Powering Innovation That Drives Human Advancement

Performance Assessment of Electric Motors

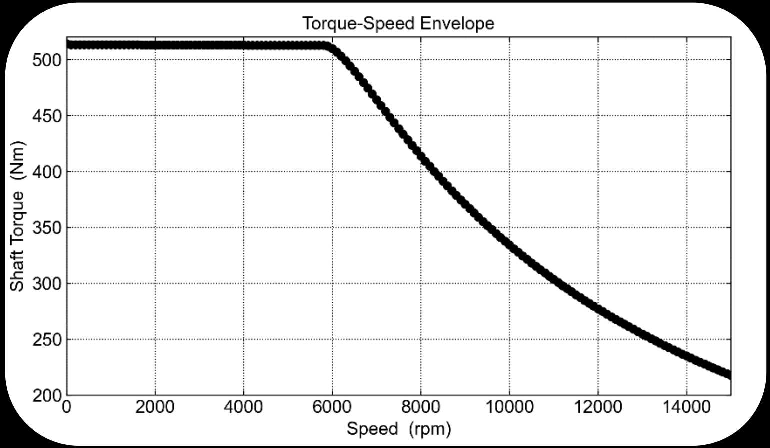
Ansys Electric Machine Innovation Conference

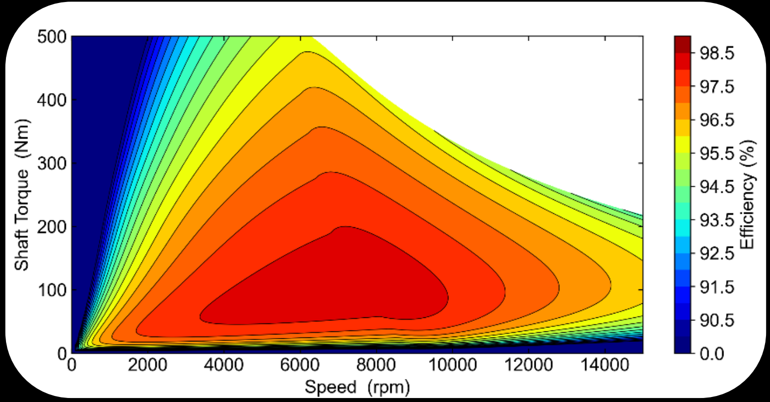
Agenda

- Motivation
- Ansys solution
  - Existing workflows
  - What's new
- Key information on new workflow
  - Example
  - Advantages of new workflow for different user types
- Outlook for the future and Summary

Motivation

- E-machine’s performance depend on operating conditions
  - Operating point (OP)
  - Control strategy applied (e.g., MTPA, max. efficiency)
  - Voltage level (e.g., modulation index)
- Torque-speed envelope can be first step
  - “Can my electric drive provide the torque at a speed?”
- Performance mapping is part of development process
  - “How do performance indicators vary vs. OP?”
- Subsequent analyses can follow performance mapping
  - Drive / Load cycle analyses (e.g., for vehicle range analysis)

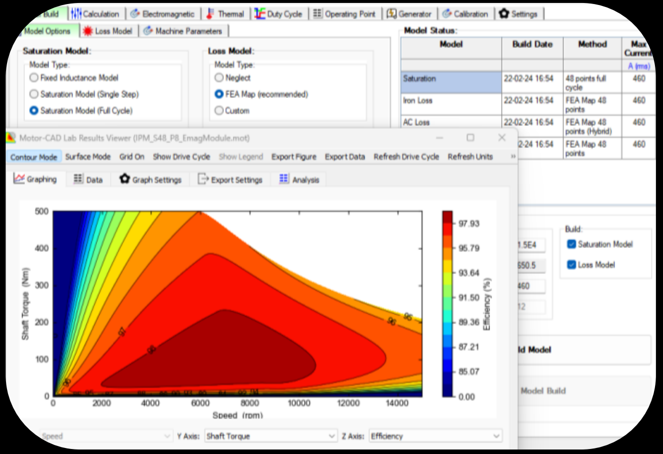




Ansys Solutions for Performance Assessment of Electric Machines

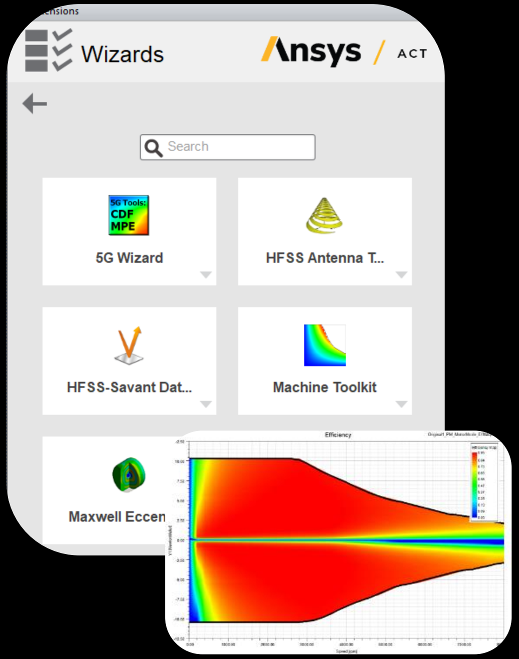
Ansys Motor-CAD Lab Module

- Solution in dedicated motor design platform
  - Ansys Motor-CAD Emag as FEA engine
  - Torque speed capability, performance mapping, drive cycle simulation
  - Coupling to thermal module
  - Versatile and tailored post-processing capabilities



Ansys Maxwell Machine Design Toolkit

- Solution in general EM analysis software (AEDT)
  - Ansys Maxwell as FEA engine
  - Performance mapping + drive cycle visualization
  - No coupling to thermal

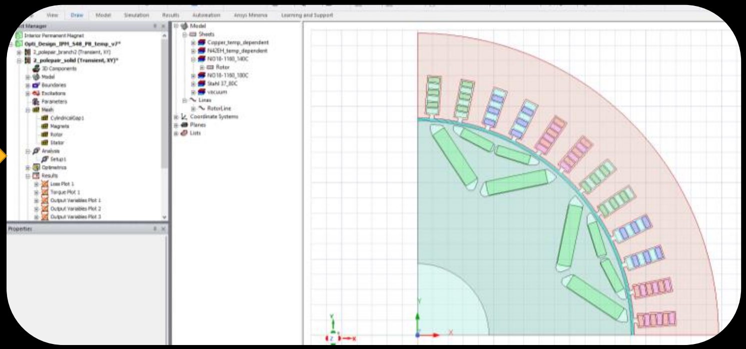


Combining the Best of Two Worlds

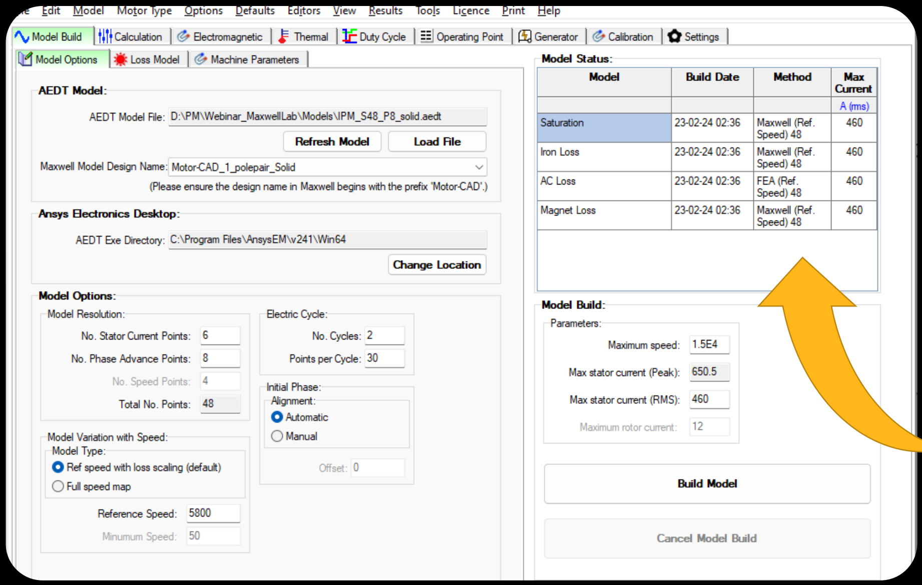
- Combine tailored performance assessment tools in Lab module with Ansys Maxwell's FEA engine
  - Emag module can be "exchanged" by Maxwell in model build stage

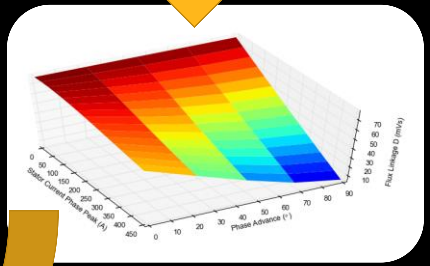
- Supports both:
  - Models exported from Motor-CAD
  - Models created independently
  - Same user experience regardless of FEA solver used

Ansys Maxwell



Ansys Motor-CAD Lab

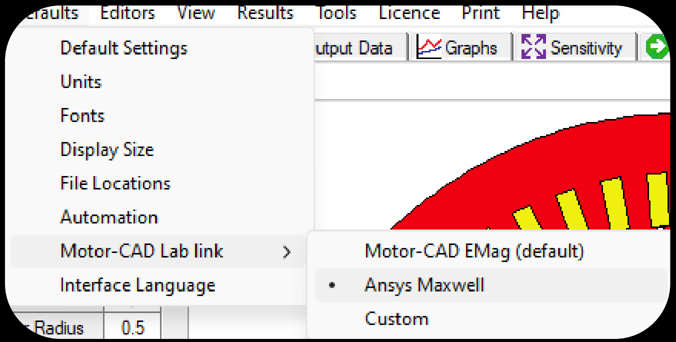


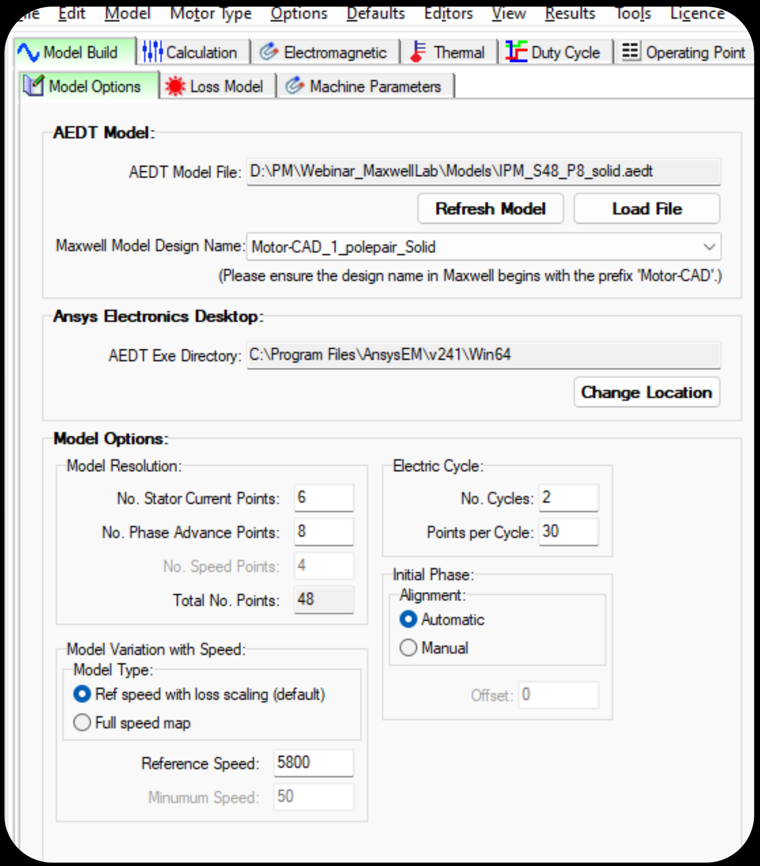


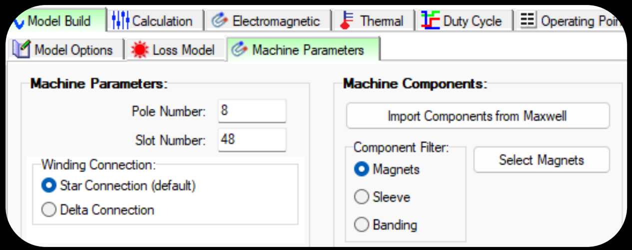
Flux and Loss Maps

How to Try it Out

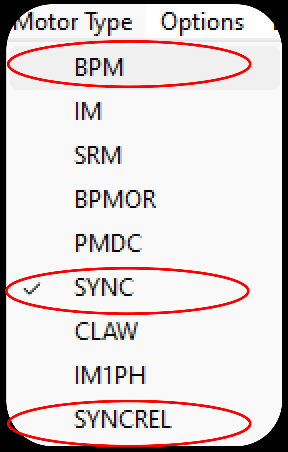
- Set default value of Motor-CAD Lab link
  - Changes tabs of Lab module
- Link an AEDT file and select a design
- Settings / Configurations analogous to Lab – Emag workflow
  - Slight changes when reasonable
- Design definitions in Motor-CAD are independent from Maxwell model
  - Consistent definitions populate settings with correct data
    - E.g., pole and slot number



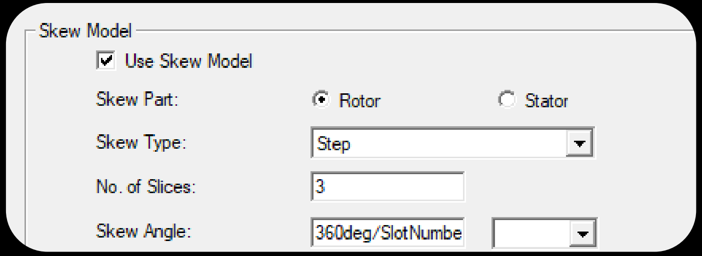




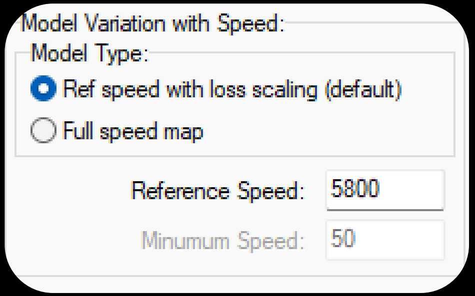
Current Capabilities - General



- Machine type for coupling set by motor type active in Motor-CAD
  - Currently, supports synchronous machines with sine drive
    - Permanent Magnet Synchronous (BPM)
    - Synchronous Reluctance (SYNCREL)
    - Wound-Rotor Synchronous (SYNC)
- Skew model for 2.5D simulation definable in Maxwell

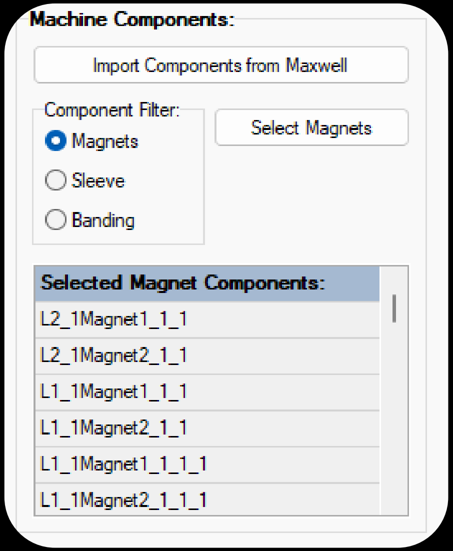


- Two options for considering frequency-dependent effects
  - Calculation at reference only (as when driving Emag)
    - Analytical scaling of quantities
  - FEA calculation at different speeds and interpolation
    - For BPM and SYNCREL only

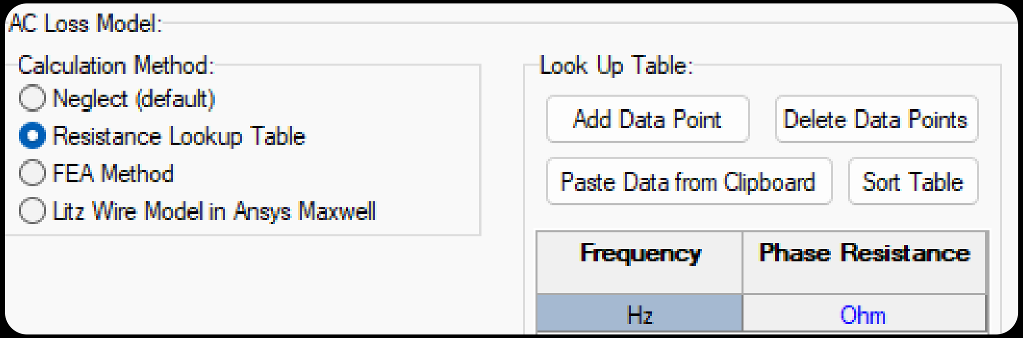


Current Capabilities - Losses

- Eddy-current solid losses in
  - PMs, Banding, Sleeve
  - Selection in Machine Parameters tab
- Iron Losses as computed by Maxwell
  - Bertotti calculation method

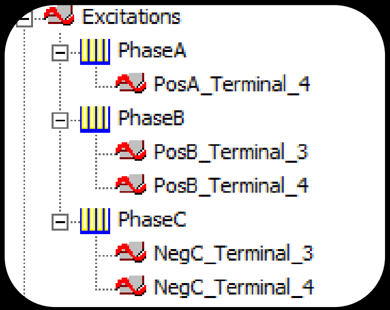


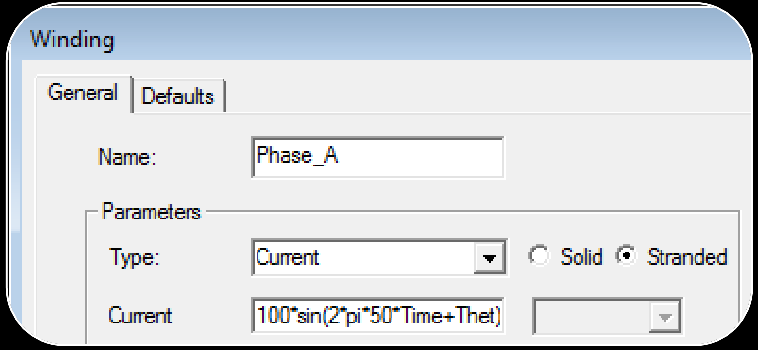
- AC-Losses in Armature Conductors
  - Resistance LUT vs. frequency
  - Full FEA (solid winding in Maxwell)
  - Litz wire material model in Maxwell

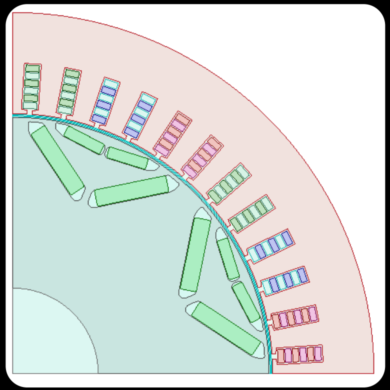


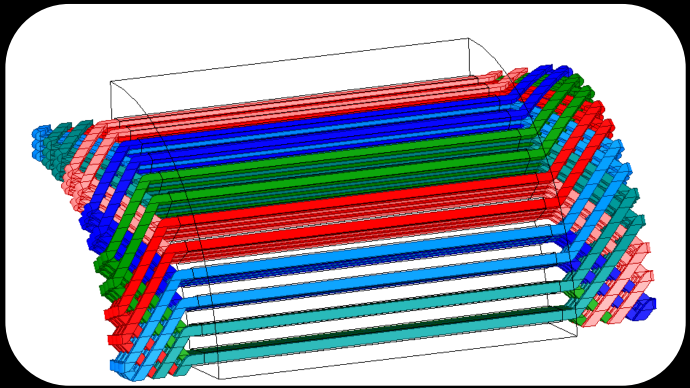
Recap – AC Loss calculation in Ansys Maxwell FEA

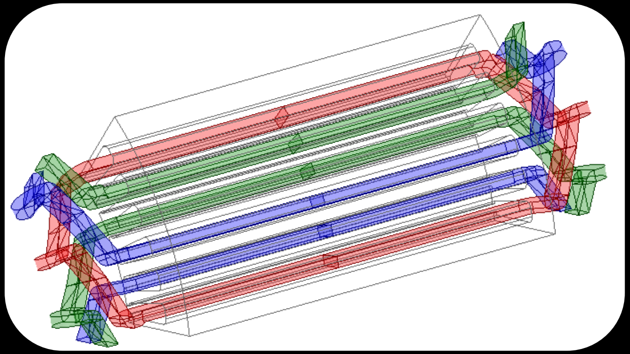
- E-machine's phases are defined as windings in Maxwell
  - Determines connection of coils
  - Voltage, current or circuit excitation
- Windings can be solid or stranded
  - Individual conductors' geometry resolved for solid windings
  - Eddy-currents neglected for stranded windings (homogeneous J assumed)
    - Allows geometrical simplification (e.g., modeling layer geometry only)
    - Reduces simulation time





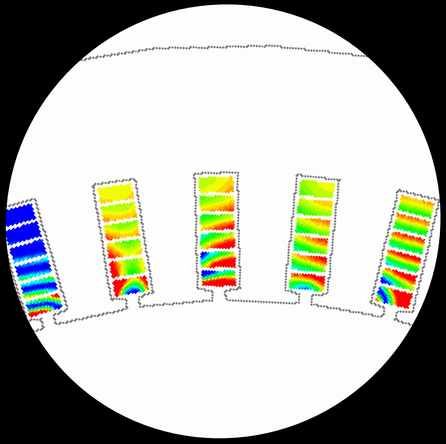






Current Capabilities - AC-Losses in Armature Conductors

- R_{phase} vs. frequency (stranded winding in Maxwell)
  - Empirical / measurement values
  - Calculated (e.g., harmonic simulation)
- Litz wire model (stranded winding in Maxwell)
  - AC-losses accounted for in material model
    - Assumes skin depth > strand dimensions



Look Up Table:

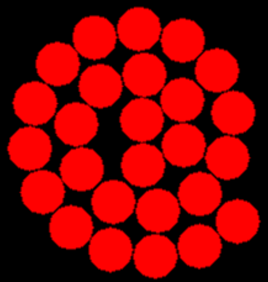
Add Data Point | Delete Data Points | Paste Data from Clipboard | Sort Table

Frequency	Phase Resistance
Hz	Ohm
0	0.01887
30	0.01887
60	0.02264
90	0.03019
120	0.04026

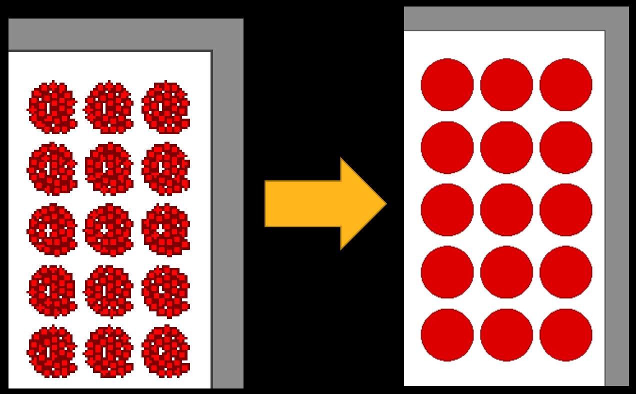
D. Lin, C. Lu, N. Chen and P. Zhou, "An Efficient Method for Litz-Wire AC Loss Computation in Transient Finite Element Analysis," in *IEEE Transactions on Magnetics*, vol. 58, no. 5, pp. 1-10, May 2022, Art no. 7400710

Properties of the Material

Name	Type	Value	Units
Relative Permittivity	Simple	1	
Relative Permeability	Simple	0.999991	
Bulk Conductivity	Simple	58000000	siemens/m
Dielectric Loss Tangent	Simple	0	
Magnetic Loss Tangent	Simple	0	
Core Loss Model		None	w/m^3
Mass Density	Simple	8933	kg/m^3
Composition		Litz Wire	
- Wire Type		Round	
- Strand Number	Simple	26	
- Wire Diameter	Simple	0.278	mm

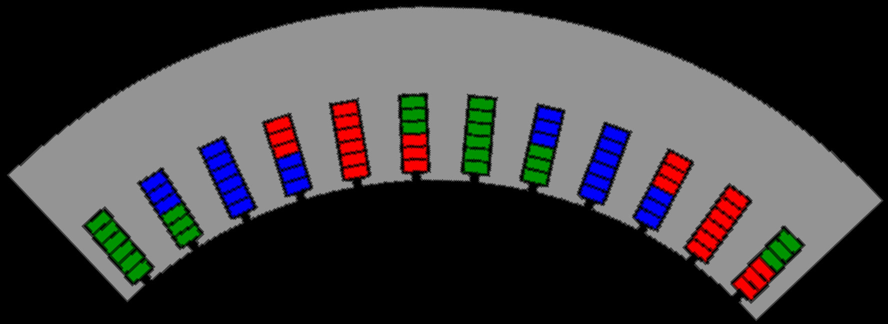


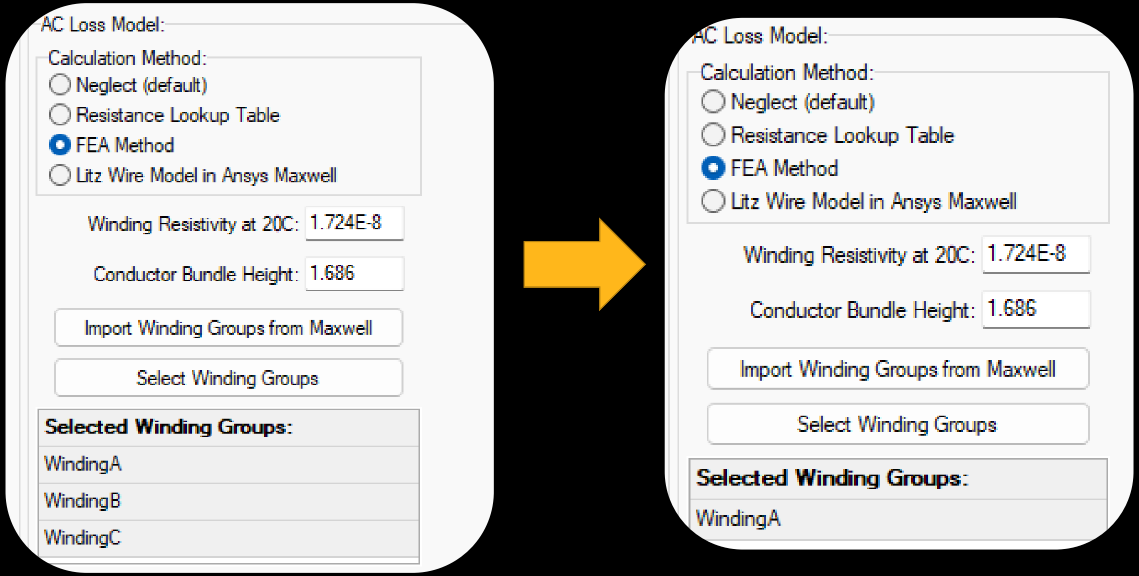
Litz bundle (26 strands)

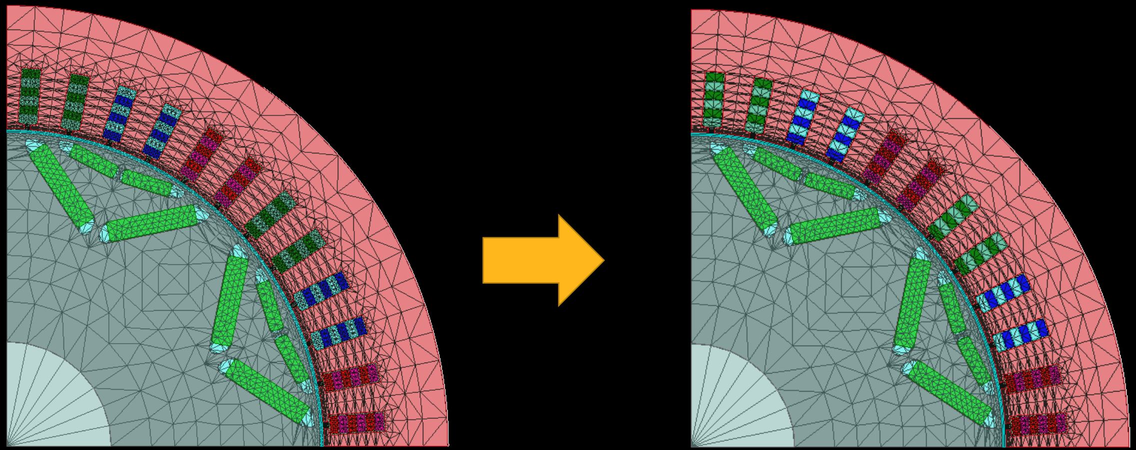


Current Capabilities - AC-Losses in Armature Conductors

- Full FEA (solid winding in Maxwell)
  - Resolving current density in FEA
  - Usually, one phase as solid is enough
  - Allows precise calculation for chorded windings
    - Natively, Motor-CAD uses one reference slot
    - AC-effects depend on “slot type” (lower for slots carrying different phases)

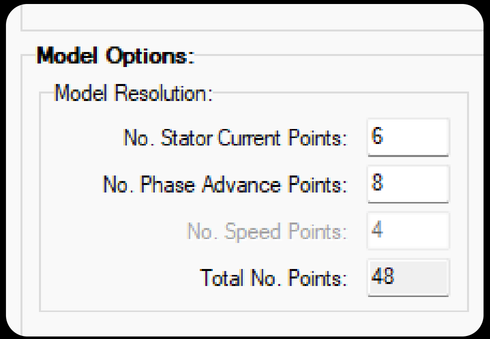


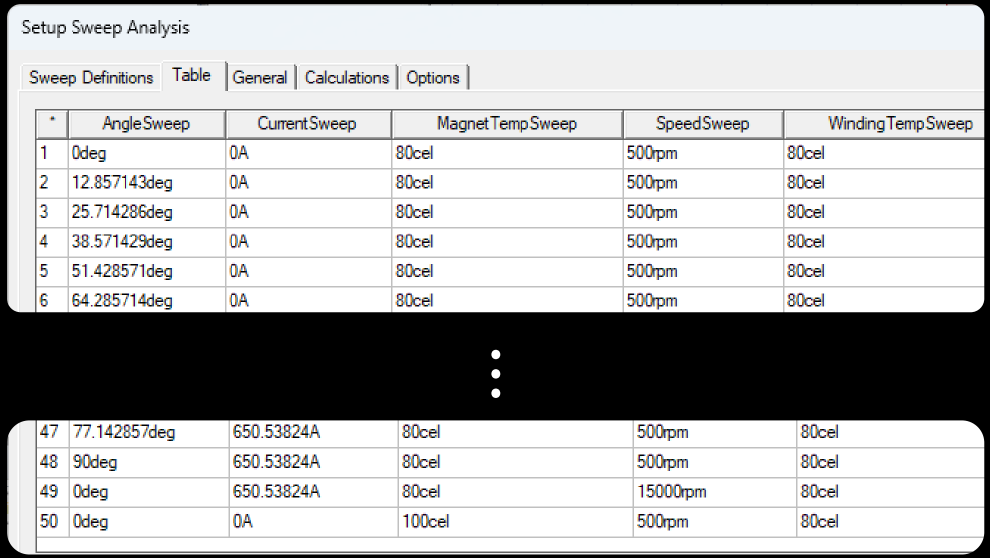




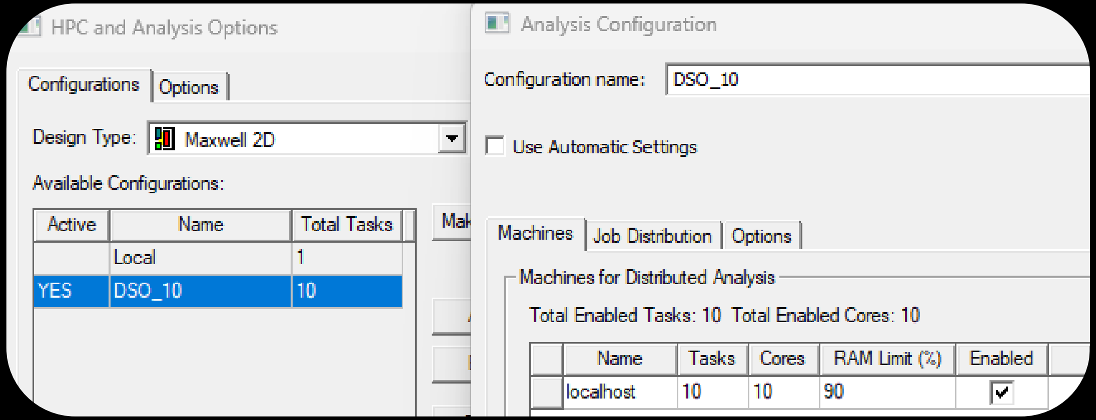
Model Build and HPC Settings

- Model build triggers optimetrics parametric setup in Maxwell
  - Additional points for
    - Frequency scaling (if single speed solution is used)
    - Capture temperature effects on PMs (for BPM)





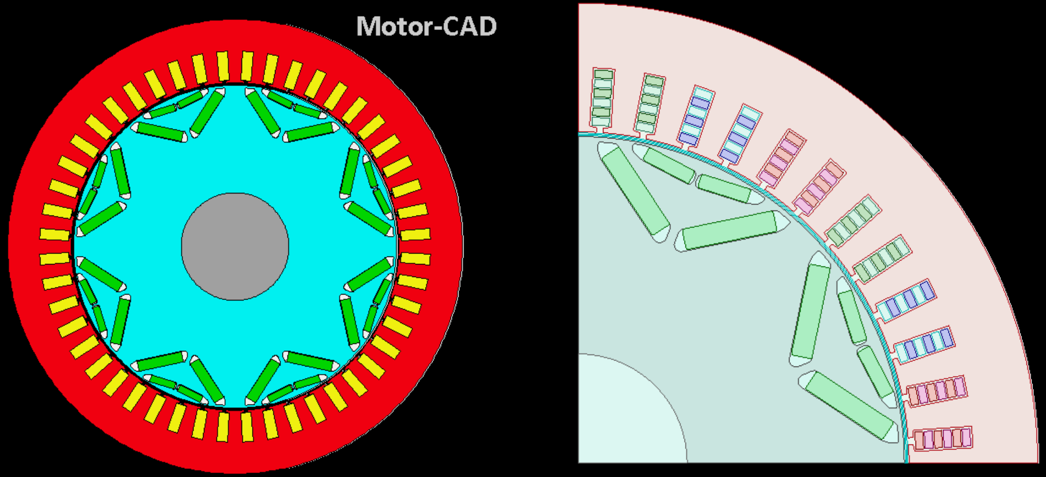
- Maxwell HPC-capabilities available
  - Parametric distribution + parallelization
  - Pre-select HPC options in Maxwell



Live Example

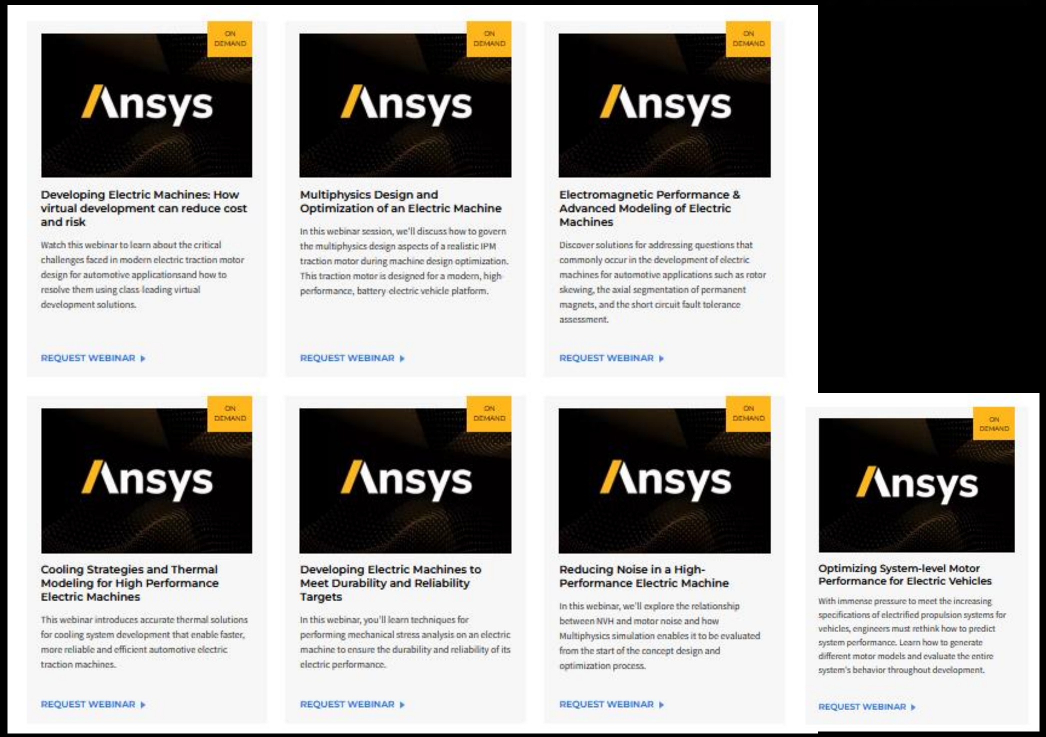
- Machine design from webinar series in 2023

https://www.ansys.com/webinars/developing-electric-machines-for-automotive-webinars

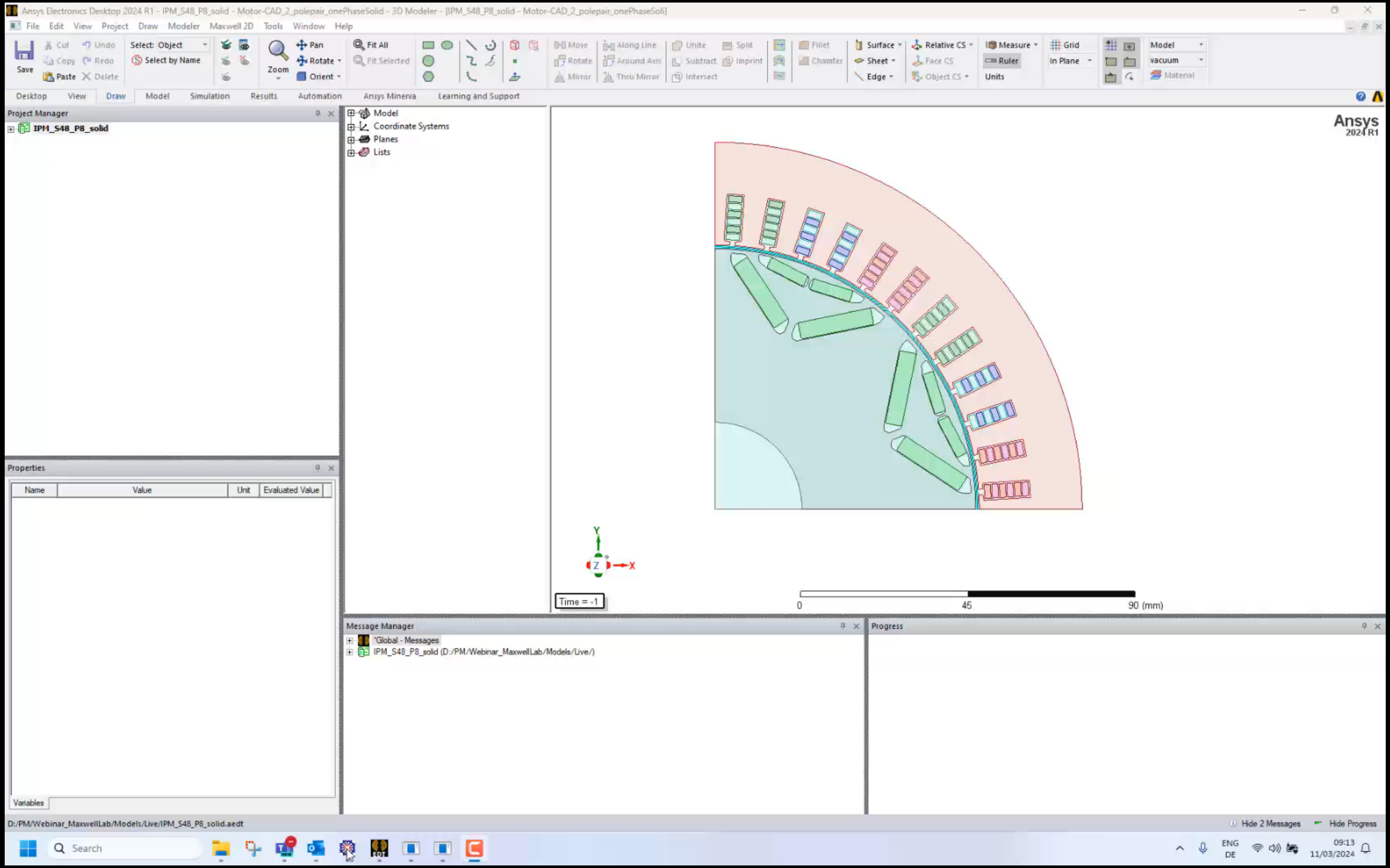


Electric Machine Development Platform Webinar Series

Virtual Development of a High-Performance Electric Machine for Automotive - from Concept to Validation



Live Example



Advantages of Consolidated Workflow - Examples

Users of Motor-CAD

- Consideration of additional effects
  - Detailed full FEA AC-Losses calculation (Litz wire, chorded windings, LuT)
  - Additional core loss calculation methods
  - Eddy-currents' feedback on field (speed sweep)
- No limitations on machine topology
- Model build with HPC support

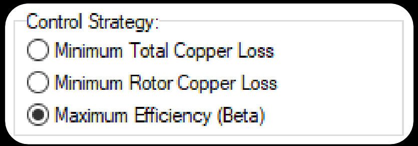
Users of Maxwell and MDT

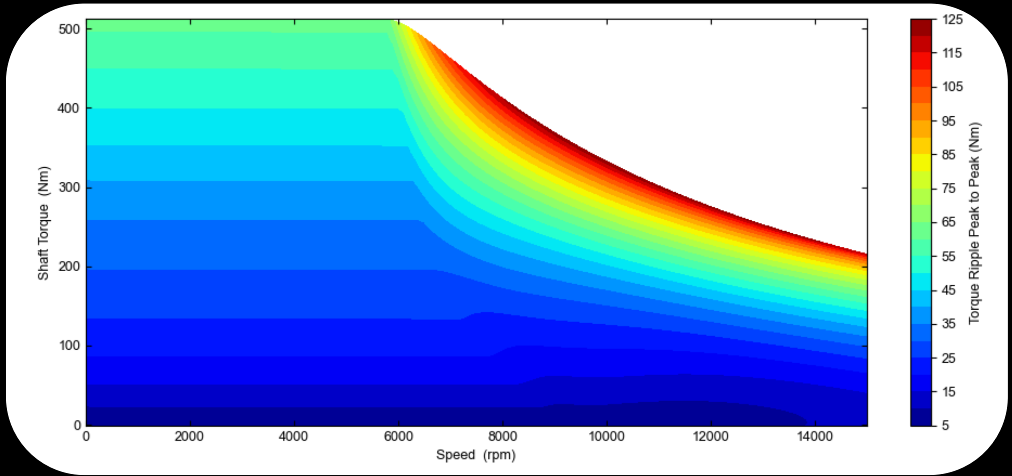
- Full FEA AC-losses capability
- Coupling to thermal
  - Continuous operation assessment
- Drive / Load cycle analyses
- Tailored postprocessing
  - Comparison of performance maps
  - Model build scaling (vary active length)

Lab module's features available to all motor designers, independently of FEA engine used and design stage (concept or detail)

Improvements for in Lab Module in 2024 R1

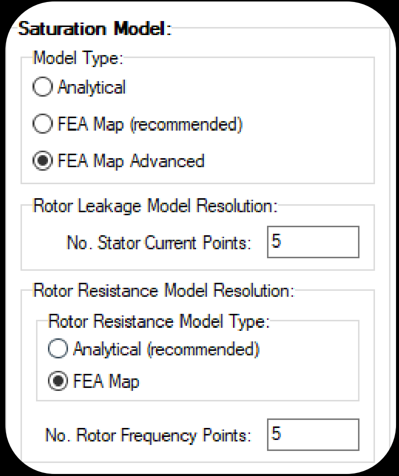
- Max. Efficiency Control for SYNC (Beta)
  - Available with Emag and Maxwell as FEA engine
  - Most impactful at high speeds and low torque (core losses large compared to joule losses)

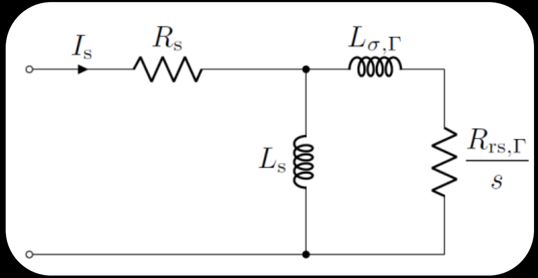




- For Emag FEA engine only
  - Torque ripple maps
  - Improved equivalent circuit for induction machine modelling
    - Look-up tables for $L_\sigma(I_s)$ and $R_{rs}(f)$

  Previously only for $L_s(I_s)$





Outlook

- Torque ripple map with Maxwell FEA for model build
- Induction Machine Support
  - Populating LUTs of equivalent circuit using Maxwell FEA data

- Configuration of Maxwell HPC setting from Motor-CAD GUI
- Calculation of parametric sweep independently of Motor-CAD process
  - Leverage cluster / Linux support
  - Leverage 3D model support

Summary

- Performance assessment of electric machine in variable-speed-drives is inherent part of development process (in both, concept and detailed design stage)
- Ansys offers a consolidated workflow inside Motor-CAD's Lab module
  - Supports Motor-CAD Emag and Maxwell as FEA computation engine
  - Torque-speed envelope computation, performance mapping, drive / load cycle analysis
  - Legacy workflows continue to exist (Lab Module + Emag), Maxwell's Machine Design Toolkit
- Combine strengths of two software packages' capabilities depending on use-case
- Consolidated workflow will offer users tangible enhancements in each version release
  - Independent of FEA engine used