



NVH Analysis and Optimization of Induction Motors using 2D and 3D FEA

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General Motors Electrification Overview

- We envision an all-electric future with 0 crashes, 0 emissions and 0 congestion
- The modular propulsion system and global EV platform enable GM to produce vehicles for every segment of the market, including entry-level cars, work trucks, and high-performance sports cars
- Estimated range up to 400+ miles on a full charge; Up to 800V battery packs and 350 kW fast-charging capability; 0 to 60 mph acceleration as low as 3 seconds
- Electric Drive Units are designed in-house support front-wheel drive, rear-wheel drive, all-wheel drive, and performance all-wheel drive applications: Dominant NVH sources include E-machines


Chevy Blazer EV


Chevy Equinox EV


Chevy Silverado EV


Chevy Bolt EUV


GMC Hummer EV


Cadillac Optiq EV

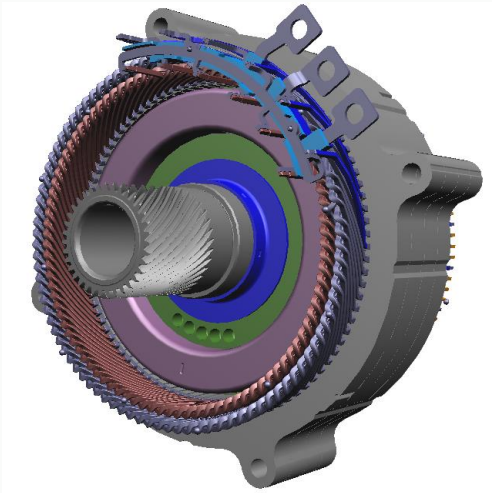

Cadillac Vistiq EV

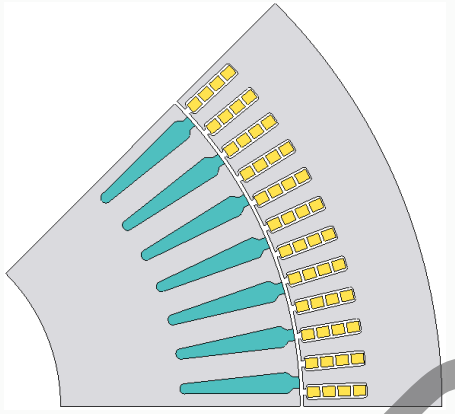

Cadillac Escalade IQ


Cadillac Lyriq

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Why Induction Motors for ELECTRIC VEHICLES?





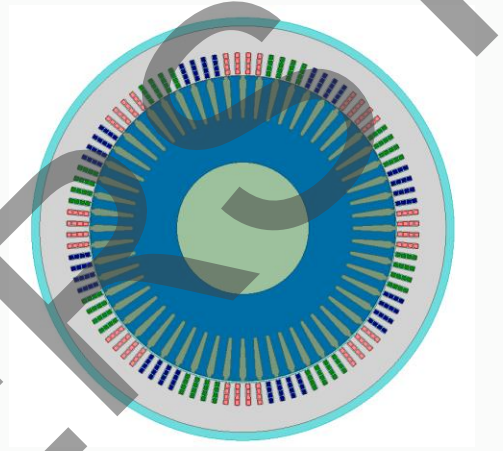
- **No Permanent Magnets – Supply Chain & Cost Certainty**
  - – Zero reliance on rare-earth materials → no price volatility or geopolitical risks
  - – Significantly lower material cost for high-power traction motors
- **Inherently Safe at High Speeds**
  - – No back-EMF at loss of excitation
  - – No risk of magnet demagnetization due to over-temperature or over-current
  - – Enables simpler and safer failure modes
- **Excellent Over-speed Capability with Active Field-Weakening**
  - – Rotor flux can be actively reduced to nearly zero
  - – Allows constant power operation over a much wider speed range than a similar IPM
- **Robust & Low-Maintenance Rotor**
  - – Simple squirrel-cage rotor: no magnets, no windings, no brushes
  - – Withstands high centrifugal force, thermal cycling, and mechanical shock
  - – Ideal for high-volume, cost-sensitive EV platforms
  - – Decades of industrial maturity → well-understood thermal and electromagnetic behavior
- **NVH Challenges for Induction Motors**
  - – Induction motor slip frequency leads to non-integrate induction orders as a function of motor controls: Different from IPM motors with motor noise at pole pass harmonics
  - – Induction motor analysis requires long simulation time to reach steady state: high computational costs for NVH design and optimization

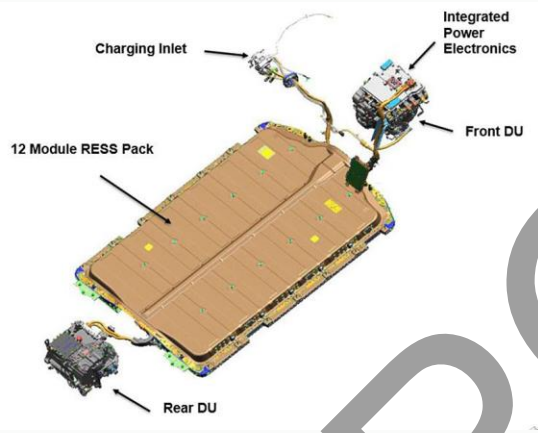
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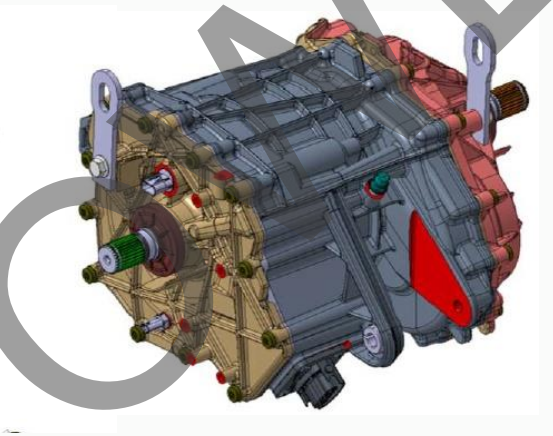
GM's Induction Motor Design for Assist RDU

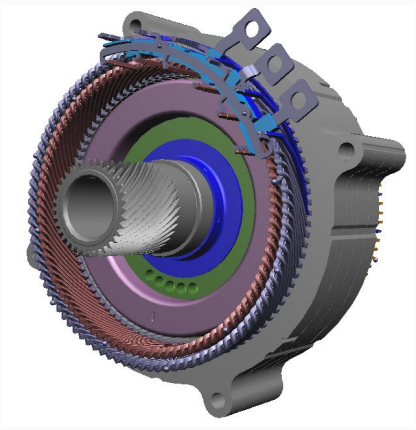
- Induction motor specifications

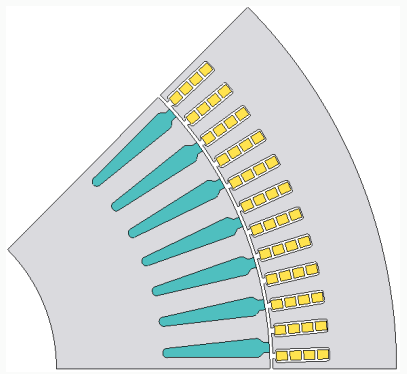
Poles:	8
Stator slots:	96
Turns:	32
Conductor per slot:	4
Rotor bar number:	56
Power:	85 kW
Torque:	164 Nm











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FEM Analysis for Induction Machines

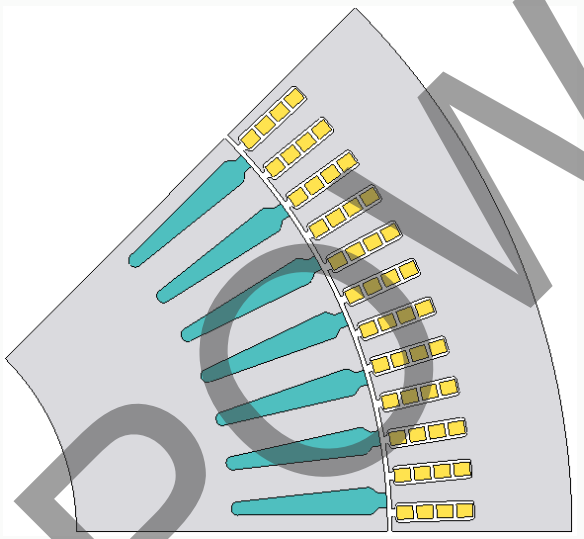
	2D FEA	3D FEA
Stack length	Low impact on simulation time	Longer stack length -> longer simulation
End Effect	Cannot capture	End winding & end ring leakage are included
Skew Effect	Multi-slice condition (approximation)	Included
Simulation Time (no skew)	~5000 steps per day (8 cores)	100~300 steps per day (36 cores)
Simulation Time (skew)	~2200 steps per day (8 cores)	100~300 steps per day (36cores)

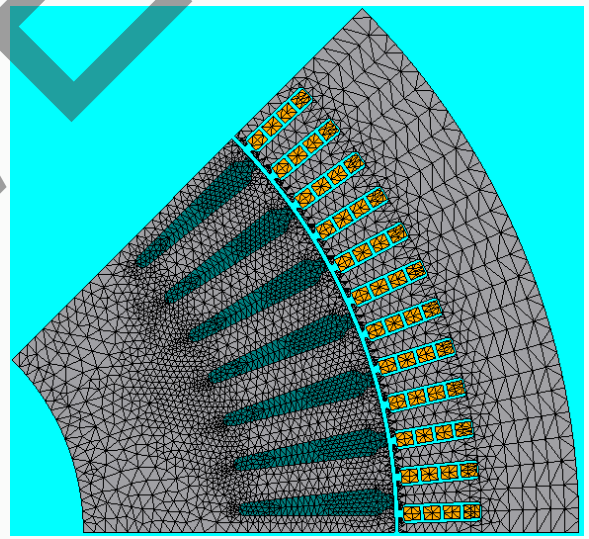
	Frequency Analysis	Transient Analysis
Power Supply	Sinusoidal power supply	Sinusoidal/PWM power supply
Efficiency map	2D takes ~ 1 hour for 620 points (20 cases in parallel)	2D takes more than a day
Simulation Time	2D: ~1 minute 3D: ~20hours for ~ 8million element (36 cores)	Transient analysis simulation time is skipped by using frequency analysis results as the first step.

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2D Analysis for Induction Machine

- **Objective**
  - Calculate EM forces at stator teeth as a function of motor rpm, current and slip frequency
  - Require transients to reach steady stator for accurate NVH
- **2D FE model size**
  - 10,729 elements with refined mesh density around air gap and rotor bars
- **Modeling rotor bar skew using multi-slice methods**
  - No-skew model takes about 2 days
  - 61,201 steps take about 7~8 days on 8 CPU cores (2.x GHz)

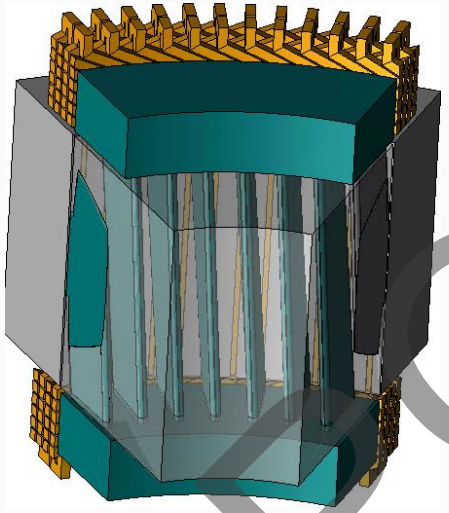


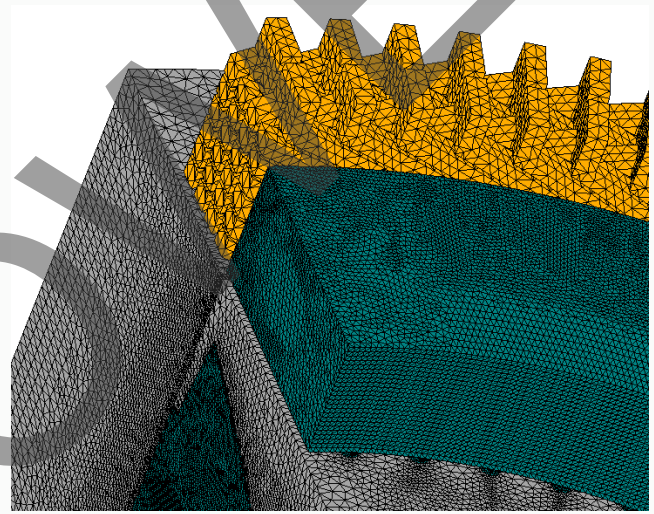


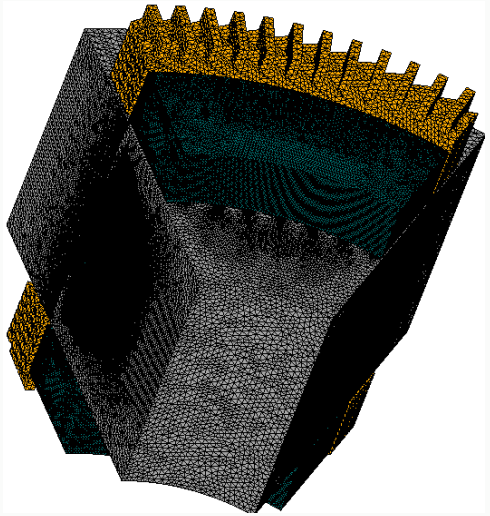
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3D Analysis for Induction Machine

- **Objective**
  - Calculate 3D EM forces at stator teeth as a function of motor rpm, current and slip frequency
  - Require transients to reach steady stator for accurate NVH
- **Modeling 3D design features**
  - 3D model of rotor bar skew
  - 3D winding created by the Coil Template tool in JMAG
- **2D FE model size**
  - 8 million elements with refined mesh density around air gap and rotor bars
  - 18,001 steps took about 38.5 days on 36 cores (CPU 4.8GHz)



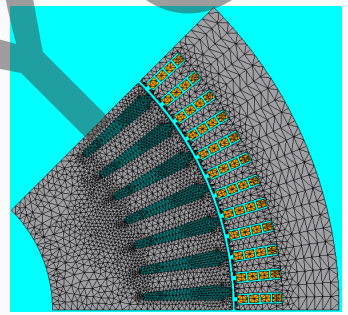


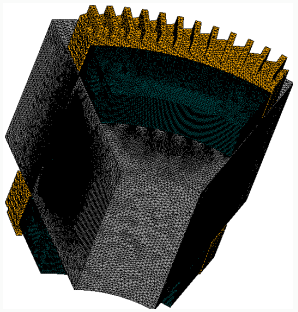


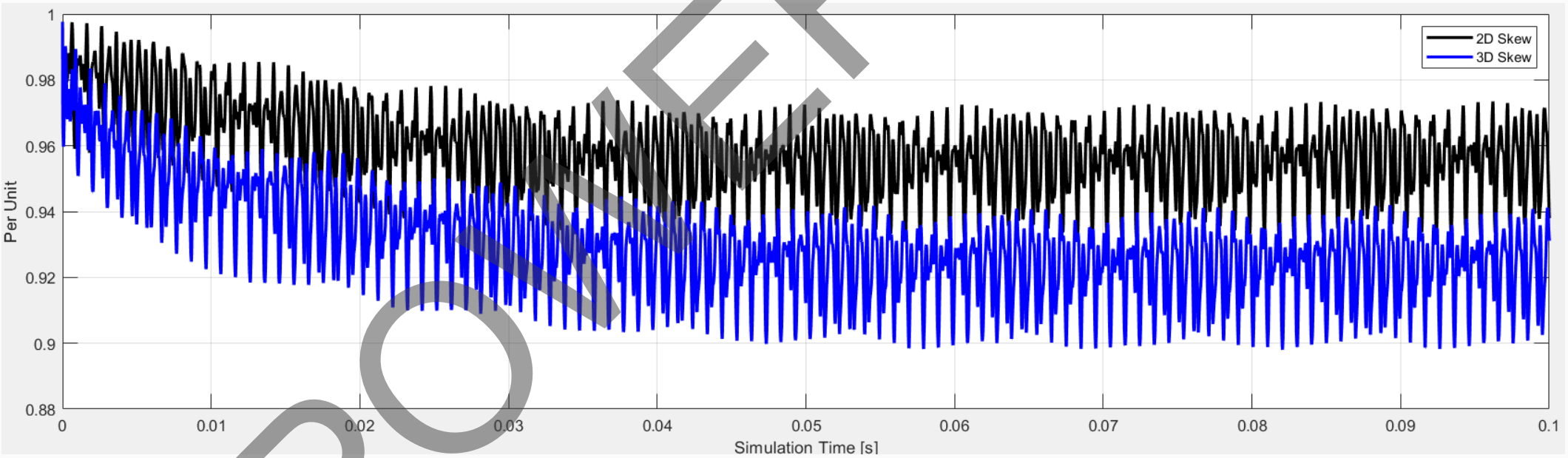
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Comparison of 2D and 3D Torque Waveforms

- 2D and 3D torques are calculated and compared for the same operating point
- Overall, torque harmonics align well for waveforms and their harmonic contents, which are critical for NVH evaluation
- 3D analysis predicts lower mean torque due to leakage inductance and 3D winding impact not captured in 2D model



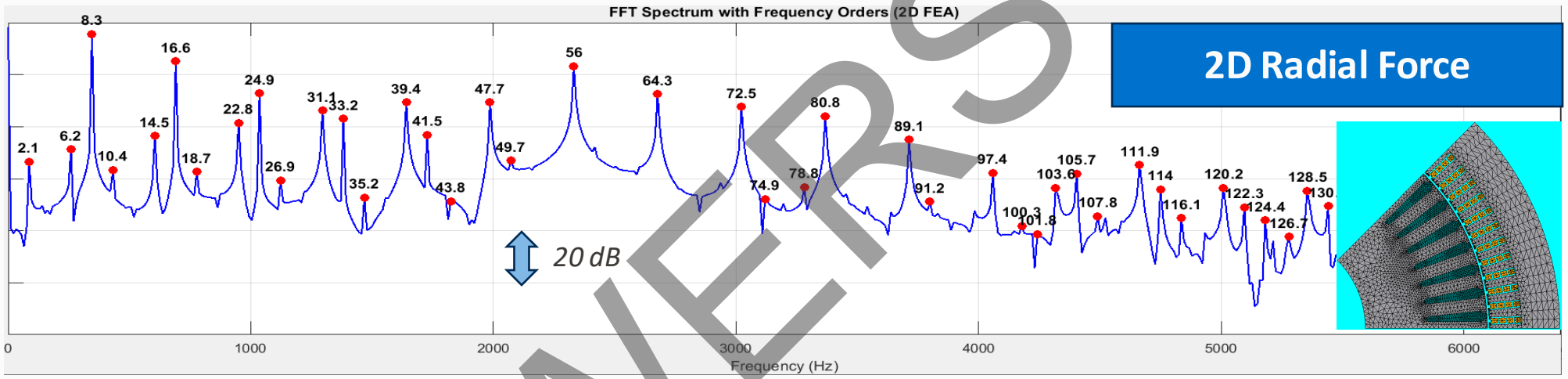


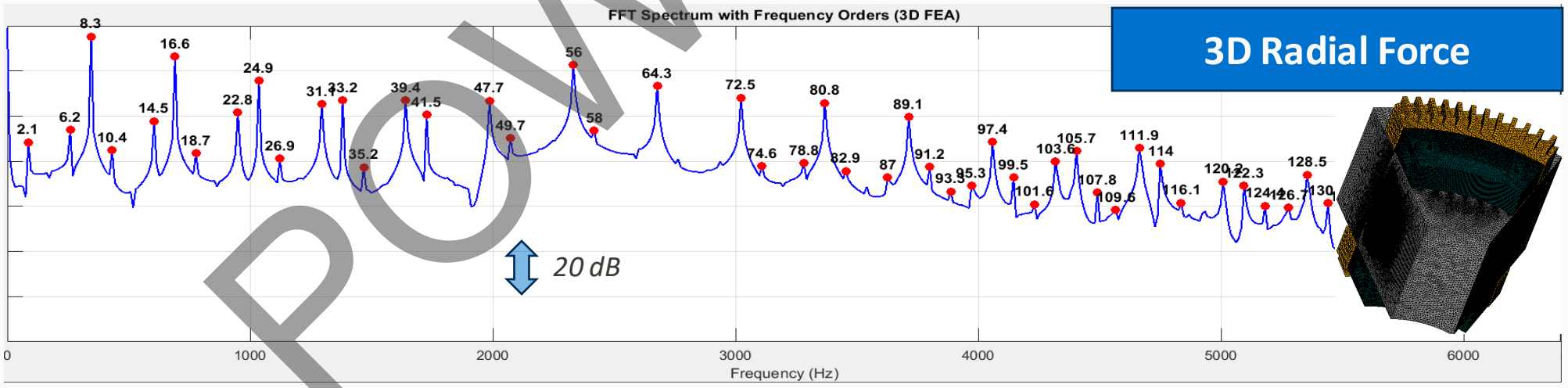


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Comparison of 2D vs 3D Radial Forces for Induction Motor

- 2D and 3D radial forces are calculated and compared at 100% load at 2500 motor rpm
- Spectrum analysis is conducted after the force waveforms reach steady state
- Non-integer induction orders are predicted due to IM split frequency

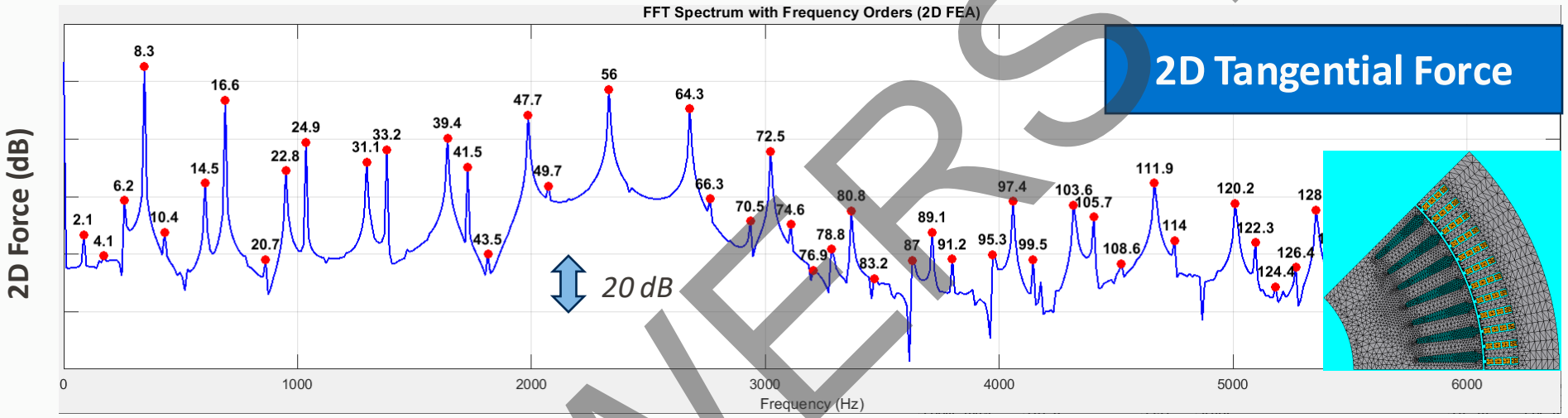


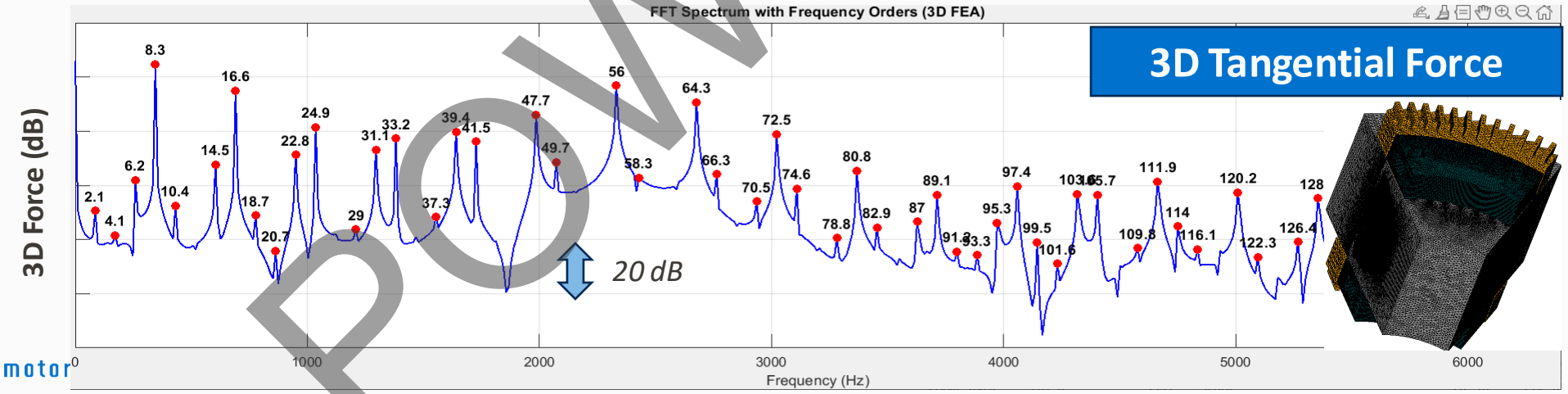


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Comparison of 2D vs 3D Tangential Forces for Induction Motor

- 2D and 3D tangential forces are calculated and compared at 100% load at 2500 motor rpm
- Spectrum analysis is conducted after the force waveforms reach steady state
- Non-integer induction orders are predicted due to IM split frequency

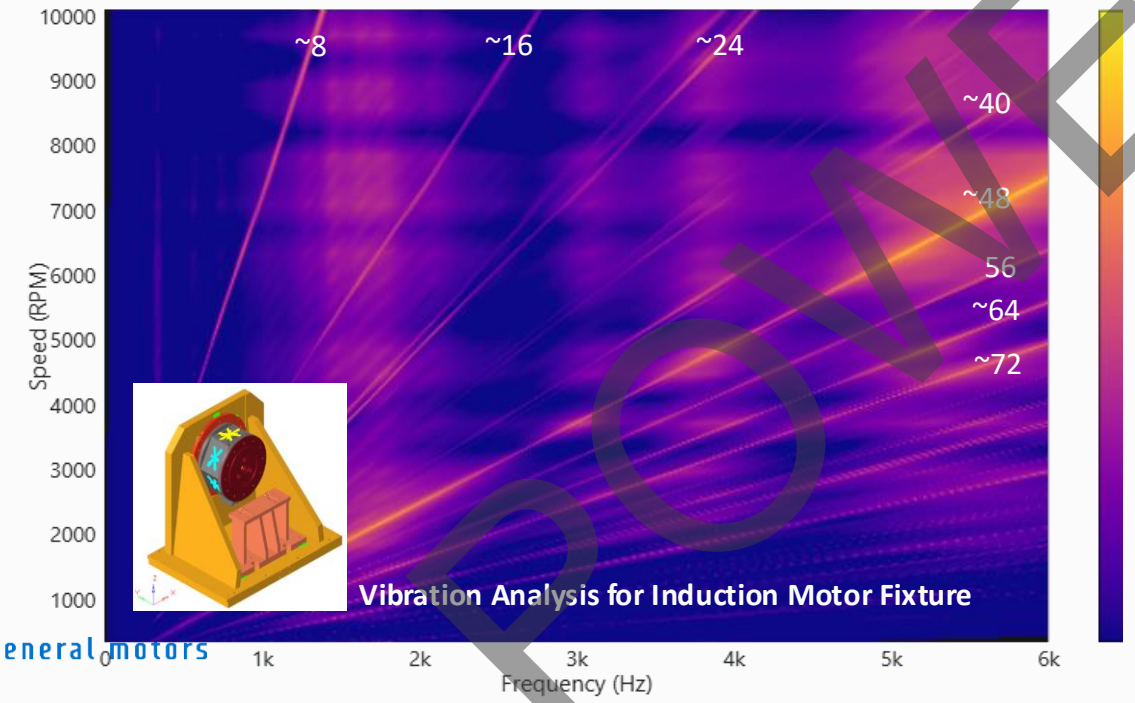


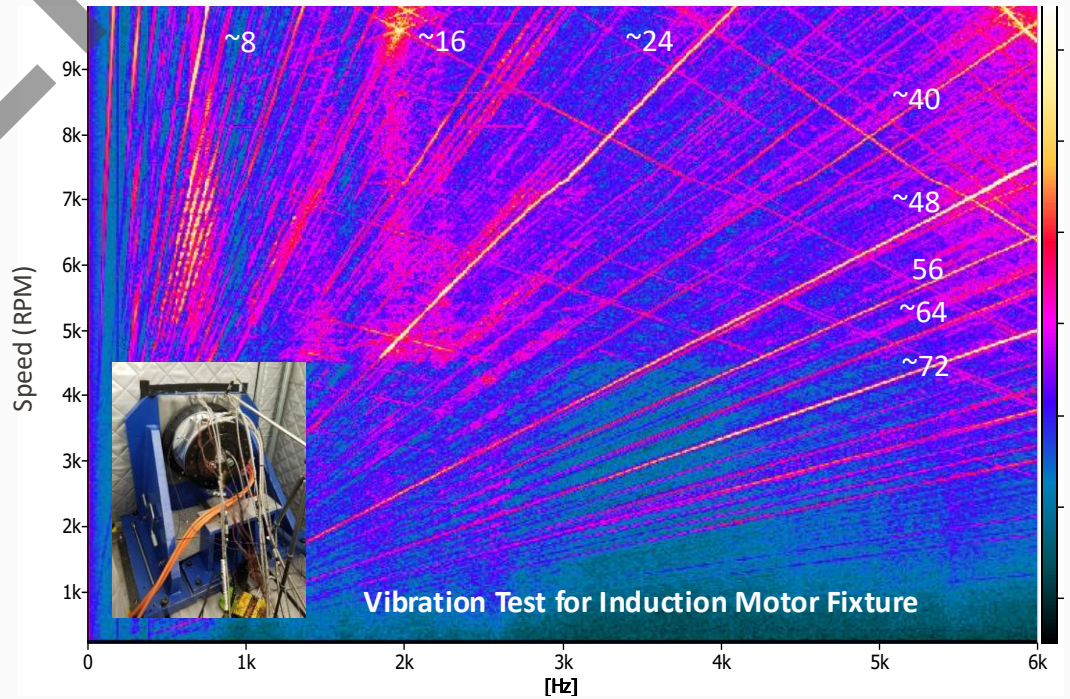


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Analysis vs Test Correlation for Induction Motor NVH

- Predicted EM forces are mapped on the induction motor stator, which is integrated into a motor fixture system model corresponding to the motor dyno setup
- Waterfall plots of RMS motor fixture vibration responses during a motor run-up sweep are predicted and compared to the test results: Good correlation are observed
- Analysis captures the dominant non-integer induction orders around 8th, 16th, 24th, 48th and 56th order, but also accurately predicts the change in induction order due to variation of slip frequency during motor operation

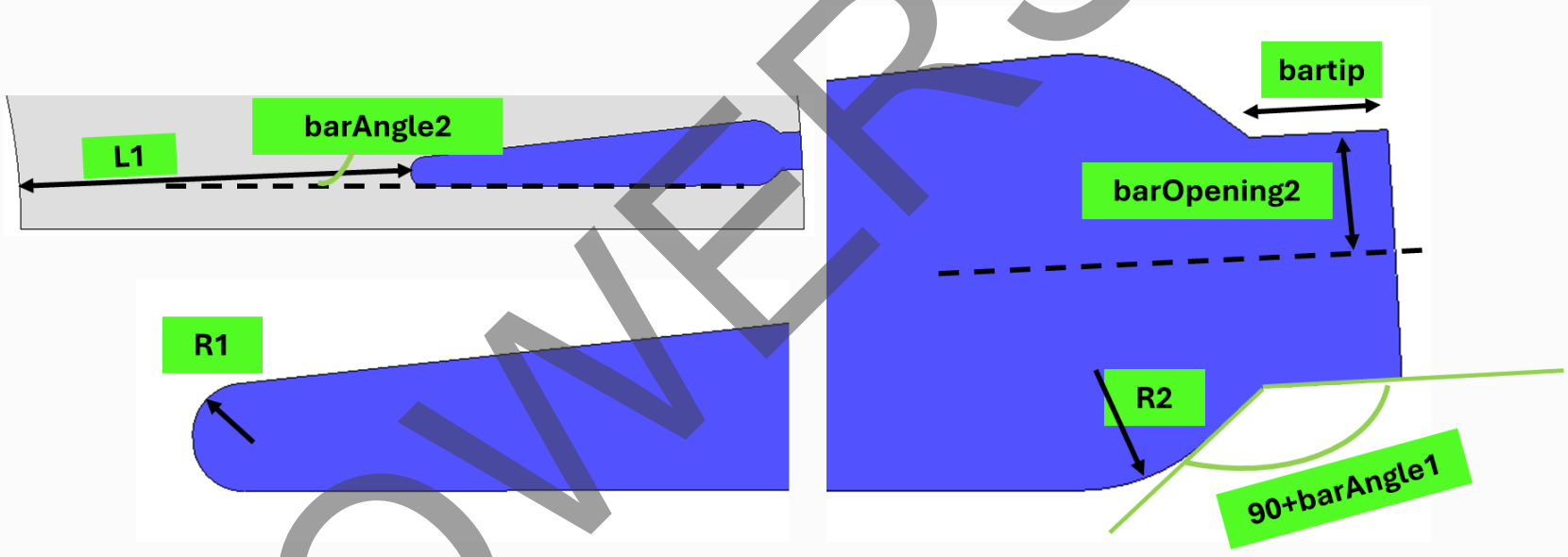




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Rotor Bar Dimension Optimization for Induction Motor

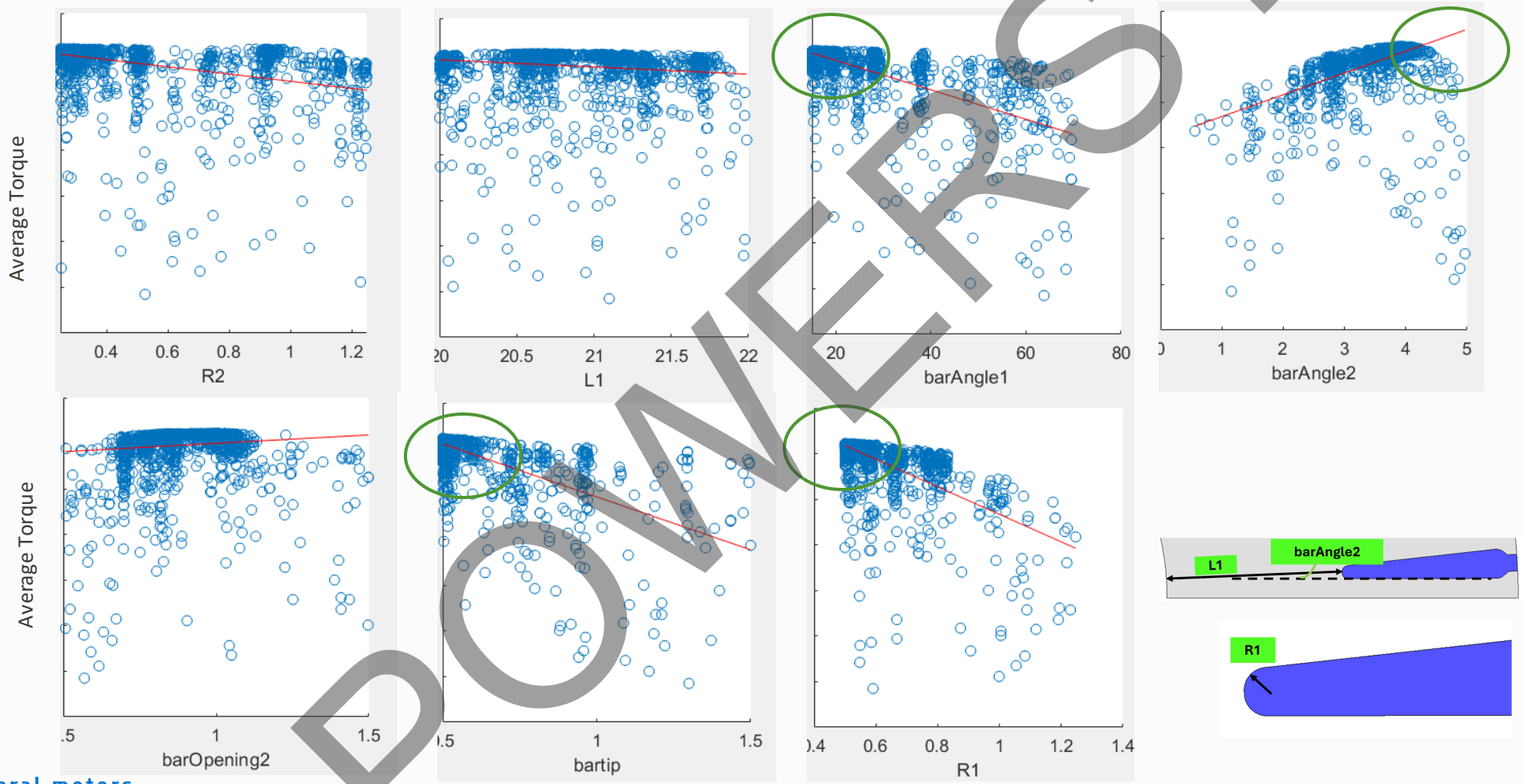
- Rotor bar dimension optimization is conducted to maximum torque and reduce NVH
- 7 dimensions are considered including the size, shape and position of rotor bar designs



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Impact of Rotor Bar Design Variables on Motor Torque

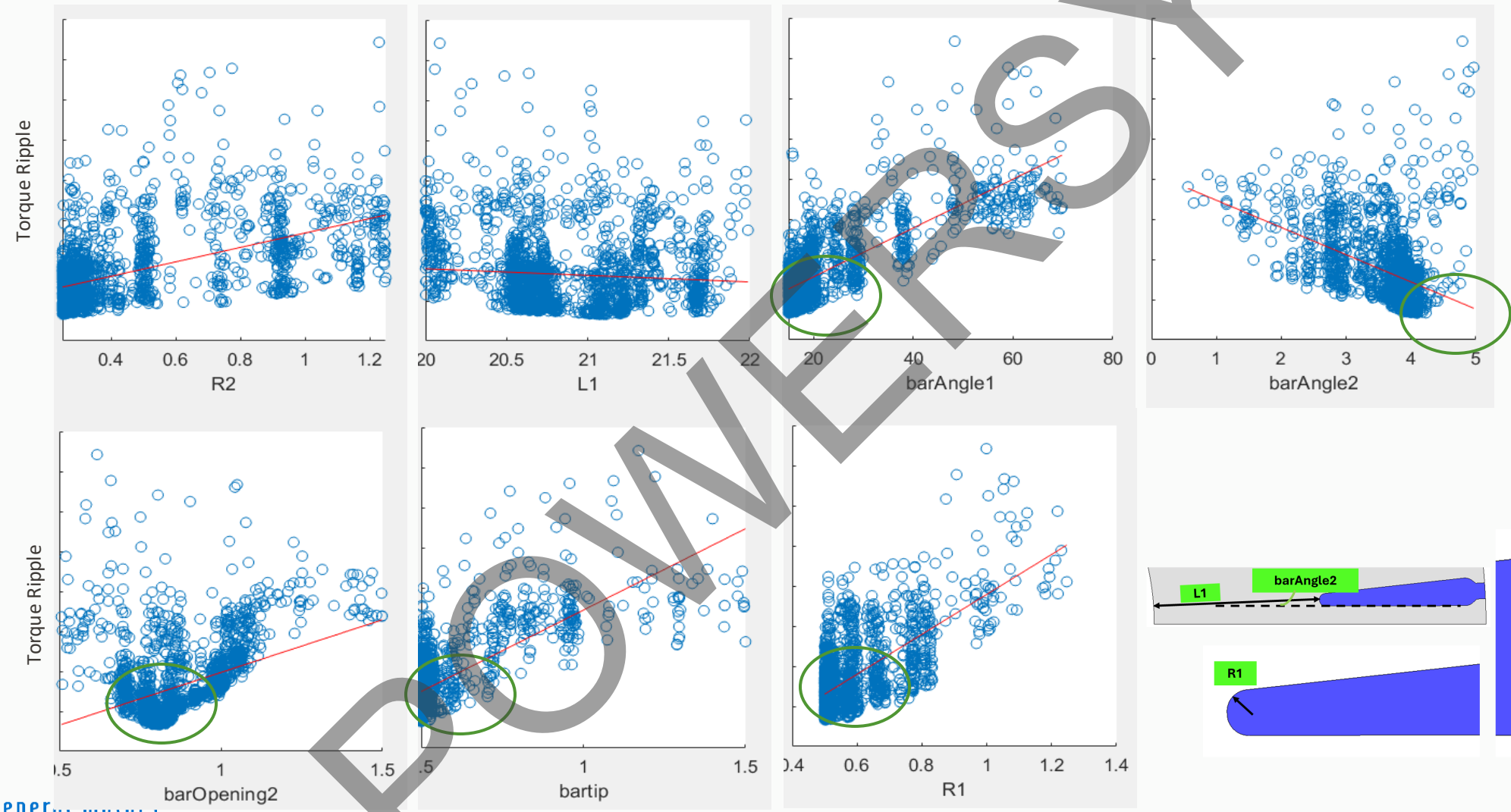
- Smaller bar angle 1, bar top and R1 radius and larger bar angle 2 are favorable for higher torque



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Impact of Rotor Bar Design Variables on Torque Ripple

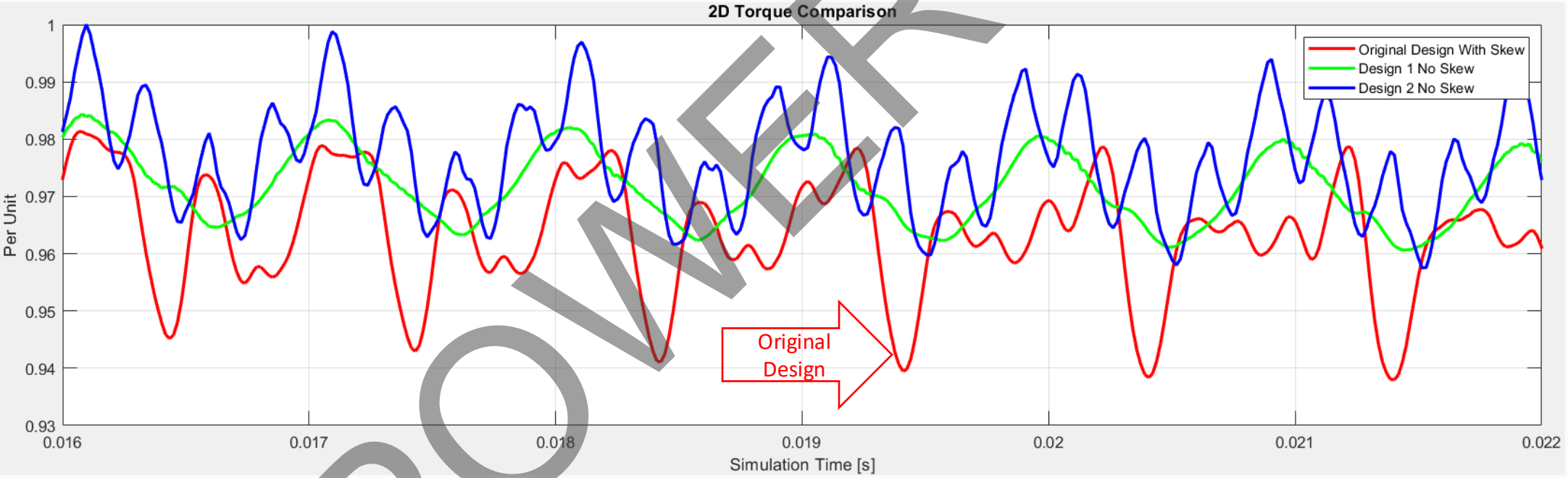
- Smaller bar angle 1, bar top and R1 radius and larger bar angle 2 are favorable for low NVH



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Rotor Bar Number Optimization: 2D FEA

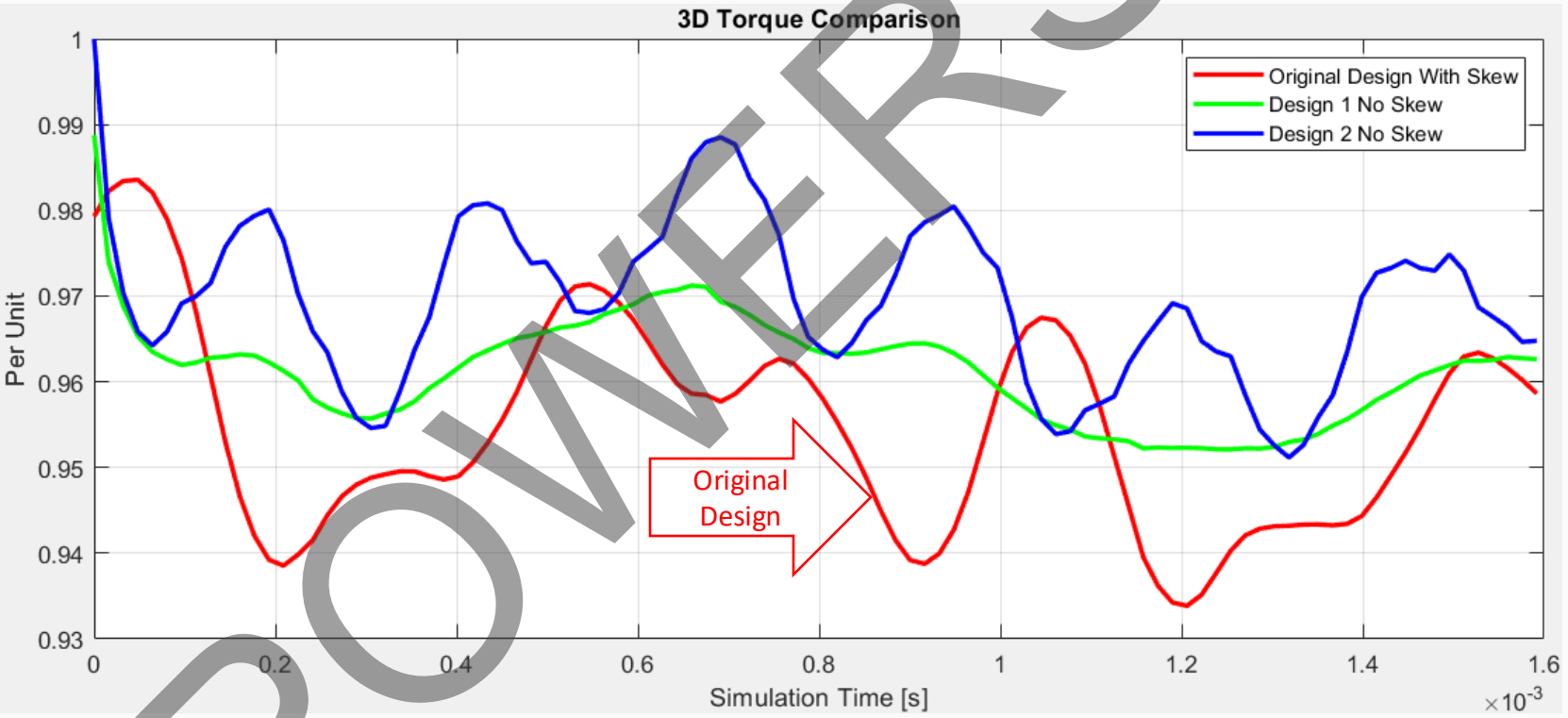
- Different numbers of rotor bars are analyzed and compared
- Original design uses rotor bar skew to reduce noise, leading to reduced motor torque
- The torque ripple and force harmonics are reduced by 50% or more with optimized bar number
- Optimized rotor bar designs do not require skew: Reduced manufacturing costs



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Rotor Bar Number Optimization: 3D FEA

- 2D and 3D torque and force waveforms correlate well
- The torque ripple and force harmonics are reduced by 50% or more with optimized bar number
- Optimized rotor bar designs do not require skew: Reduced manufacturing costs



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Summary

- **The NVH simulation results correlate with test data**
  - Analysis captures the dominant non-integer induction orders around 8th, 16th, 24th, 48th and 56th order
  - Accurately predicts the change in induction order due to variation of slip frequency during motor operation
- **JMAG 2D and 3D optimizations improve the NVH performance for induction production design**
  - Average torque is kept the same or higher
  - Torque ripple reduced by 50% across operating conditions
  - Force harmonic amplitude is reduced by up to 50%
  - Motor efficiency are comparable





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zero crashes
zero emissions
zero congestion