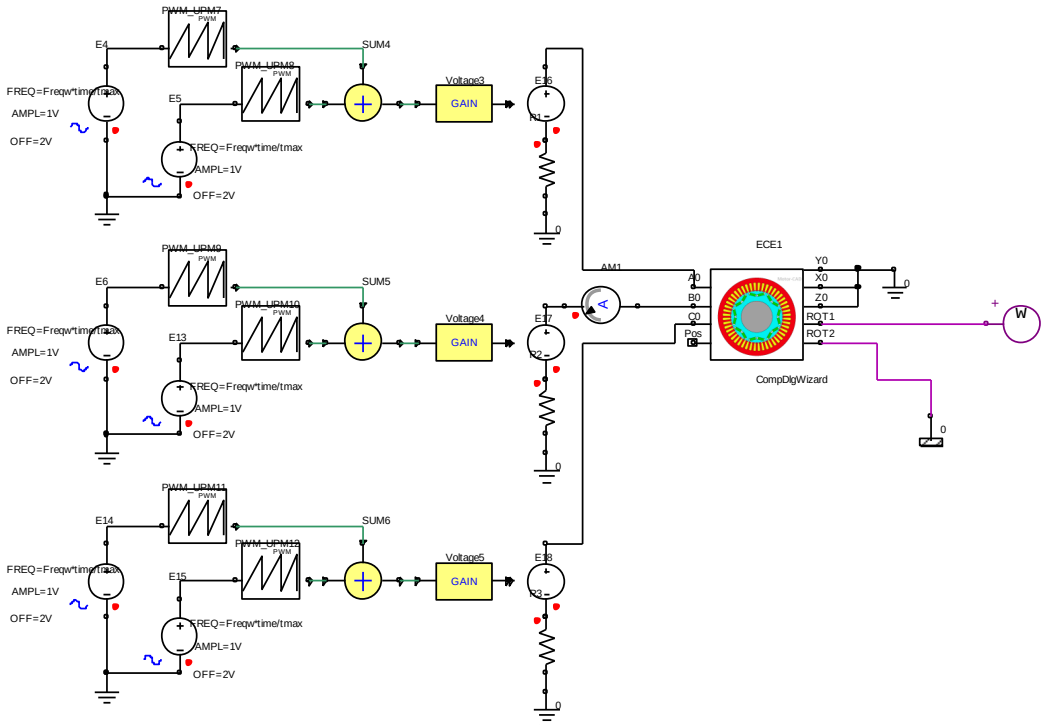




Acoustic response

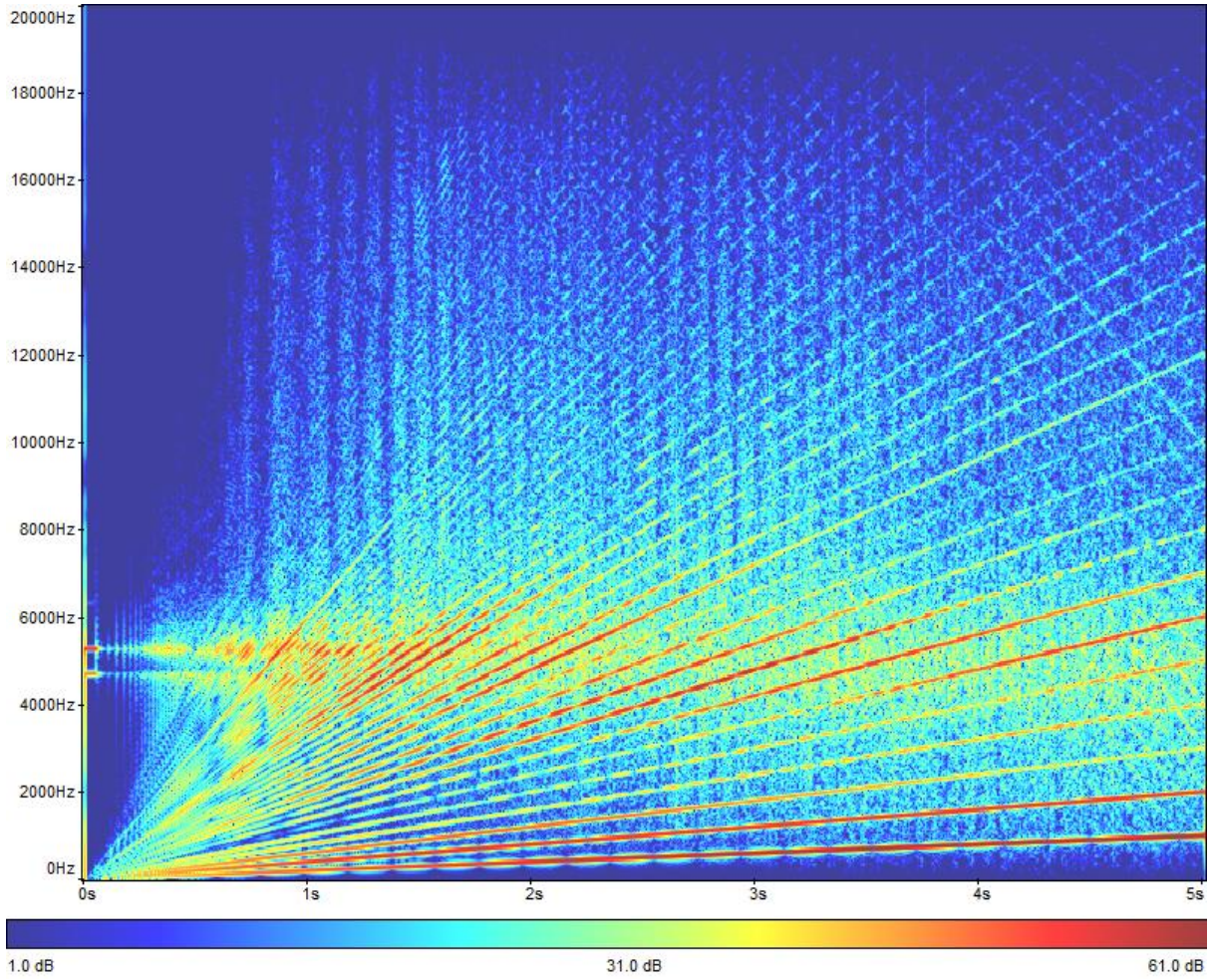




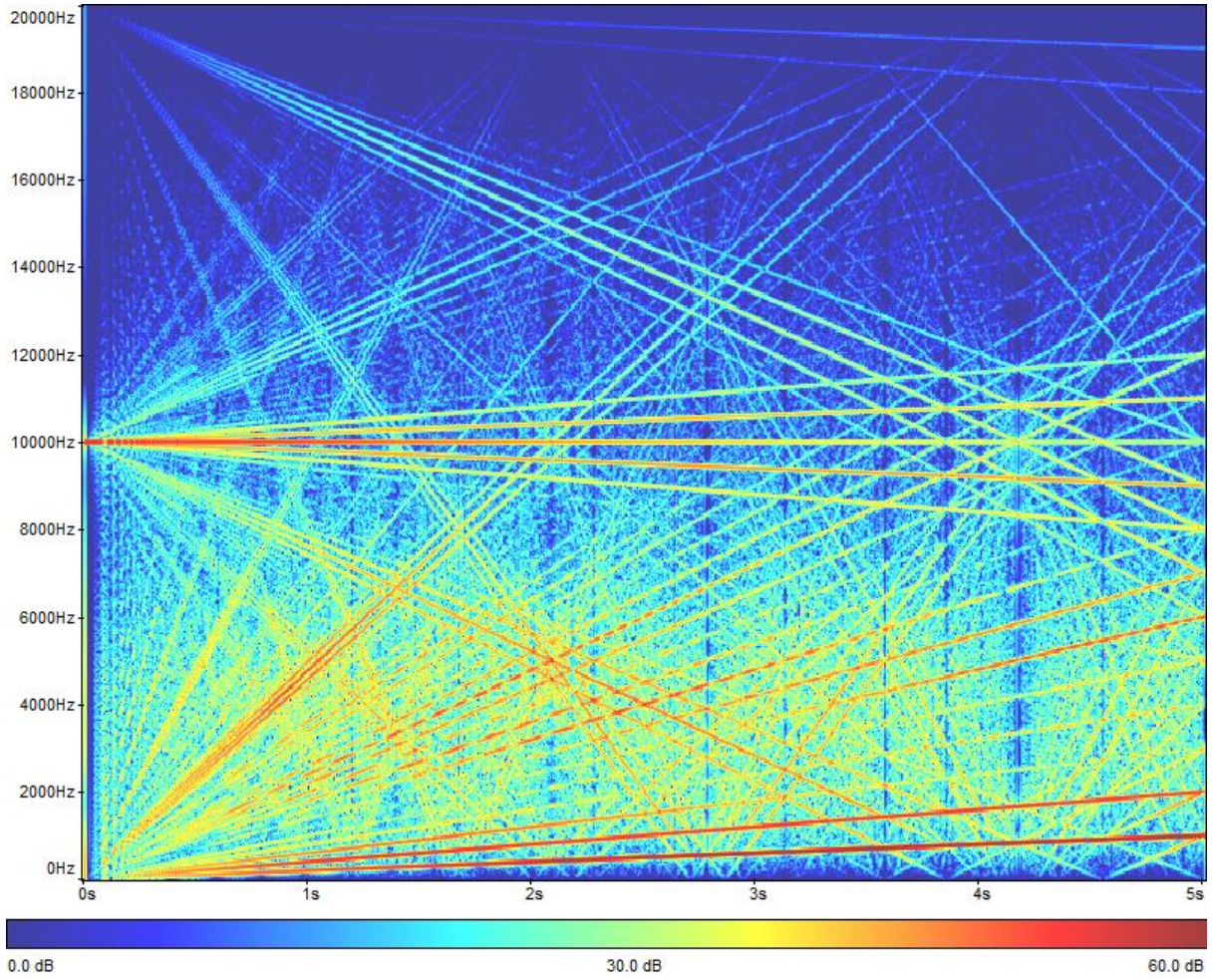


Waterfall diagrams comparison

Voltage source



PWM excitation



Motor Design Software by Motor Design Engineers