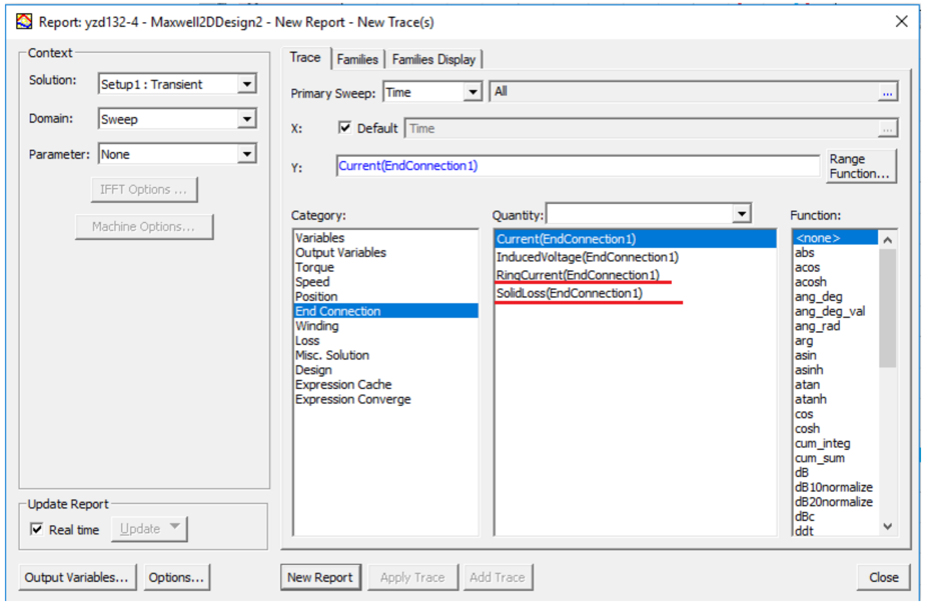
2019 R2 Highlights – Low Frequency Electromagnetics

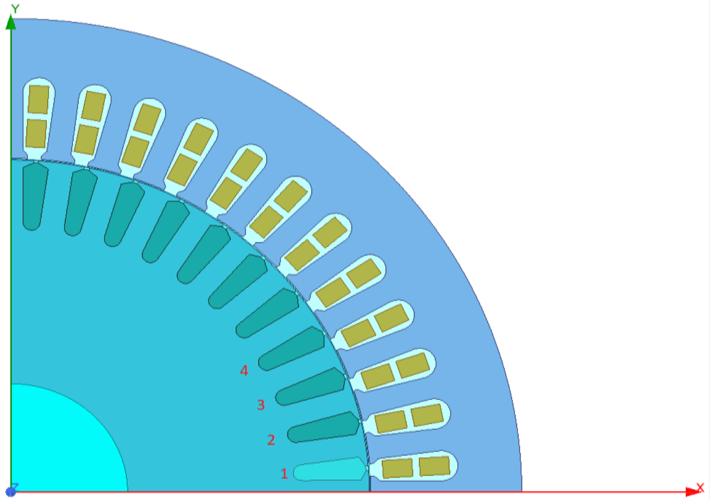
Outline

- 2D Transient end-ring Loss and Current Output
- Enhancements for Electrical Machine Design Toolkit
- High Frequency Resolution in Harmonic Force Coupling
- Field Loss Output Independent of Save Field Setup
- Conductance Matrix Extraction from 3D DC Conduction Solution
- Band Layer Mesh for both Static and Moving Side
- UDP for Slot-less Motor
- Temperature-Dependent Multiple BH Curves
- Anisotropic Core Loss Coefficient Support

2D Transient end-ring loss and current output

- **Add solid Loss curve for each end connection in result report**
  - The solid loss includes solid loss on all the bars and on two end rings of the specified end connection
- **Add end-ring current curve for each end connection in result report**
  - The end-ring current is the current in the ring between first bar and second bar of the specified end connection
  - In end connection, the bars are numbered starting from x axis and in counterclockwise direction





Enhancement for Induction Machine Design

- **Periodic TDM Improvement**
  - **Half-periodic TDM option**
  - **Rotor loss at rated operation**

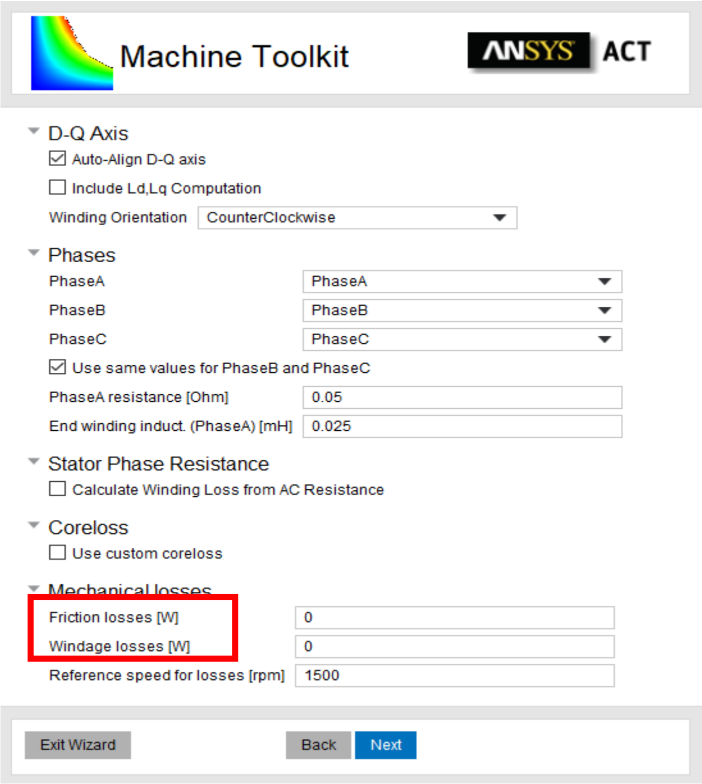
	TDM (referred to locked-rotor)	Non-TDM (at rated speed)	Difference
Torque	3.0 kN	3.16 kN	5%
Current	3.06 kA	3.03 kA	1%
Core Loss	472.8W	529.9 W	10.8%
Eddy Current Loss	$41+23.4*0.1^2$ = 41.2W	41.1+5.5=46.6 W	11.6%
Hysteresis Loss	401.4+191.9*0.1=420.6W	403.9+67.1 = 471W	10.7%
Excess Loss	$10.9+6.1*0.1^{1.5}$=11W	10.9+1.4=12.3W	10.6%
Rotor Solid Loss	240.5/ 24.05 kW	29.45 kW	18.3%
Stator Winding Loss	140.5 kW	137.7 kW	2%
Total loss	165 kW	167.7 kW	1.6%

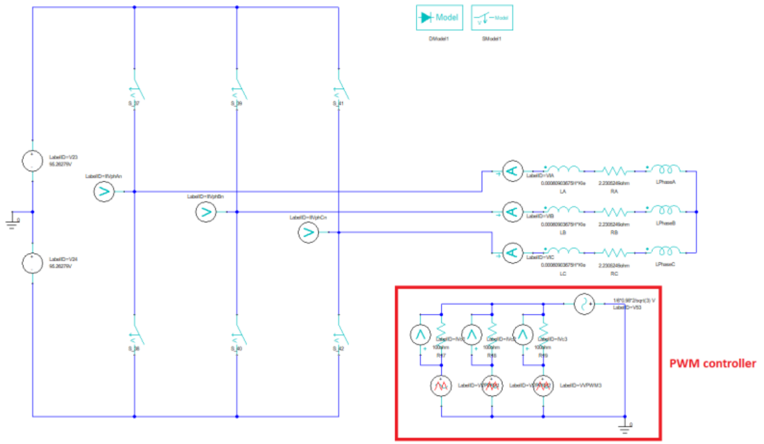
Enhancement for PM Synchronous Machine Design

- **Support Periodic TDM**
  - Observation : at synchronous speed, the rotor will satisfy the full periodic condition even if the stator satisfies the half periodic condition
- **Auto-Align DQ Axis**
  - Zero stator current
  - The angle gamma is obtained based on the phase shift of the fundamental component of phase-A flux linkage

Main Improvements in Pre-Process

- **Separate Mechanical Loss Input**
  - Friction losses
  - Windage losses
- **Remove Periodic TDM Setting**
  - Get TDM information from the source design
  - Reduce DOE settings for periodic TDM
- **IM: Sinusoidal PWM Control**
  - User defines DC voltage and limit of modulation index
  - External circuit with PWM control is created
  - $K_f = fc/fm = 30$

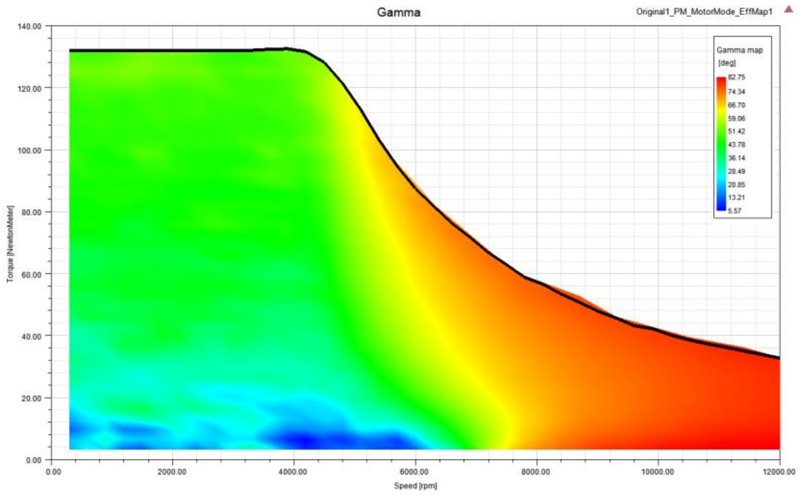


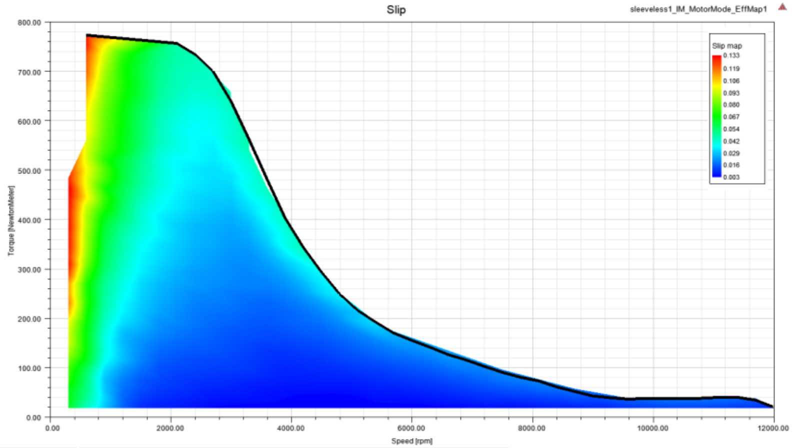


External circuit with SinPWM modules

Main Improvements Post Process

- **More Maps**
  - Gamma map: for PM synchronous machines
  - Slip map: for induction machines
  - Winding loss map
  - Core loss map
  - Solid loss map
  - Mechanical loss map
  - Power factor map
  - Torque ripple map





- **Values from Time-Varying Curves**

Variables	Version 2019 R1	Version 2019 R2
Torque and Loss	average	average
Phase AC Variables	rms	rms
DQ Variables	rms	average

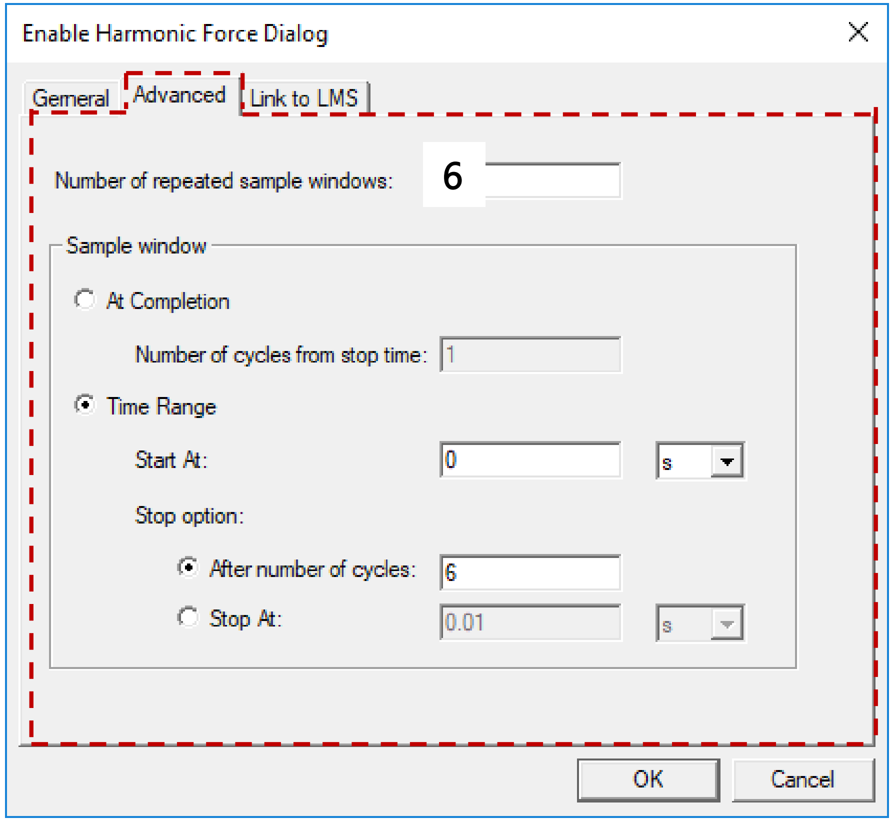
Main Improvements in Post Process (Cont.)

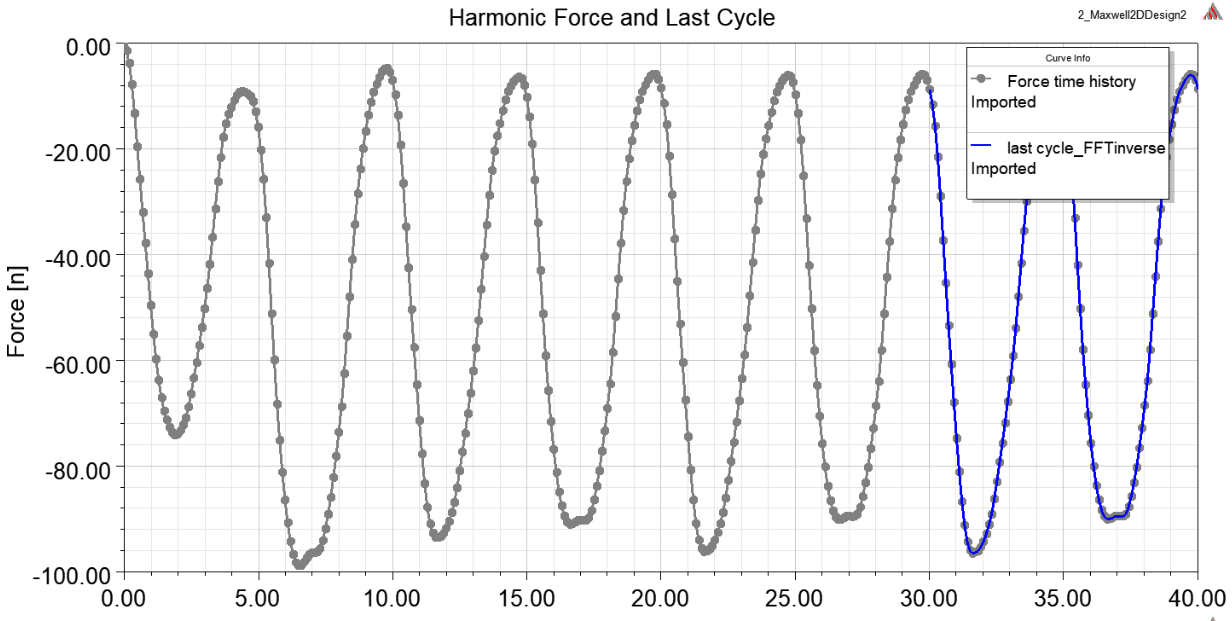
- **Induced Voltage RMS Values**
  - **Before:** derived directly from the waveforms, including fundamental and harmonic components
  - **New:** derived from d-q flux linkages, including fundamental component only, to balance applied sinusoidal voltages
- **Terminal Voltage RMS Values**
  - **Before:** directly obtained from induced voltages, which will not vary with leakage impedance
  - **New:**
    - **For induction machines:** obtained directly from swept voltage variable, leakage impedance already considered in the parametric solutions
    - **For PM synchronous machines:** derived from d-q currents and flux-linkages, leakage impedance is considered in post process, map profile changes with leakage impedance

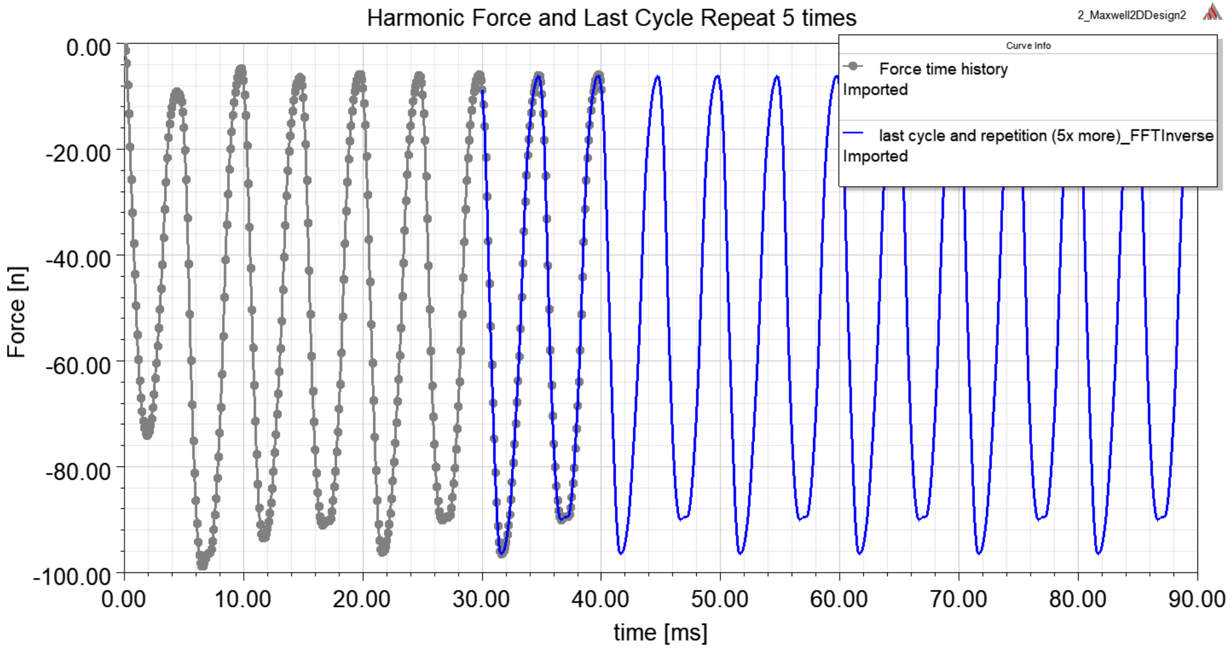
High Frequency Resolution in Harmonic Force Coupling

Harmonic Force Calculation

- ❑ New option: **Repeat of sampled data**



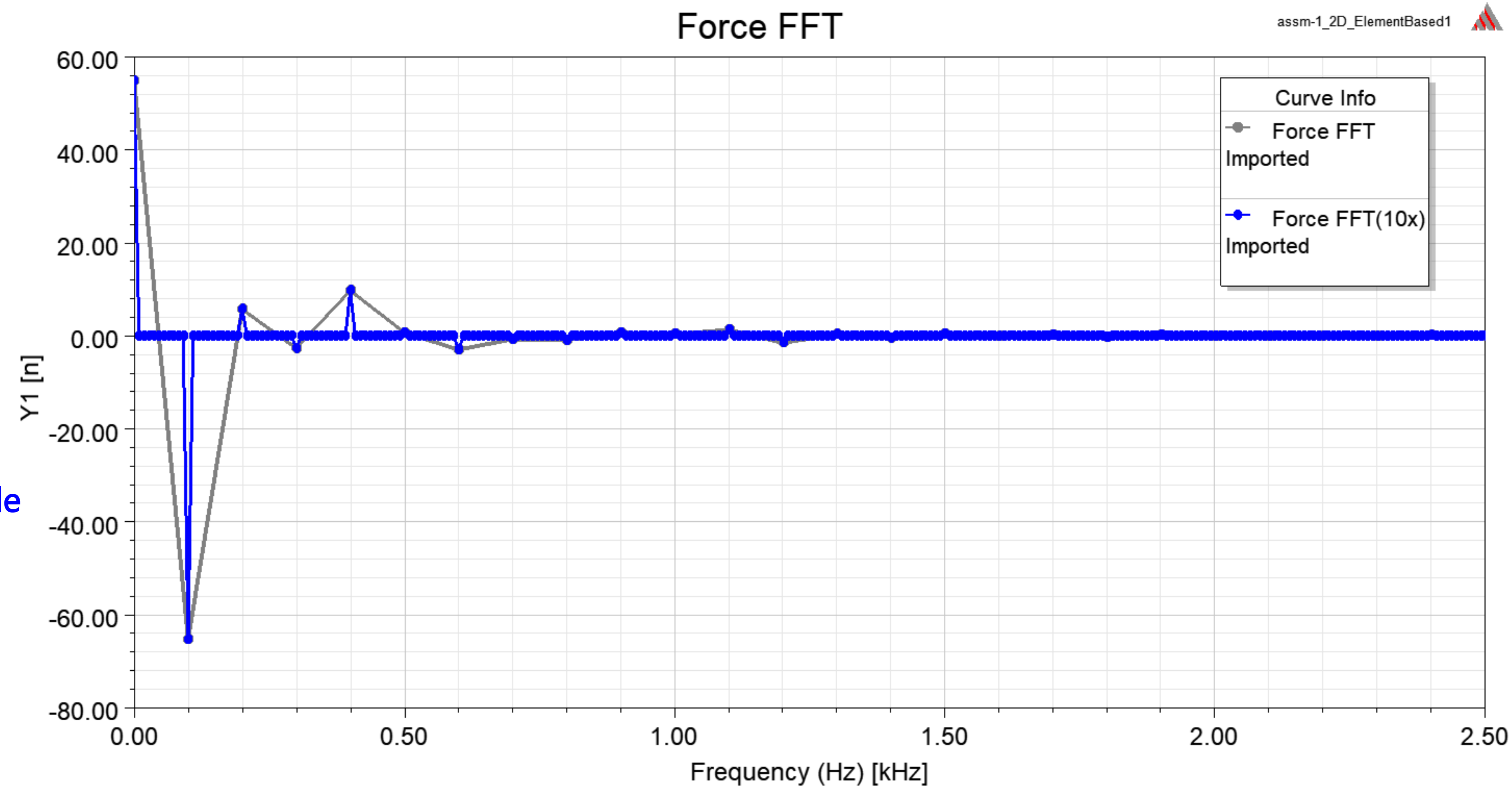




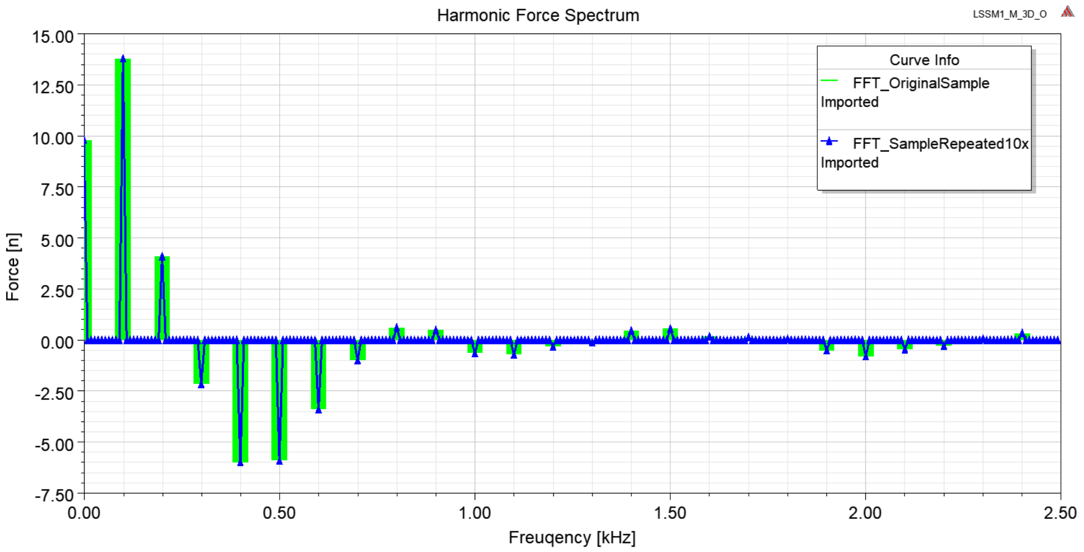
Enable High Resolution Spectrum

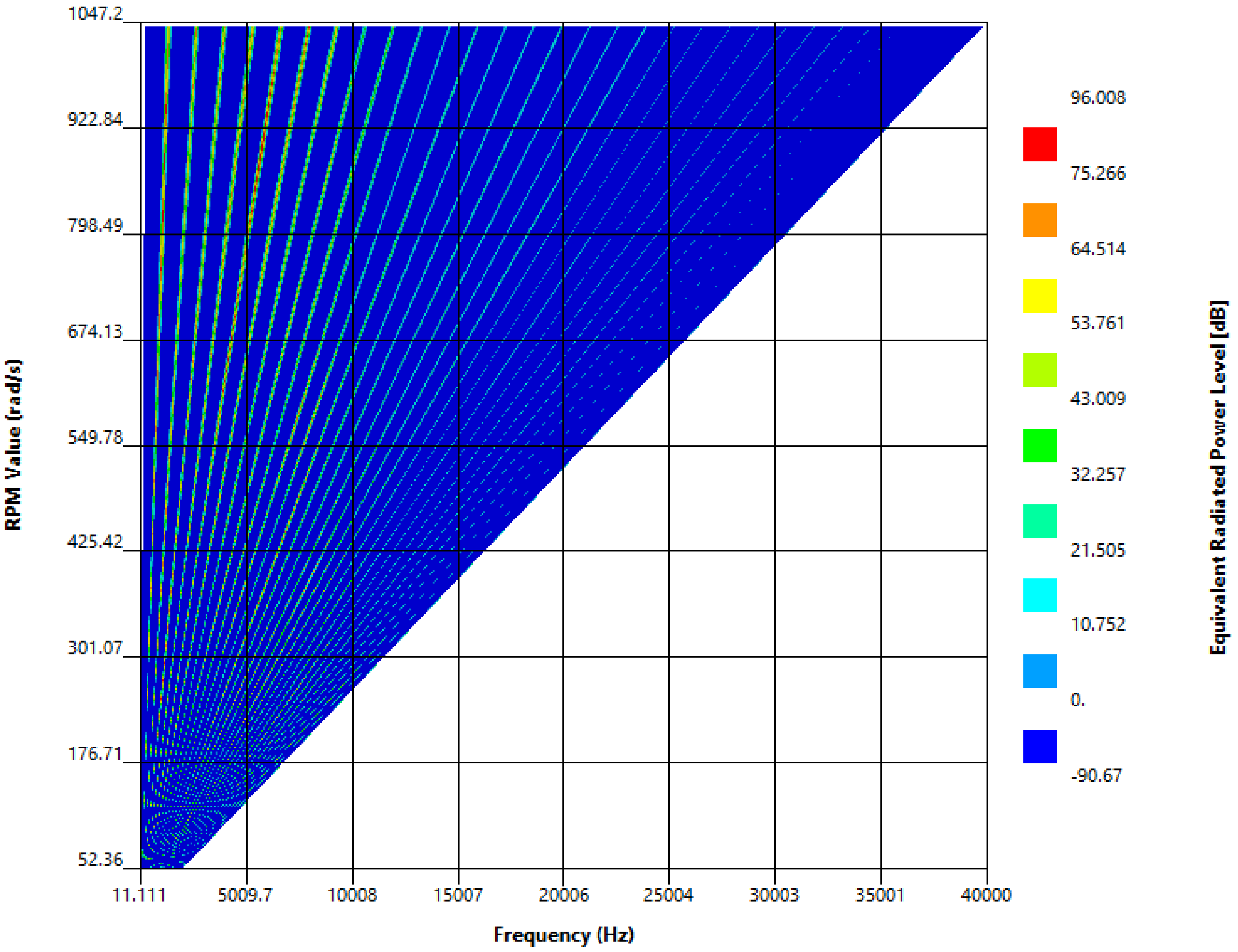
FFT from
Original Sample

FFT from
Repeated Sample



Enable High Resolution ERP Waterfall Plot



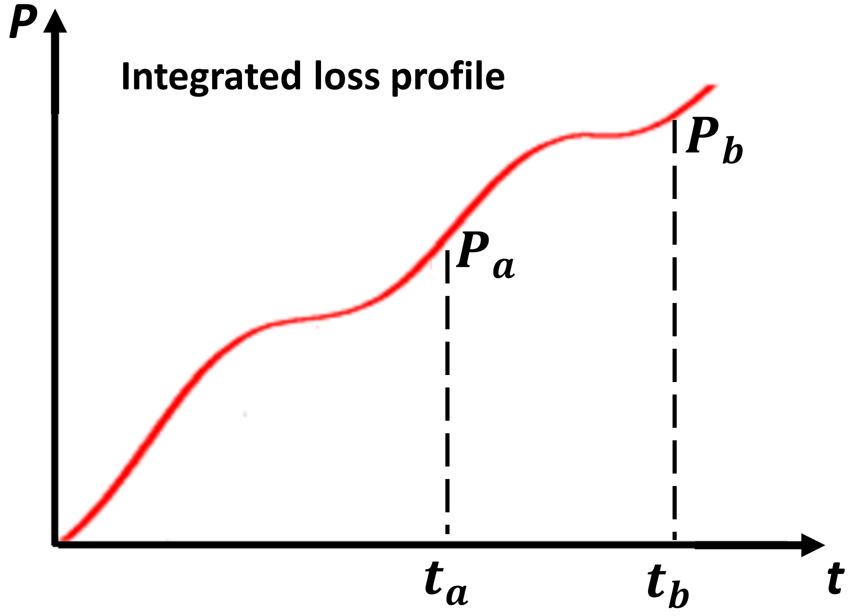


Field Loss Output Independent of Save Field Setup

- For multi-physics coupling, averaged loss over one cycle is required
- Averaged loss can be obtained from integrated loss with time by

$$(P_b - P_a) / (t_b - t_a)$$

time points t_a, t_b …. have to be included in save field setup

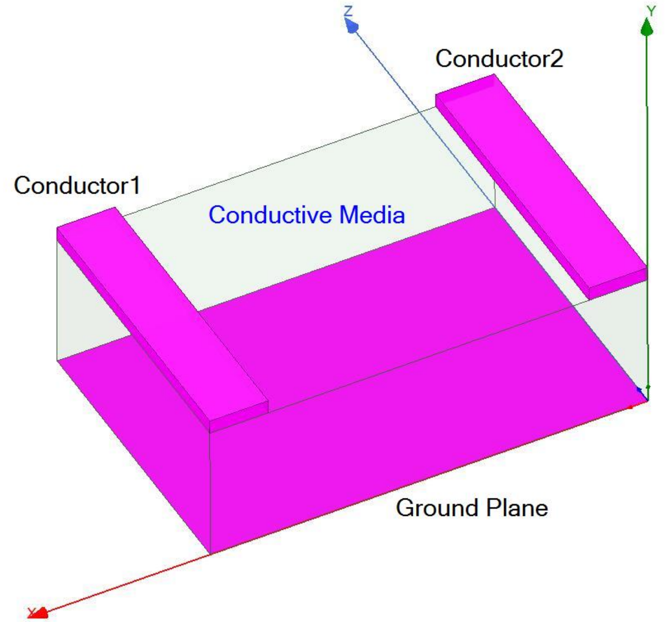


- Currently, solver only output integrated loss to field post-process. Thus, instant loss has to be recovered from integrated loss
- Recovered Instant loss is correct only if all time steps are included in save field setup
- This enhancement is to have solver to directly output instant loss in addition to integrated loss so as to be independent of save field setup

Conductance Matrix Extraction from 3D DC Conduction Solution

- Definition

$$\begin{bmatrix} I_1 \\ I_2 \\ \cdots \\ I_n \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} & \cdots & G_{1n} \\ G_{21} & G_{22} & \cdots & G_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ G_{n1} & G_{n2} & \cdots & G_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \cdots \\ V_n \end{bmatrix} \quad \text{or} \quad \boldsymbol{I} = \boldsymbol{GV}$$

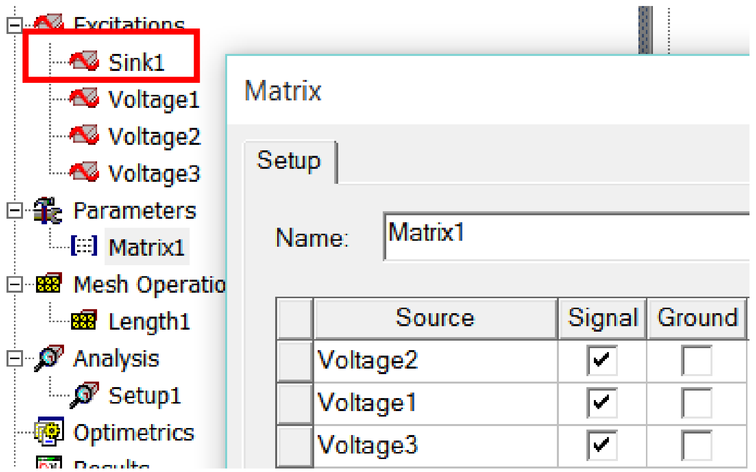


For example, a two conductor system with a ground plane

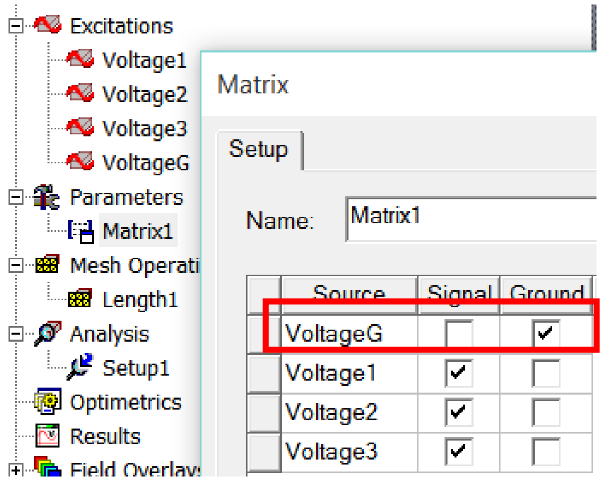
$$I_1 = G_{11} * V_1 + G_{12} * V_2$$

$$I_2 = G_{21} * V_1 + G_{22} * V_2$$

- Either a "sink" excitation or at least one "ground" to be explicitly selected from voltage excitations has to be defined
- For the time being, only voltage excitation is supported (exclude current excitations)



Sink defined

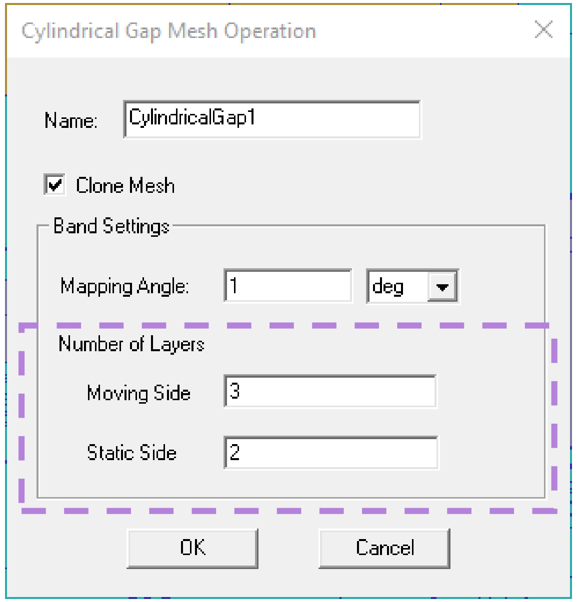


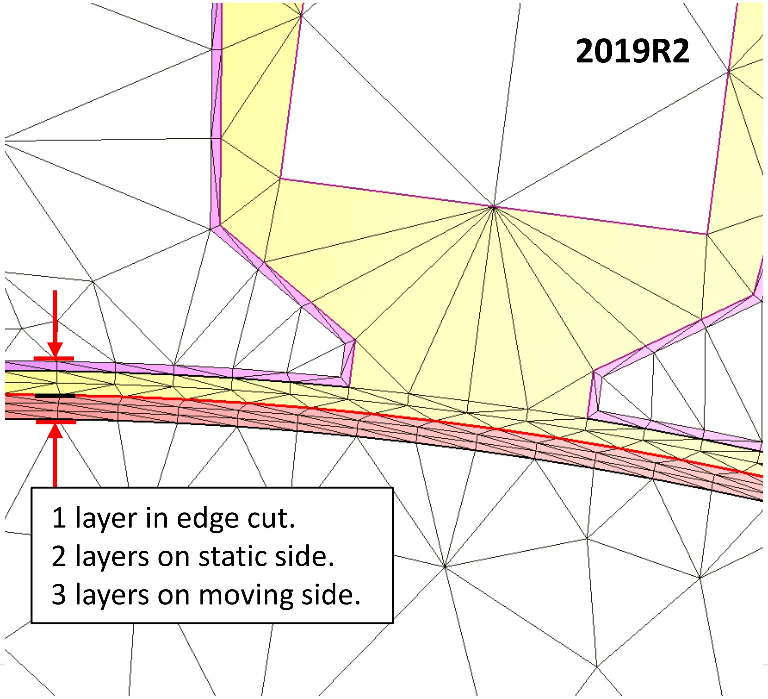
Ground defined

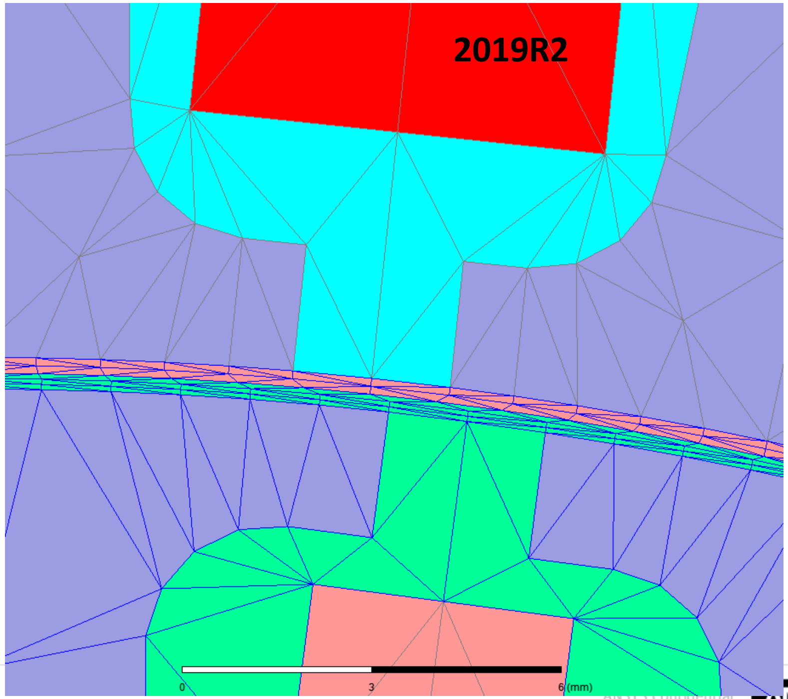
Band Layer Mesh for both Static and Moving Side

- New option in clone band mesh: number of layers
- User will be able to control the number of layers near the band on both static and moving side without destroying clone mesh
- Coupled with pre-existing band mapping angle option to allow user to have more freedom to control the mesh near the band

2019R2
New UI

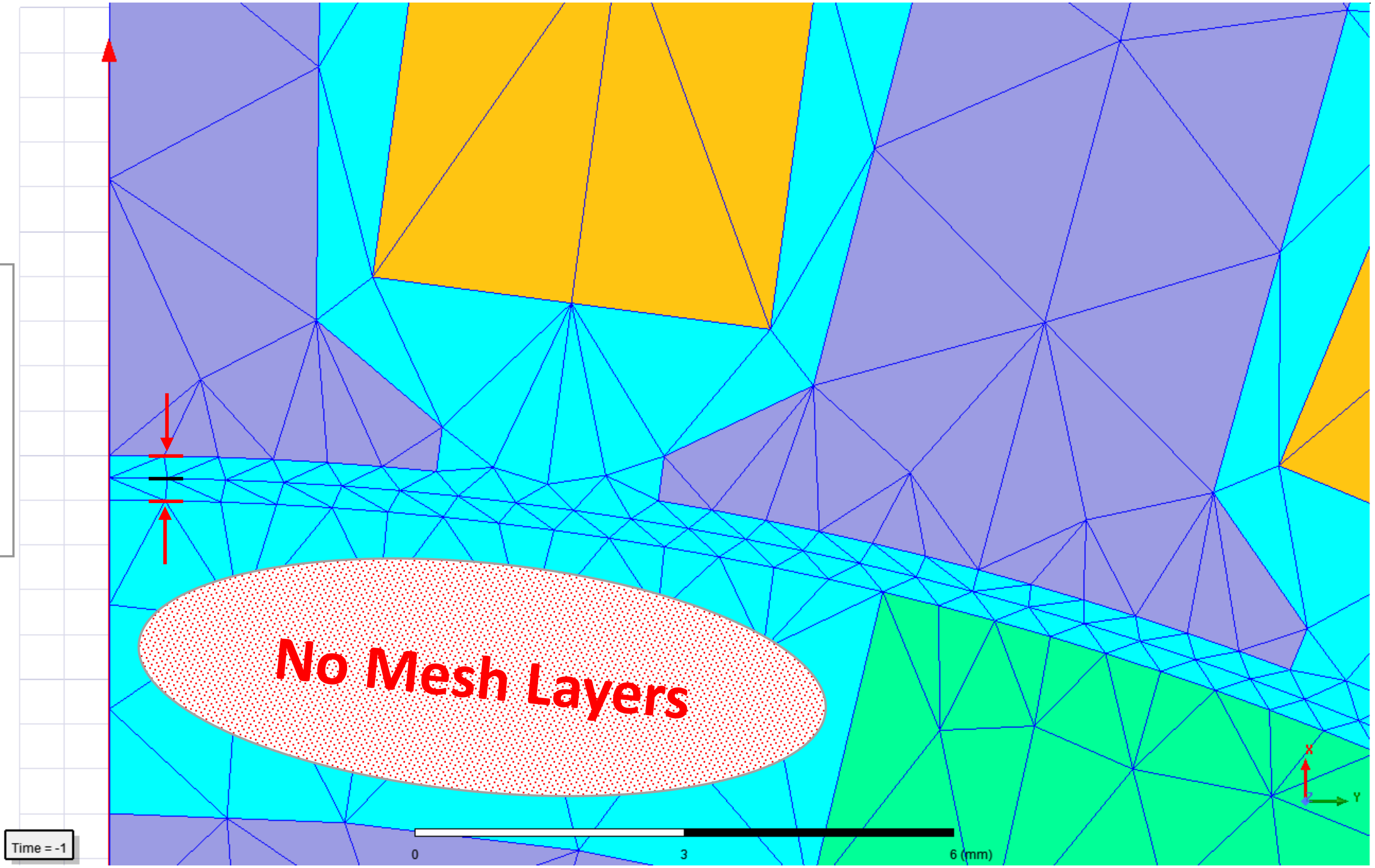






Band Layer Mesh for both Static and Moving Side

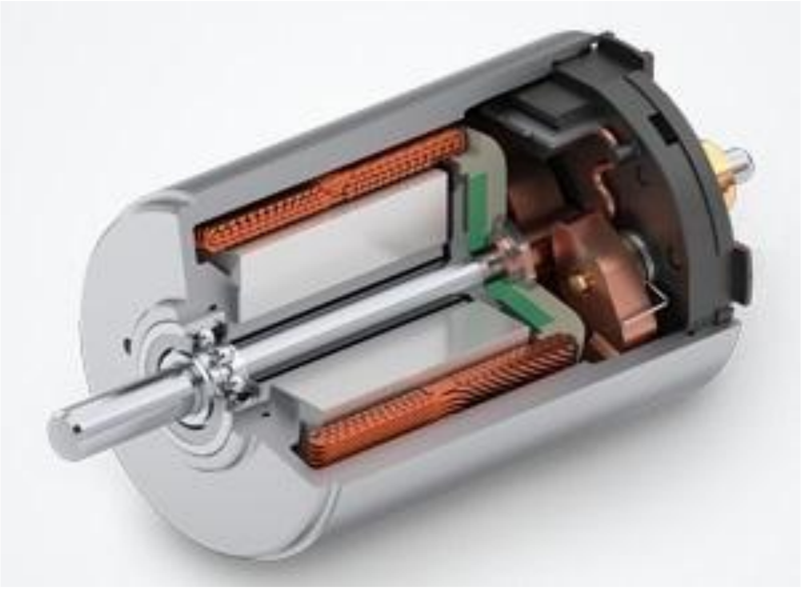
The Band-Layer Mesh occurs only above and below the "Band"
- Between the <u>bottom surface</u> of any object associated with "Stator" and <u>top surface</u> associated with "Rotor"

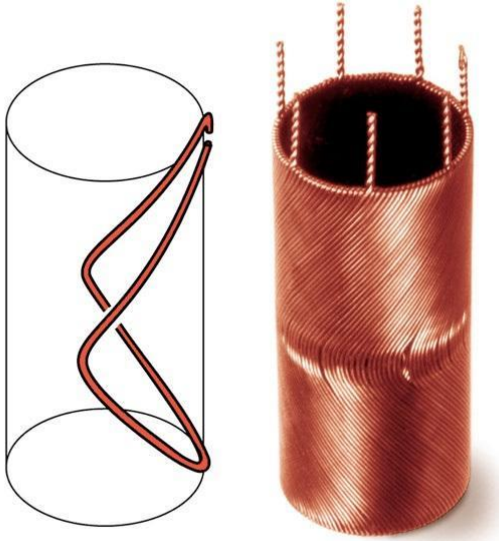


UDP for Slot-less Motor

A slot-less motor:

- Poly-phase hollow-cup windings without slot
- Extremely quick response and high acceleration
- Quiet and smooth operation
- Able to run at very high speed due to less core-losses
- Applications: Medical and portable industrial tools

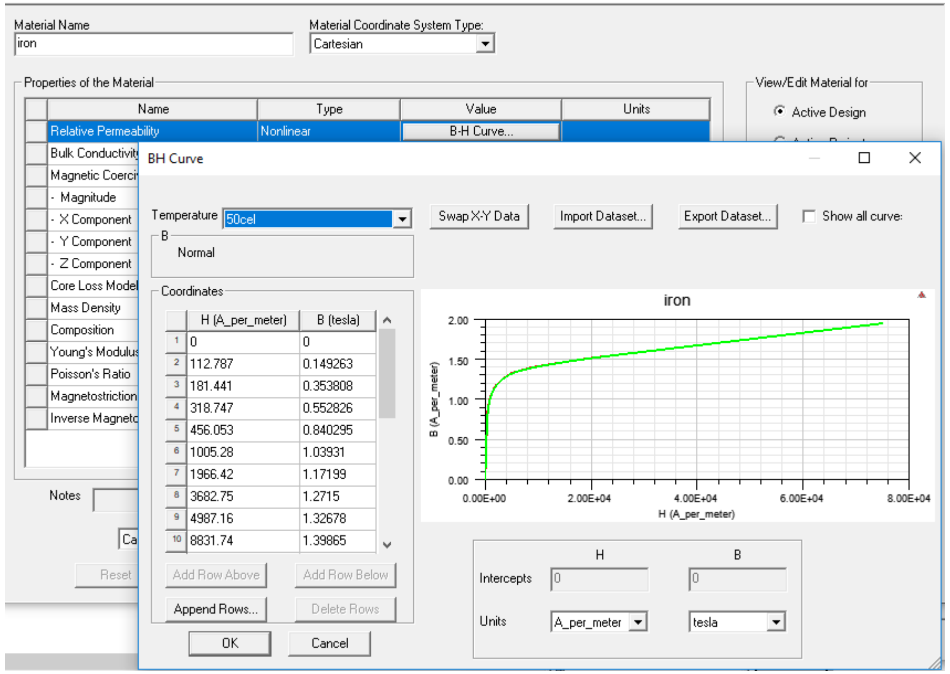


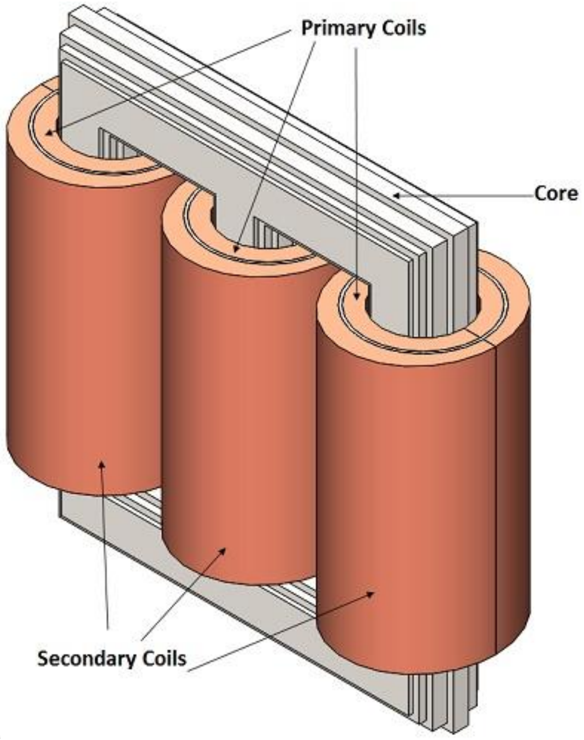


Temperature-dependent Multiple BH Curves

In addition to existing thermal modifier, support input temperature-dependent multiple BH curves

- Solver will recreate a new nonlinear BH curve based on specified or computed temperature element by element
- Two way thermal coupling is supported
- Applicable to both 2D and 3D
  - Magnetostatics
  - Eddy current
  - Transient

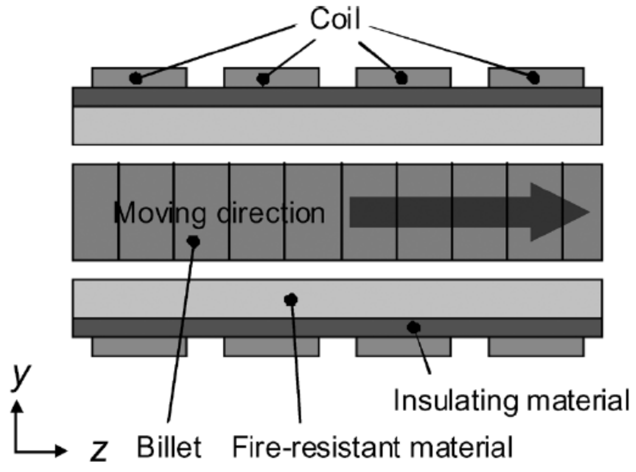




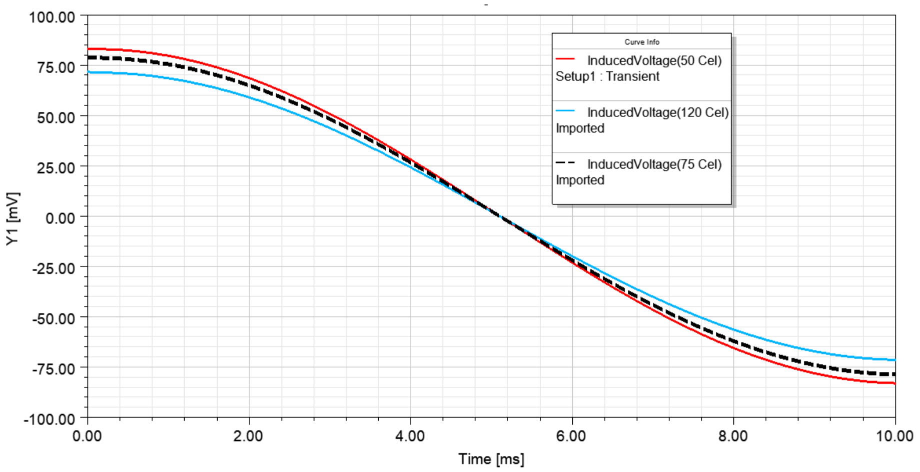
Application examples

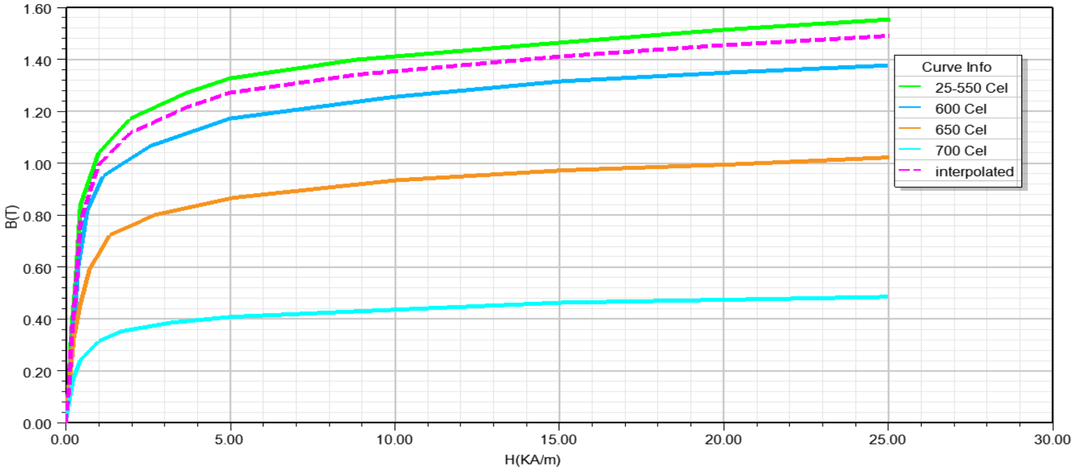
- Eddy-current heating
- Transformer

Eddy-Current Heating of Ferromagnetic Materials



Billet Heater





S45C (carbon steel, carbon: 0.45%).

Anisotropic Core Loss Coefficient Support

- **For isotropic core loss coefficients, the core loss in frequency domain**

$$P_v = P_h + P_c + P_e = K_h f(B_m)^2 + K_c (fB_m)^2 + K_e(fB_m)^{1.5}$$

- **For anisotropic core loss coefficients, the coefficients have different value in different principle directions:**

$$(K_{hx}, K_{hy}, K_{hz}), (K_{cx}, K_{cy}, K_{cz}) \text{ and } (K_{ex}, K_{ey}, K_{ez})$$

- **Input anisotropic coefficients by choosing “Anisotropic” from pull-down list of the property type**