AI-Assisted Axial-Flux Motor Design and Optimization

with MotorXP-AFM, MATLAB and AI Coding Agents

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MOTORXP

AXIAL-FLUX MOTOR MODEL SETUP

- **Stator–rotor, stator–rotor–stator (with a yoked or yokeless rotor), and rotor–stator–rotor (with a yoked or yokeless stator) topologies**

- **3D stator and rotor geometry templates**
  Stator geometries: parallel flat slots, parallel round slots, and PCB stators
  Rotor geometries: trapezoidal magnets with or without skewing, rectangular magnets, Halbach arrays, and cylindrical magnets

- **Custom geometry templates**
  Create fully parameterized 3D geometry templates for custom stator and rotor geometries of arbitrary complexity

- **3D geometry export to and import from STEP files**

- **Concentrated, distributed, and toroidal winding types**

- **Manual or automatic winding layouts for all pole/slot combinations**

- **Multiple wire-sizing methods**
  AWG, SWG, wire diameter, rectangular wire, or direct fill-factor definition

- **Calculation of key winding parameters**
  Fundamental and harmonic winding factors; LCM and GCD of slot and pole counts; phase resistance; and end-turn inductance

- **Materials library and custom materials**

- **Custom transistors and diodes**
  Devices can be added from datasheet parameters for inverter-loss calculations

ANALYSIS

- **High-accuracy, high-speed quasi-3D finite-element modeling**
  Up to 100 times faster than full 3D FEA without sacrificing accuracy

- **FEA and analytical methods, including the ultra-fast hybrid FEA–DQ method**

- **Sine-wave, PWM, and six-step drives**

- **All major loss components: winding DC and AC losses; iron eddy-current and hysteresis losses (including higher harmonics and minor hysteresis loops); magnet losses; and more**

- **Permanent-magnet demagnetization analysis**

- **Inverter-loss calculations for IGBTs and MOSFETs, including SiC MOSFETs**

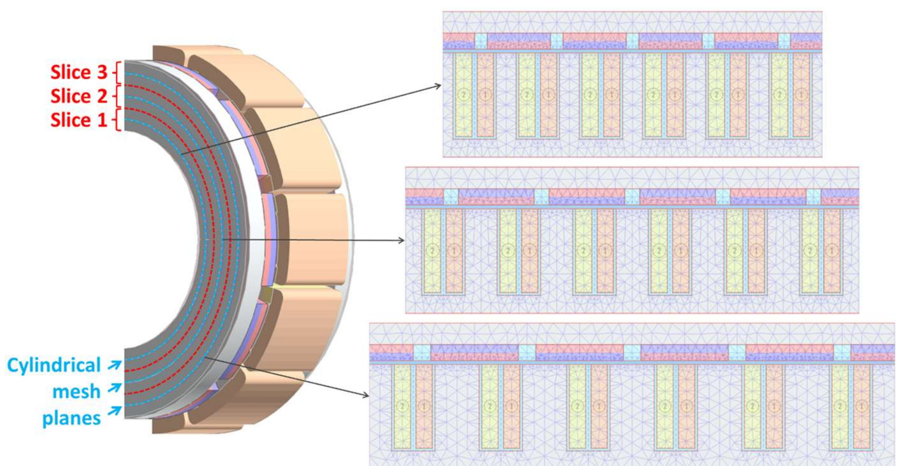
- **Parametric studies, automatic optimization, and an API for automated design workflows**

RESULTS

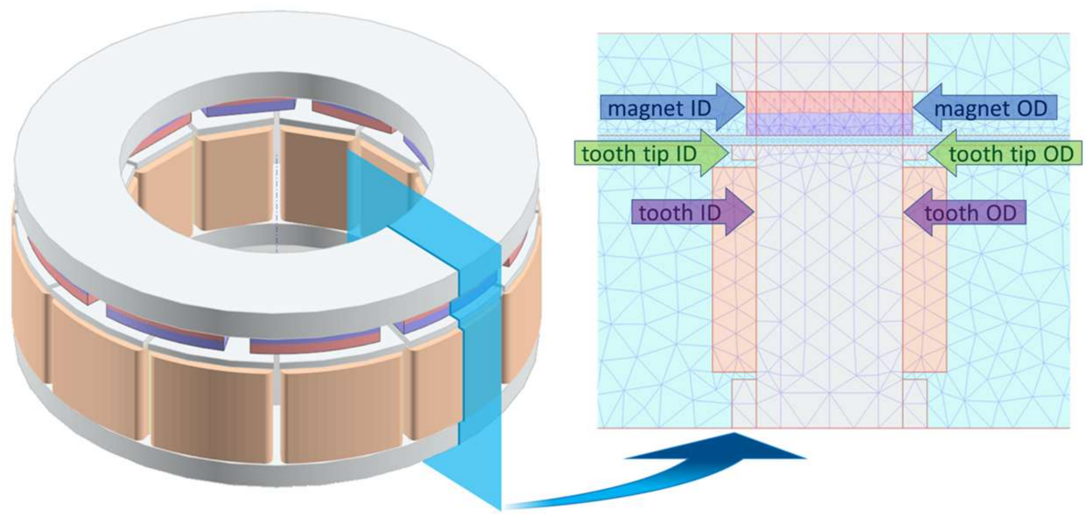
- **Time-series waveform plots and frequency spectra**
  Current, voltage, back-EMF, torque, power, losses, and more
- **Air-gap distribution waveforms and frequency spectra**
  Air-gap flux-density magnitude; tangential and normal flux-density components; radial force; and more
- **Field plots and flux contours**
  Flux-density, current-density, and loss distributions
- **Animated air-gap distributions and field plots over time**
- **Machine constants**
- **Automatic calculation of flux-density levels throughout the machine**
- **Steady-state performance characteristics accounting for field weakening**
  Torque vs. speed, torque vs. advance angle, voltage vs. speed, and more
- **Steady-state performance maps**
  Efficiency and loss maps
- **Extraction of D–Q model parameters, including Ld, Lq, and magnet flux linkage**
  For use in third-party applications
- **Id and Iq lookup tables extracted from efficiency-map data**
  For upload to a controller to optimize motor performance
- **Plots exported to CSV, Excel, and MAT files**

Quasi-3D FEA of an Axial Flux Machine: Summary

- Up to 100 times higher computational speed compared to full 3D FEA
- The magnetic field is simultaneously solved in cylindrical and radial cross-sections of the AFM
- The leakage flux alone the radial cross-section plane is taken into account
- The variation of the inner and outer diameters of different parts of the AFM is considered
- Specific 3D geometry details are taken into account via geometry correction coefficients

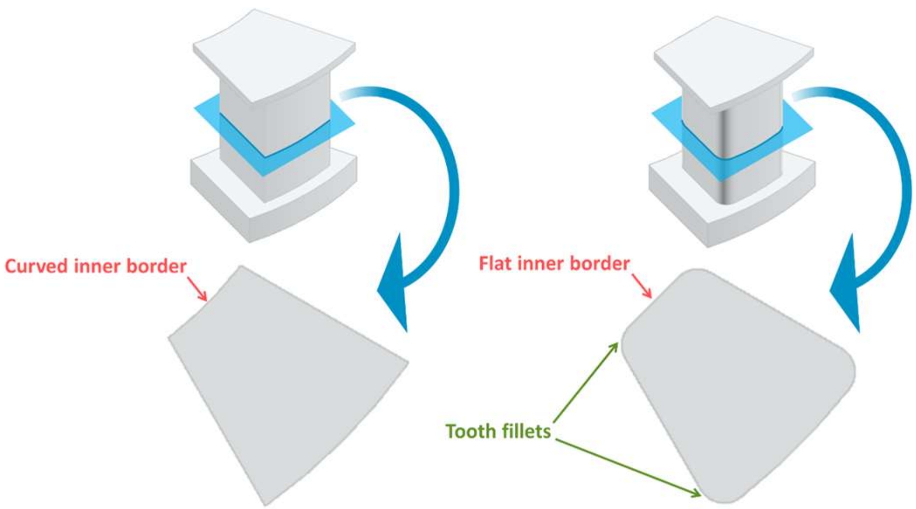


Cylindrical mesh slices



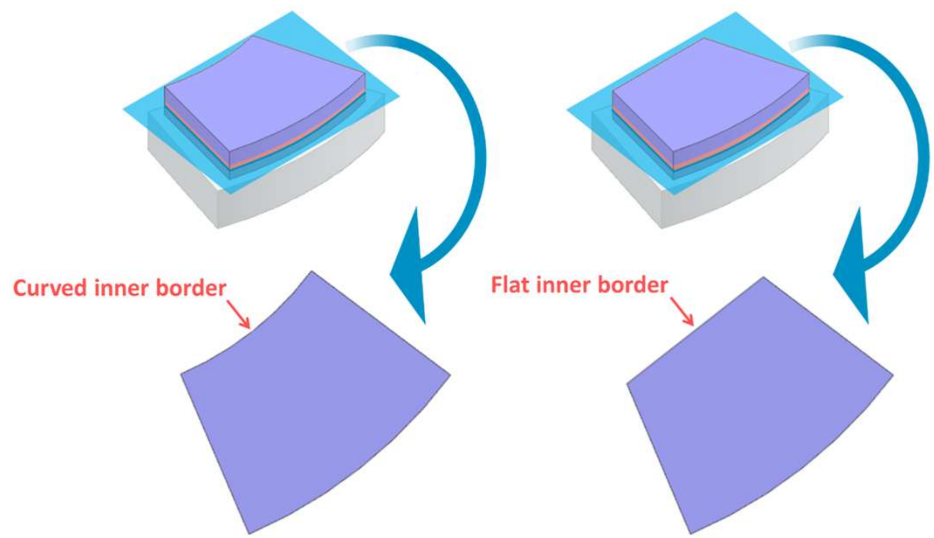
Radial cross-section mesh

Quasi-3D FEA of AFM: Geometry Correction Coefficients

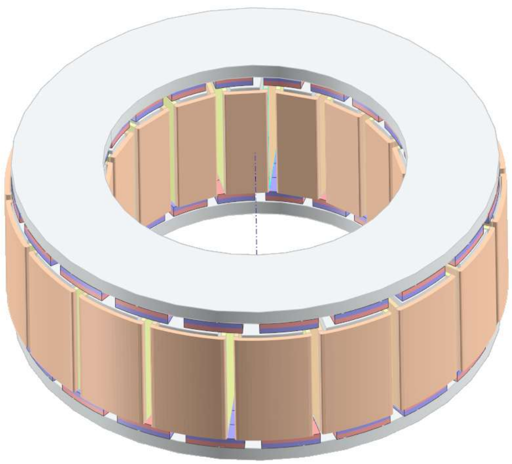


Examples of two stator tooth shapes which are taken into account using geometry correction coefficients

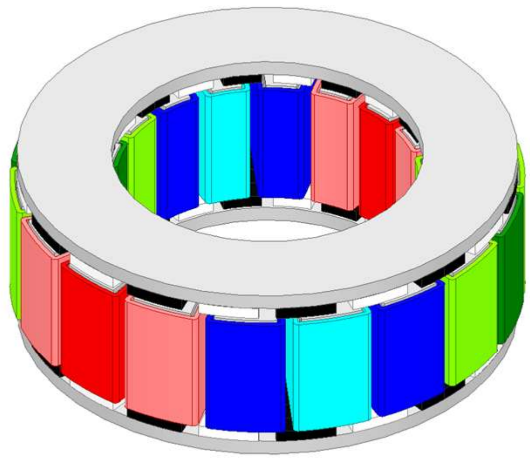
Examples of two rotor magnet shapes which are taken into account using geometry correction coefficients



MotorXP-AFM vs. Ansys Maxwell 3D: Magnetostatic FEA



MotorXP-AFM

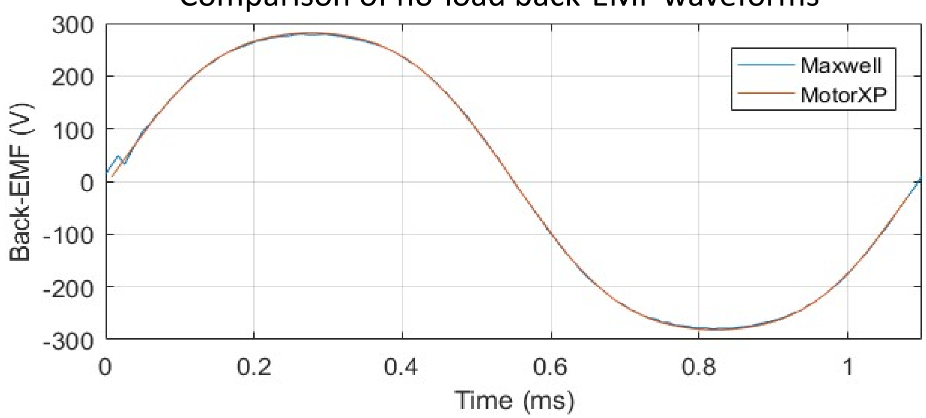


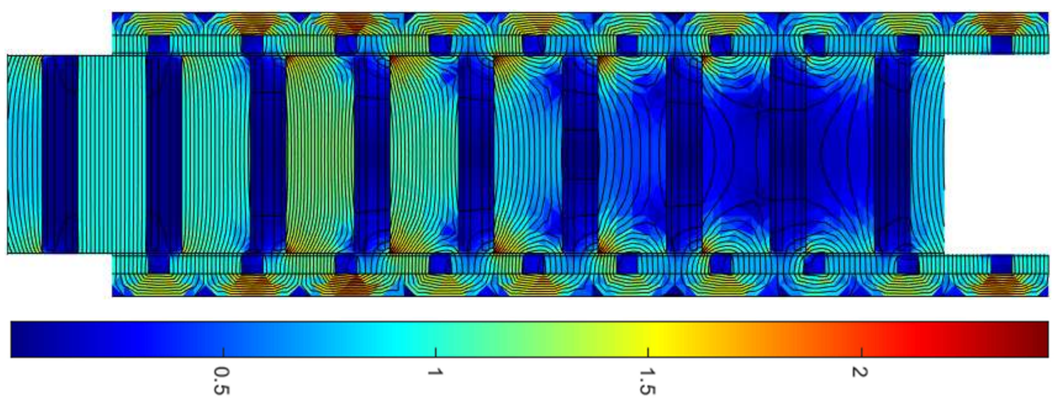
Ansys Maxwell 3D

EMRAX-228*, 5500RPM (zero current)			
	Maxwell	**MotorXP**	**Discrepancy, %**
Back EMF peak (V)	279.0	282.0	1.08
Total iron losses (W)	486.3	474.3	2.47

EMRAX-228*, 5500RPM, 57.5Arms			
	Maxwell	**MotorXP**	**Discrepancy, %**
Torque (Nm)	63.1	63.3	0.43
Induced voltage peak, Rs=0 (V)	320.2	317.7	0.78
Total iron losses (W)	562.9	536.6	4.67

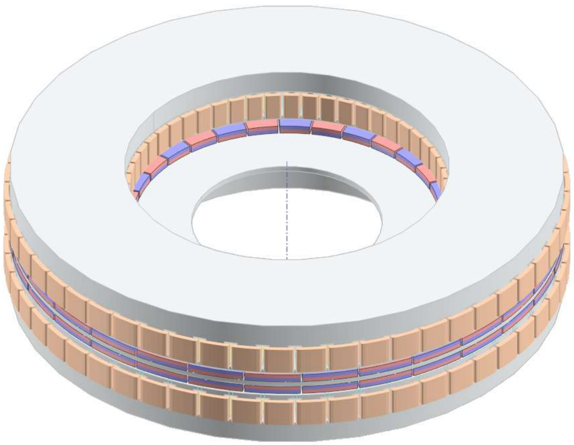
EMRAX-228*, 5500RPM, 115Arms (rated conditions)			
	Maxwell	**MotorXP**	**Discrepancy, %**
Torque (Nm)	125.8	126.2	0.38
Induced voltage peak, Rs=0 (V)	398.0	389.0	2.26
Total iron losses (W)	780.7	724.9	7.15



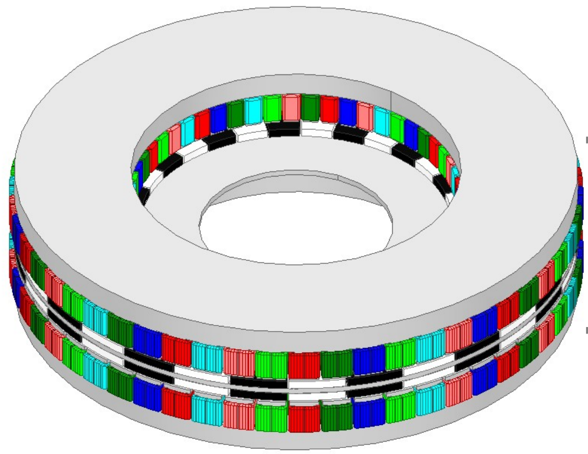


*source: https://emrax.com/e-motors/emrax-228/

MotorXP-AFM vs. Ansys Maxwell 3D: Magnetostatic FEA



MotorXP-AFM



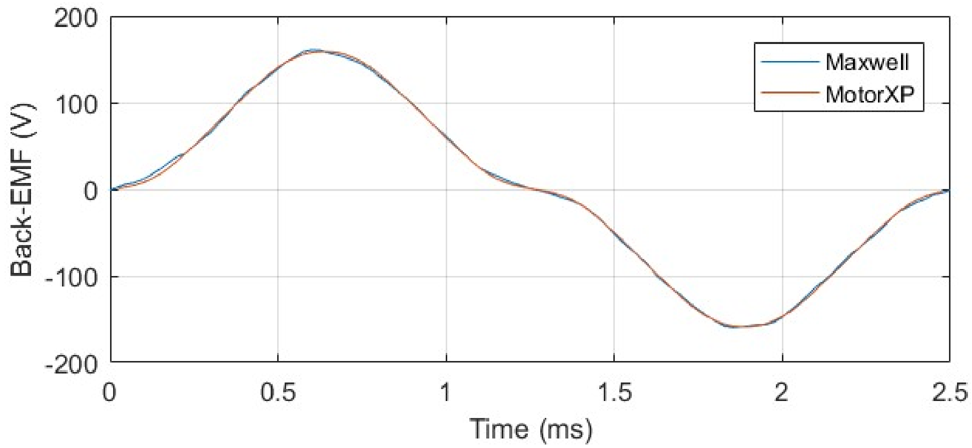
Ansys Maxwell 3D

afm_srs54_5, 1600RPM (zero current)			
	Maxwell	**MotorXP**	**Discrepancy, %**
Back EMF (V)	158.5	158.6	0.06
Total iron losses (W)	733.3	742.5	1.25

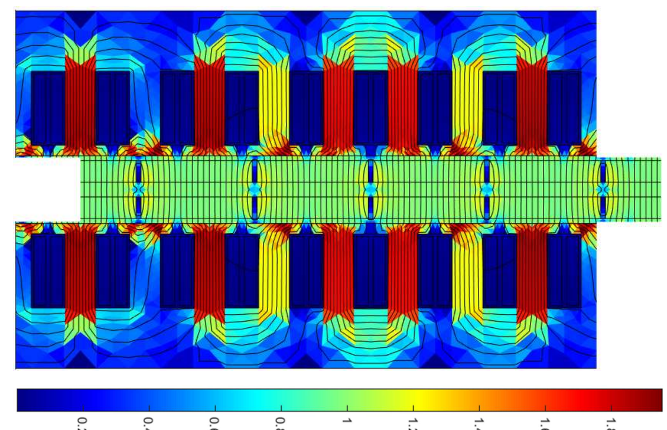
afm_srs54_5, 1600RPM, 125Arms			
	Maxwell	**MotorXP**	**Discrepancy, %**
Torque (Nm)	208.8	209.6	0.39
Induced voltage peak, Rs=0 (V)	158.0	158.5	0.32
Total iron losses (W)	750.6	758.8	1.09

afm_srs54_5, 1600RPM, 250Arms (rated conditions)			
	Maxwell	**MotorXP**	**Discrepancy, %**
Torque (Nm)	395.2	403.2	2.02
Induced voltage peak, Rs=0 (V)	160.5	159.2	0.81
Total iron losses (W)	785.9	795.1	1.17

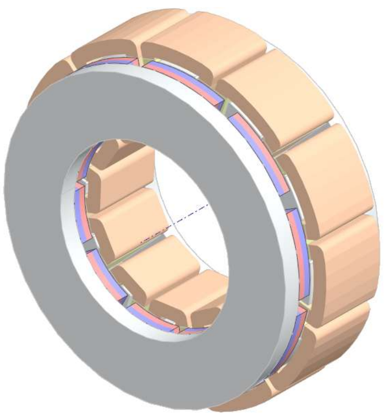
Comparison of no-load back-EMF waveforms



Flux density distribution at rated conditions (MotorXP-AFM)



MotorXP-AFM vs. JMAG 3D: Dynamic FEA

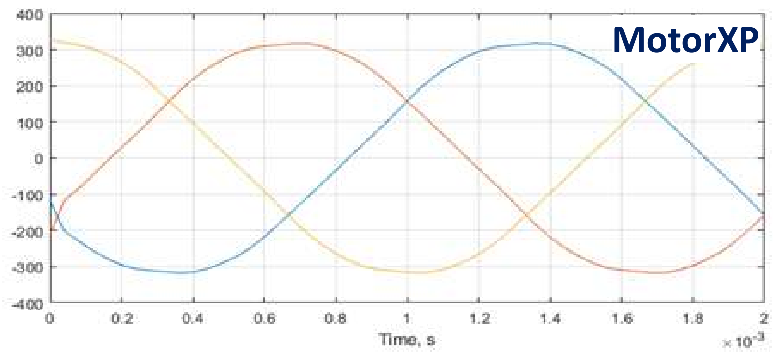


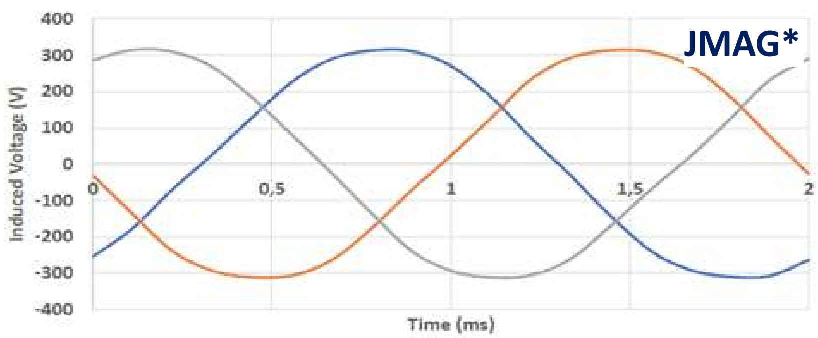
MotorXP-AFM

JMAG 3D

afm_sr12, 6000RPM, 7.79Apk (rated conditions)			
	JMAG*	MotorXP	Discrepancy, %
Torque (Nm)	3.20	3.19	0.31
Induced voltage peak (V)	312.87	306.70	1.97
Total iron losses	60.18	63.42	5.38

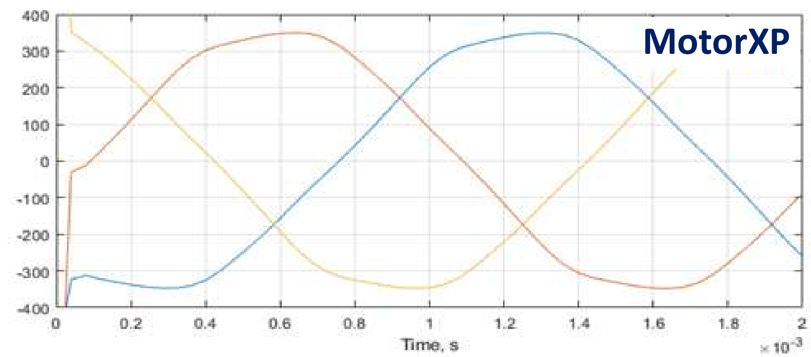
Comparison of voltage waveforms (rated conditions)

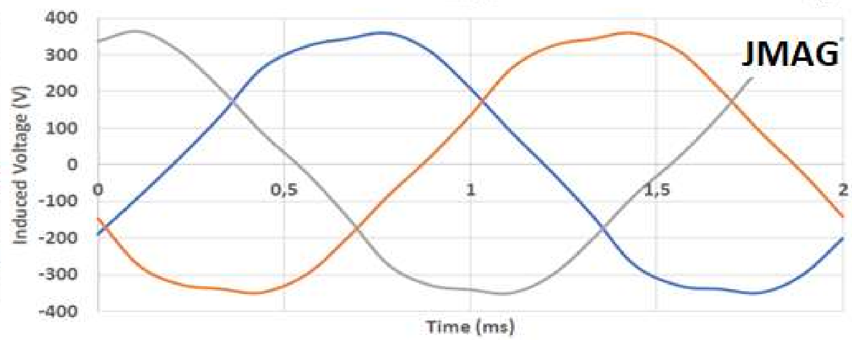




afm_sr12, 6000RPM, 20.26Apk (overload conditions)			
	JMAG*	MotorXP	Discrepancy, %
Torque (Nm)	7.94	7.86	1.01
Induced voltage peak (V)	358.40	343.8	4.07
Total iron losses (W)	73.99	78.86	6.58

Comparison of voltage waveforms (overload conditions)





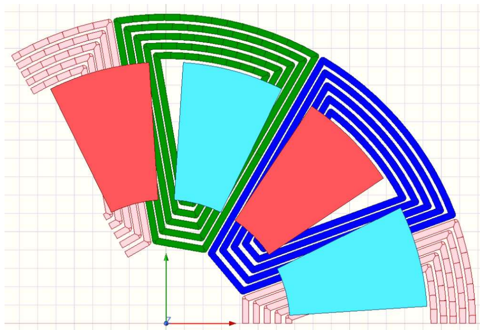
*source: https://www.jmag-international.com/motordesign-material/hoganas_001/

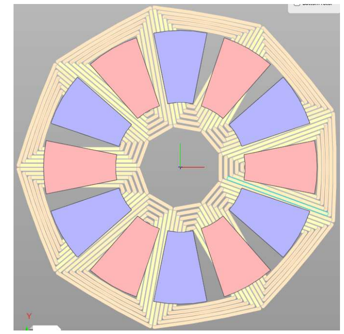
PCB Stator Validation: Three Magnet-Coverage Cases

Full PCB winding model • 5000 rpm • 2 A rms phase current

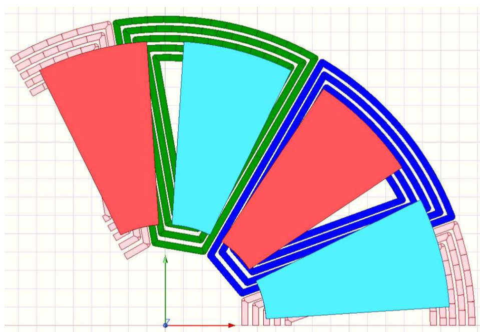
Ansys Maxwell 3D | **MotorXP-AFM**

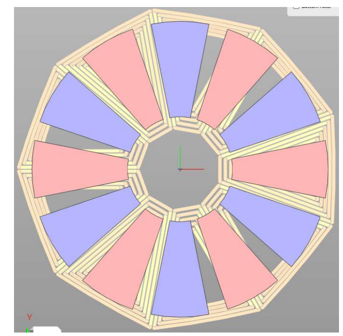
15 mm
Inner coverage



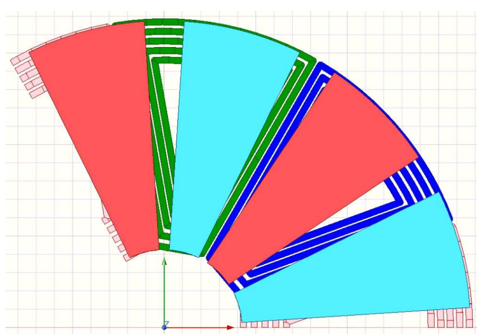


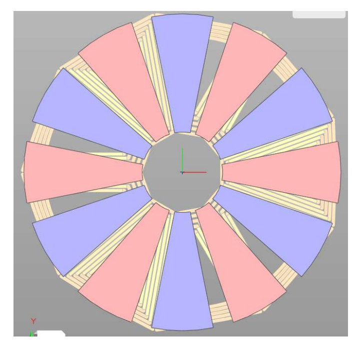
20 mm
Middle coverage





25 mm
Full radial coverage

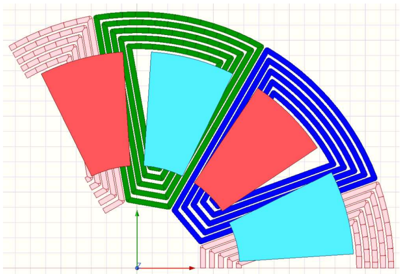




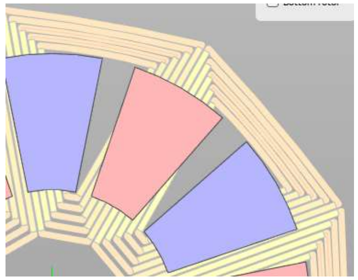
**source: https://motorxp.com/docs/part-4-validating-pcb-stator-dynamic-fea-against-ansys-maxwell-3d-accuracy-and-calculation-time/*

15 mm PCB Stator: Inner Magnet Coverage

Ansys Maxwell 3D



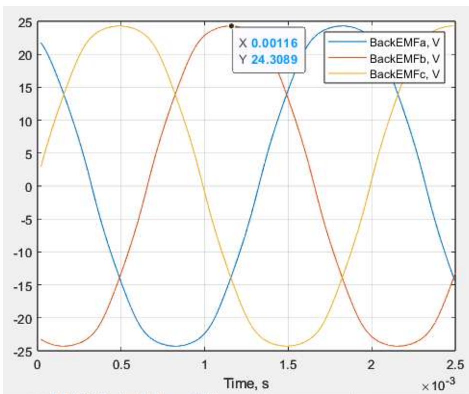
MotorXP-AFM



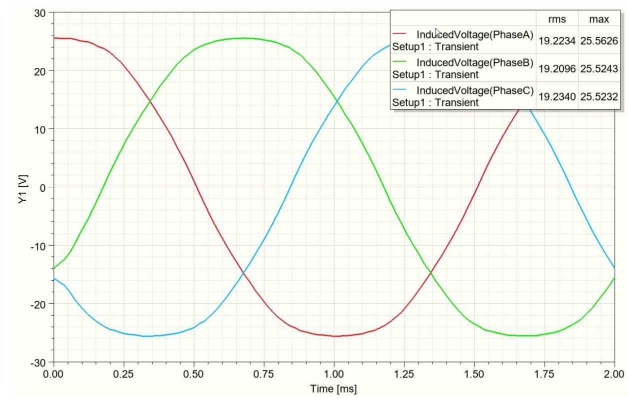
Magnets cover the inner, shortest part of the active PCB winding

Parameter	MotorXP Magnetostatic FEA	MotorXP Dynamic FEA	Ansys Maxwell 3D	MotorXP Dynamic vs. Maxwell
No-load back-EMF, V rms	18.2627	18.2601	19.2	5.15%
Torque, Nm	0.2087	0.2024	0.2146	6.03%
Calculation time	11 min 53 s	15 min	34 h 53 min	~140× faster

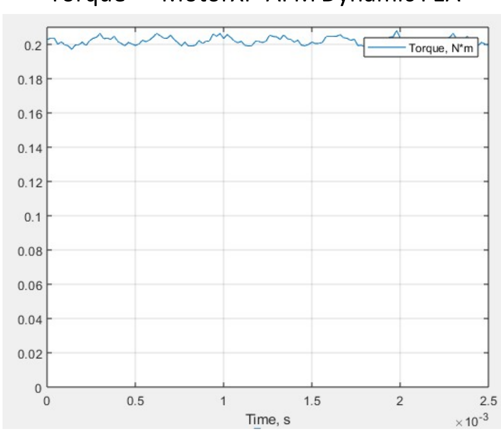
Back-EMF — MotorXP-AFM Dynamic FEA



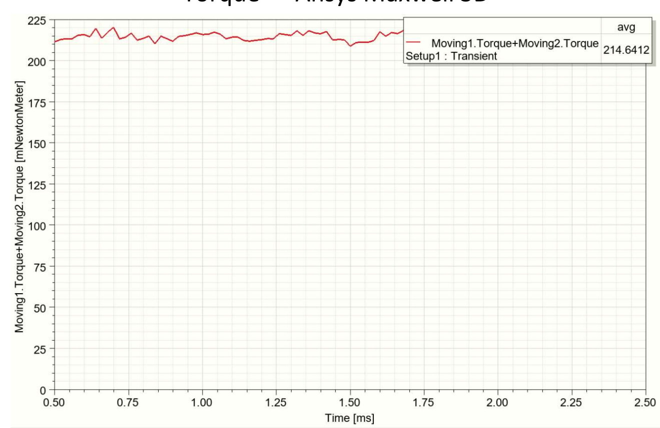
Back-EMF — Ansys Maxwell 3D



Torque — MotorXP-AFM Dynamic FEA



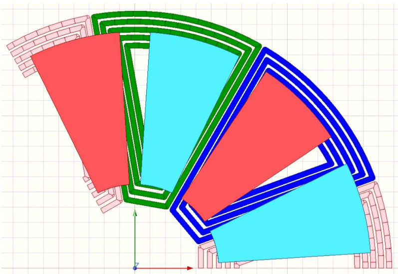
Torque — Ansys Maxwell 3D



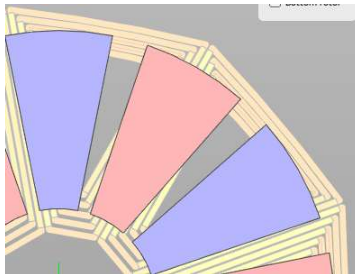
*source: https://motorxp.com/docs/part-4-validating-pcb-stator-dynamic-fea-against-ansys-maxwell-3d-accuracy-and-calculation-time/

20 mm PCB stator: Middle Magnet Coverage

Ansys Maxwell 3D



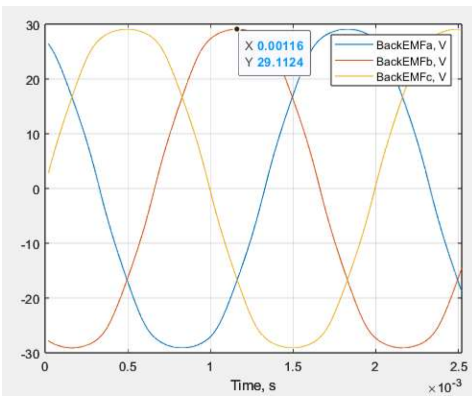
MotorXP-AFM



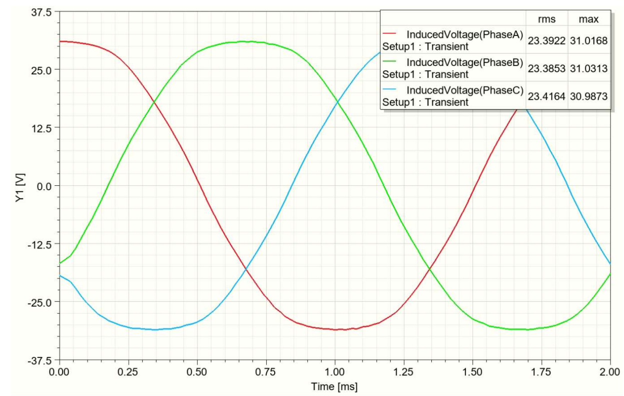
Magnets cover the middle part of the active PCB winding

Parameter	MotorXP Magnetostatic FEA	MotorXP Dynamic FEA	Ansys Maxwell 3D	MotorXP Dynamic vs. Maxwell
No-load back-EMF, V rms	21.9201	21.9212	23.38	6.66%
Torque, Nm	0.2507	0.2412	0.2529	4.85%
Calculation time	11 min 12 s	23 min 13 s	33 h 20 min	~86× faster

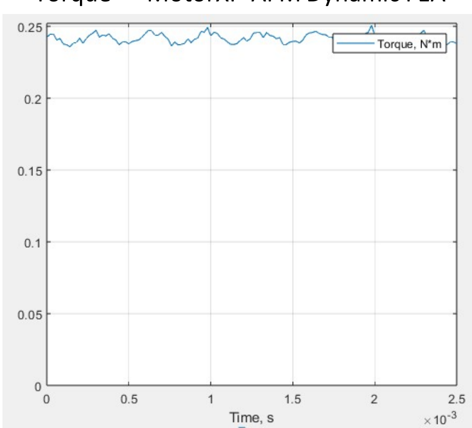
Back-EMF — MotorXP-AFM Dynamic FEA



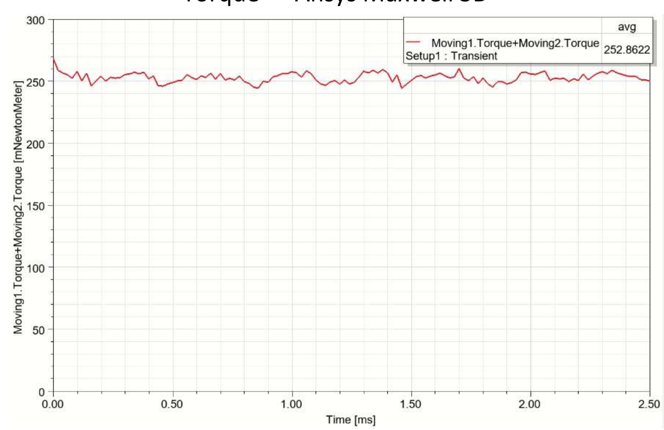
Back-EMF — Ansys Maxwell 3D



Torque — MotorXP-AFM Dynamic FEA



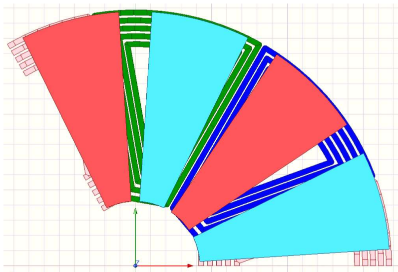
Torque — Ansys Maxwell 3D



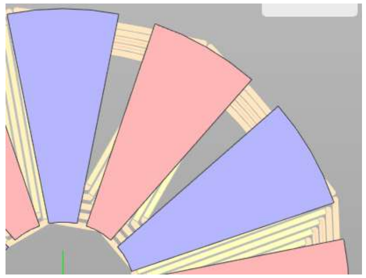
**source: https://motorxp.com/docs/part-4-validating-pcb-stator-dynamic-fea-against-ansys-maxwell-3d-accuracy-and-calculation-time/*

25 mm PCB Stator: Full Radial Magnet Coverage

Ansys Maxwell 3D



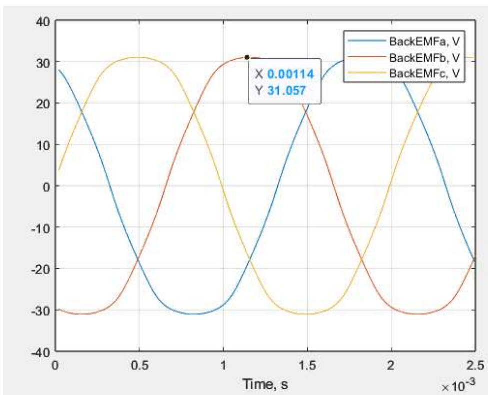
MotorXP-AFM



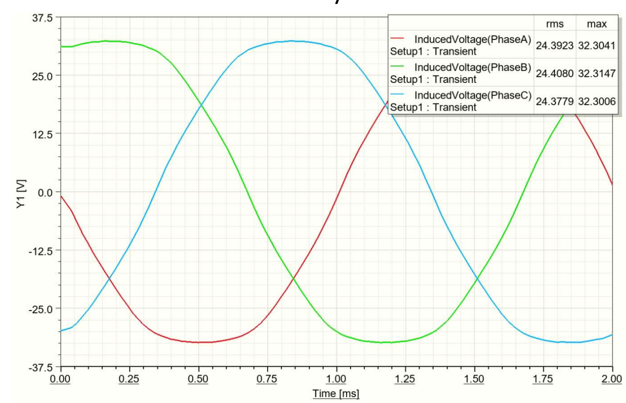
Magnets provide full radial coverage of the active winding and end-winding area

Parameter	MotorXP Magnetostatic FEA	MotorXP Dynamic FEA	Ansys Maxwell 3D	MotorXP Dynamic vs. Maxwell
No-load back-EMF, V rms	23.4256	23.4251	24.4	4.16%
Torque, Nm	0.2680	0.2577	0.2645	2.64%
Calculation time	12 min 45 s	26 min 04 s	30 h 00 min	~69× faster

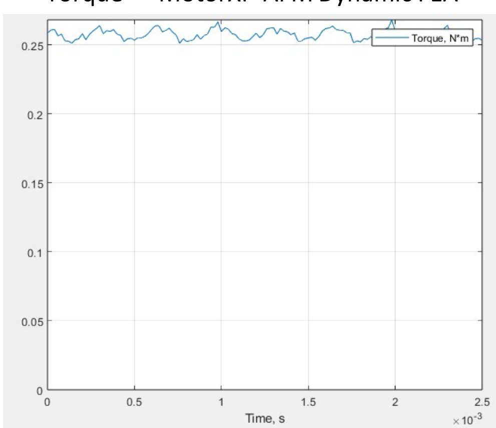
Back-EMF — MotorXP-AFM Dynamic FEA



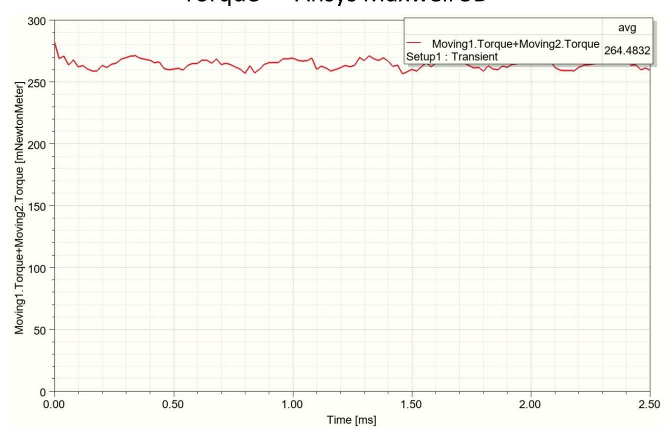
Back-EMF — Ansys Maxwell 3D



Torque — MotorXP-AFM Dynamic FEA



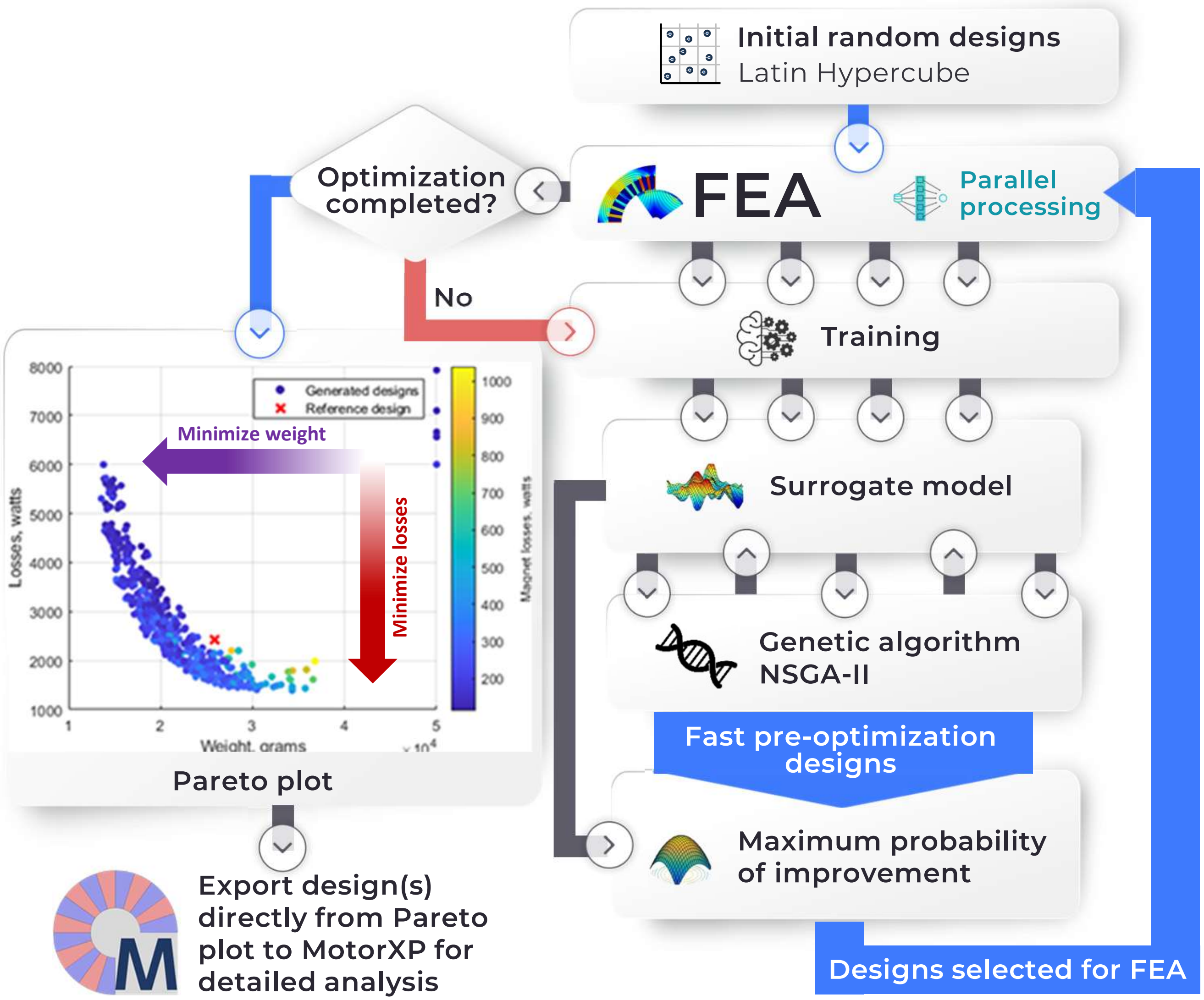
Torque — Ansys Maxwell 3D



*source: https://motorxp.com/docs/part-4-validating-pcb-stator-dynamic-fea-against-ansys-maxwell-3d-accuracy-and-calculation-time/

MOTORXP

E-MOTOR DESIGN OPTIMIZATION FLOWCHART



Initial Sampling:

A set of initial design candidates is randomly generated across the design space and evaluated using FEA. These results serve as data for the initial surrogate model training

Objective Evaluation:

FEA computes the optimization objectives for each design candidate. Thanks to parallel processing, multiple design candidates can be evaluated simultaneously, significantly reducing computation time

Surrogate Model Training:

The FEA results are used to train a surrogate model that captures the relationship between design variables and optimization objectives. The surrogate model is continuously refined with each optimization iteration as new FEA results are incorporated into the training process

Fast Exploration:

Since the surrogate model runs orders of magnitude faster than FEA, the genetic algorithm can rapidly explore the design space and evaluate thousands of design candidates within seconds

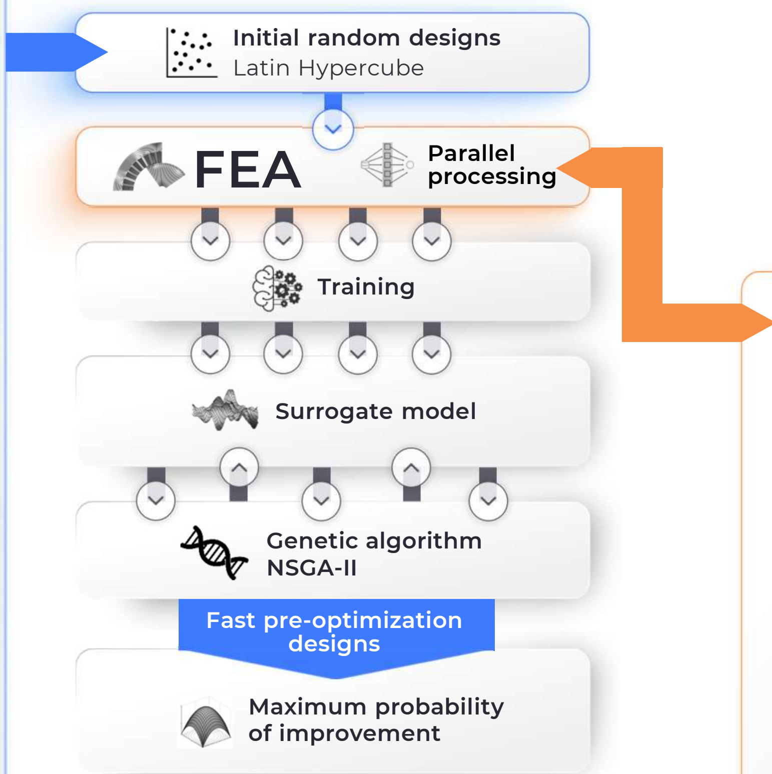
Focused Refinement:

Based on the “maximum probability of improvement” criterion, only a few of the most promising design candidates — among those generated by the genetic algorithm—are selected for further evaluation using FEA, ensuring efficient and targeted optimization

Motor Design Optimization: Implementation Using MATLAB

OPTIMIZATION SCENARIO SCRIPT

- Configures the optimization algorithm (e.g., number of iterations, number of design candidates, etc.)
- Configures MotorXP parallel processing
- Defines optimization variables and their bounds
- Defines optimization objectives (e.g., minimize motor weight, minimize losses, minimize demagnetizing field, minimize torque ripple, optimize field weakening performance, maximize power factor, etc.)
- Links to the evaluation function `@evalDesigns`
- Launches the optimization algorithm

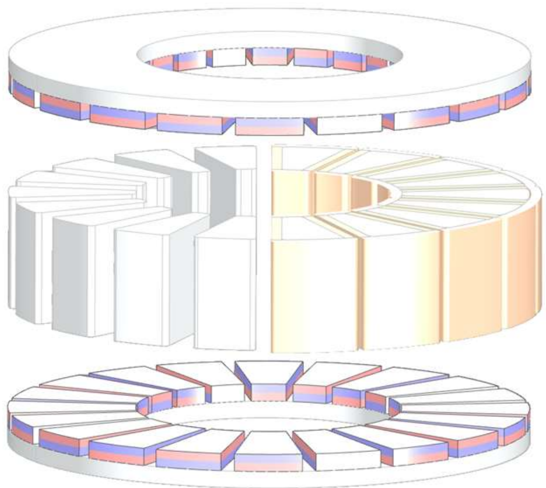


EVALUATION FUNCTION

```
function [Optimization Objectives]
= @evalDesigns(Optimization
Variables)
```

- Assembles simulation models
- **Invokes MotorXP FEA solver**
- Pre-processes and post-processes simulation data
- Implements constraints and applies penalty strategies
- Calculates optimization objectives

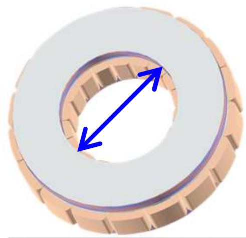
Example of Generalized Normalized-Variable Optimization Scenario



OBJECTIVES

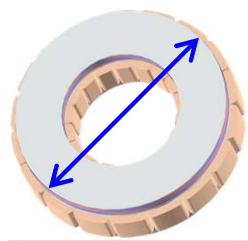
1. Minimizing motor weight
2. Minimizing losses (@ targetTorque, targetPower)
3. Minimizing magnet weight

VARIABLES (GROUP 1)



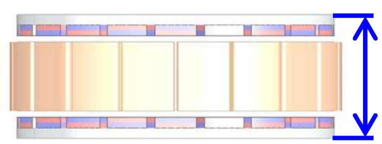
Core inner diameter, mm

Can be fixed or defined as a range



Core outer diameter, mm

Can be fixed or defined as a range

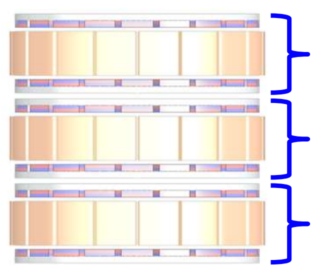


Machine height, mm

Can be fixed or defined as a range

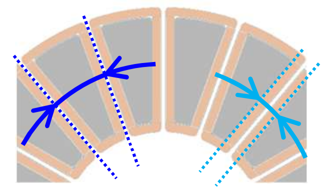
Air gap height, mm

Can be fixed or defined as a range



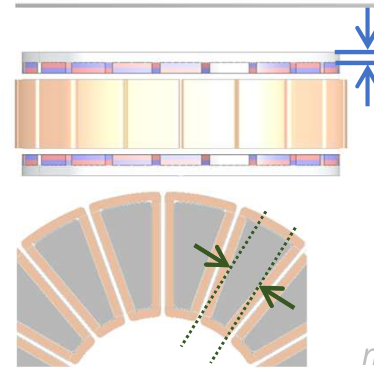
Number of identical AFM units mounted on one shaft

VARIABLES (GROUP 2)



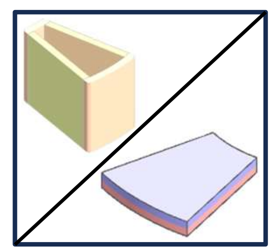
Slot width to *slot pitch* ratio

0.2 range **0.9**
min max



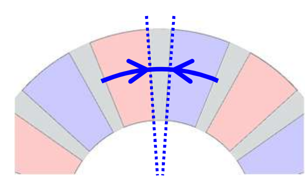
Rotor yoke to average *tooth width* ratio

0.3 range **1.2**
min max



Winding to Magnet volume ratio

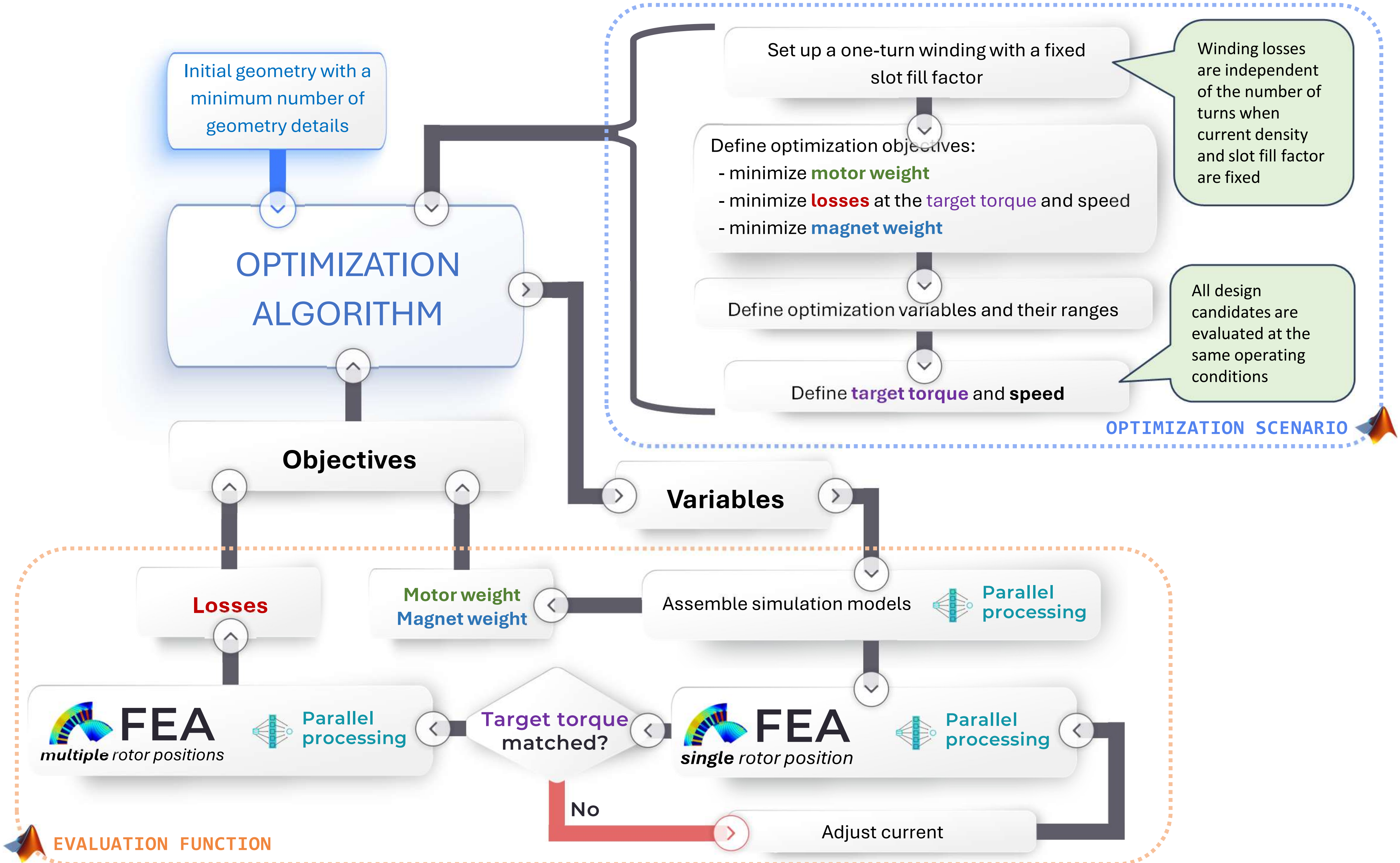
0.1 range **2.5**
min max



Magnet spacing, electrical degrees

5 range **70**
min max

Example of Optimization Scenario and Evaluation Function Implementation



AI Coding Agents in E-Motor Optimization

AI coding agents create and modify the MATLAB files for the optimization scenario and evaluation function turning engineering intent into MATLAB code. The motor design engineer defines the optimization strategy and oversees the overall process.

WHAT AI CODING AGENTS CAN DO:

- **Formulate the optimization study**
  P*ropose variables, objectives, constraints, and practical ranges*
- **Generate MATLAB code**
  Create optimization scenarios, evaluation functions, validation scripts, resume logic, and design exports
- **Prevent invalid designs and failed evaluations**
  Detect geometry conflicts and resolve dependent dimensions before FEA
- **Run and validate the study**
  Manage sampling and parallel execution, and verify result integrity
- **Interpret the results**
  Analyze Pareto fronts, identify candidates, and recommend follow-up studies

The motor design engineer makes the final decisions on the optimization strategy.

MotorXP skills for AI coding agents:
https://motorxp.com/docs-category/ai-tools/

Prompt-Ready Optimization Task Statement

Prompt 1

Geometry and manufacturing constraints:
- AFM topology: rotor-stator-rotor with yokeless stator
- Fixed outer diameter: 49.5 mm
- Fixed air gap: 1.3 mm
- Motor length <= 20 mm
- Slot fill factor: 0.35
- Magnet segmentation: radial, 4 segments

Operating point and electrical loading:
- Torque: 0.5 Nm
- Speed: 3200 RPM
- Current density <= 40 A/mm^2

Materials:
- Magnet: N48SH
- Stator core: M-19 29 Ga
- Rotor core: 1010
- Winding: Copper

Temperatures:
- Winding: 40° C
- Magnet: 30° C

Selected slot/pole configuration:
18 slots, 20 poles

Optimization objectives:
Minimize motor weight, total losses (@ 0.5 Nm and 3200 RPM), and magnet weight.

Prompt-Ready Optimization Task Statement (Continued)

Prompt 1 (continued)

Suggest an optimization strategy for the above specifications and requirements based the generalized normalized-variable optimization scenario, including:

- Optimization variables and their ranges
- Penalty function: Apply a penalty proportional to the amount by which the current density exceeds 40 A/mm²
- Optimization objectives
- Optimization algorithm and parallel processing settings

Use *“**[local computer path]**”*\SimFiles*Webinar_Sept2026\proto1.mxa”* as the baseline design.

Extract the optimization variable values from the baseline design and suggest appropriate variable ranges based on the baseline values and the geometry constraints.

Use the baseline design as a reference point on the Pareto plot for comparison and assessment of the improvements.

Do not create any M-files before receiving approval.

A penalty function is one way to handle optimization constraints. If a design candidate requires a current density above 40 A/mm², its objective values are increased proportionally to the constraint violation, making the design less favorable and guiding the optimization toward the feasible design region.

Replace ***[local computer path]*** with the actual paths on your local computer

Prompt 2

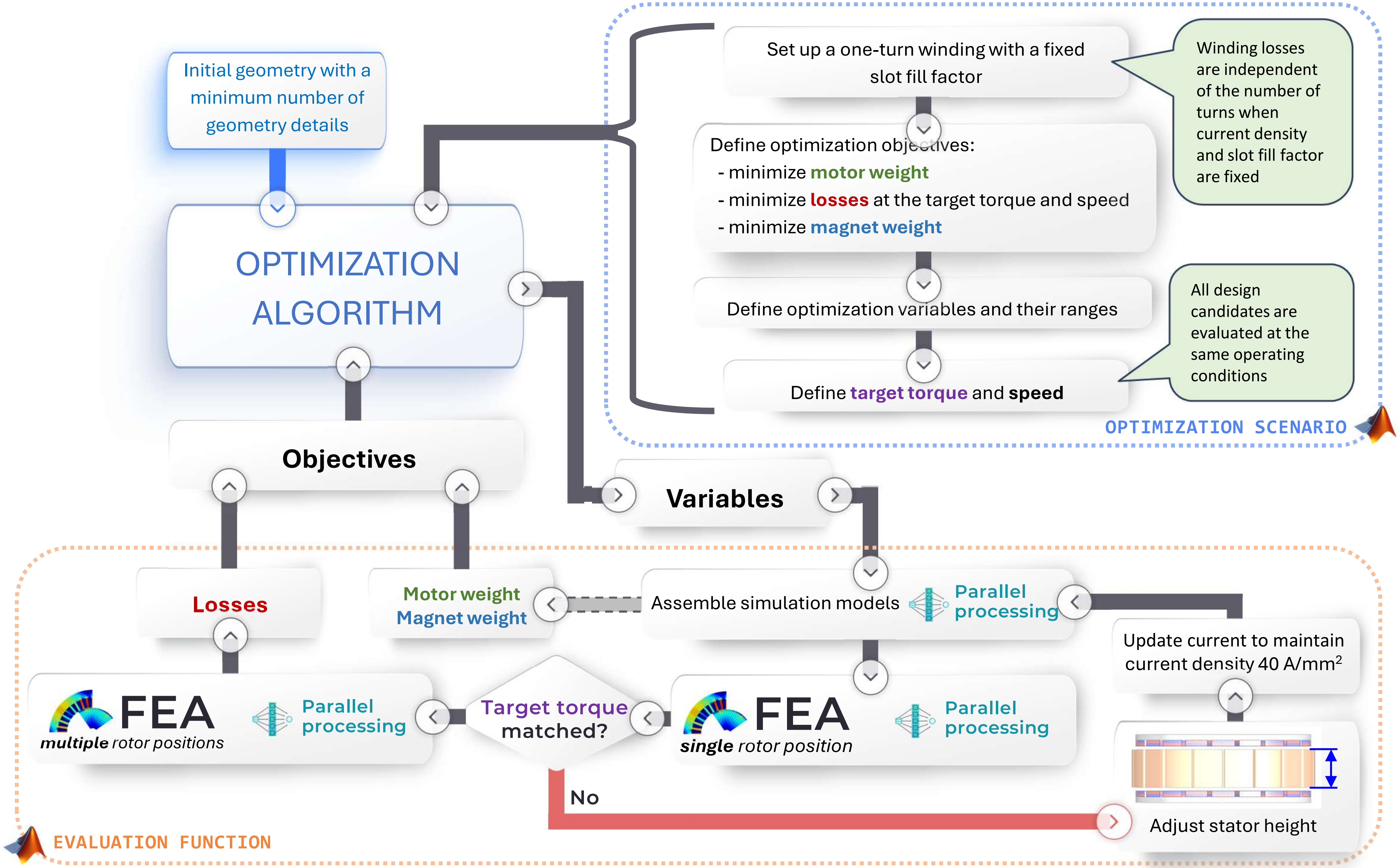
Use the suggested settings, ranges, and parameters, with the following exceptions:

- Initial dataset: 100 designs
- Sequential batch size: 12
- Iterations: 50
- Total evaluations: 100 + 50×12 = 700

Create the optimization scenario and evaluation function M-files in *“**[local computer path]**”*\CustomScripts\Webinar_Sept2026”

If possible, do not create more than two M-files for this optimization study.

Fixed-Current-Density Optimization with Dependent Stator Height



Prompt-Ready Task Statement for Fixed-Current-Density Optimization

Prompt 3

For the same study, suggest an optimization strategy with the current density fixed at 40 A/mm^2:

- Where possible, use the same optimization variables and ranges.
- Minimize motor weight, total losses at 0.5 Nm and 3,200 rpm, and magnet weight.
- To maintain the fixed current density, adjust the stator height until the target torque is matched. Note that, due to stator tooth saturation, torque may not be linearly proportional to stator height.
- Replace the winding-to-magnet volume ratio with the absolute magnet height. This will simplify the dependent-height formulation.
- Use the same optimization algorithm and parallel-processing settings.

Use the same file,
"***[local computer path]***\SimFiles\Webinar_Sept2026\proto1.mxa",
as the baseline design.

Use the baseline design as a reference point on the Pareto plot for comparison and assessment of the improvements.

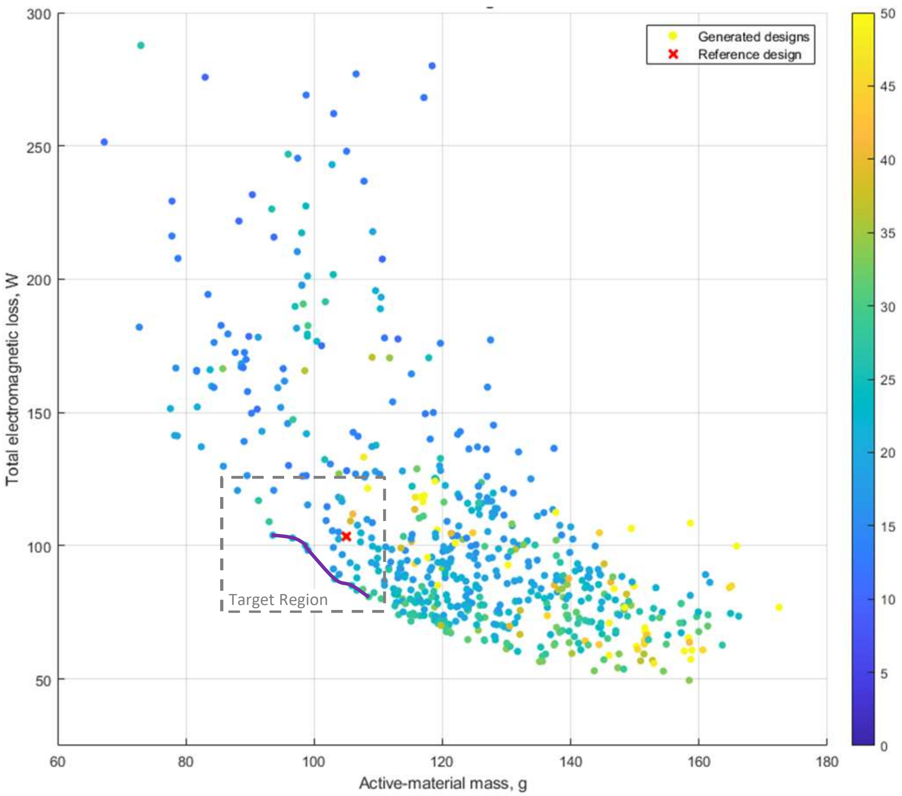
Do not create any M-files before receiving approval.

Prompt 4

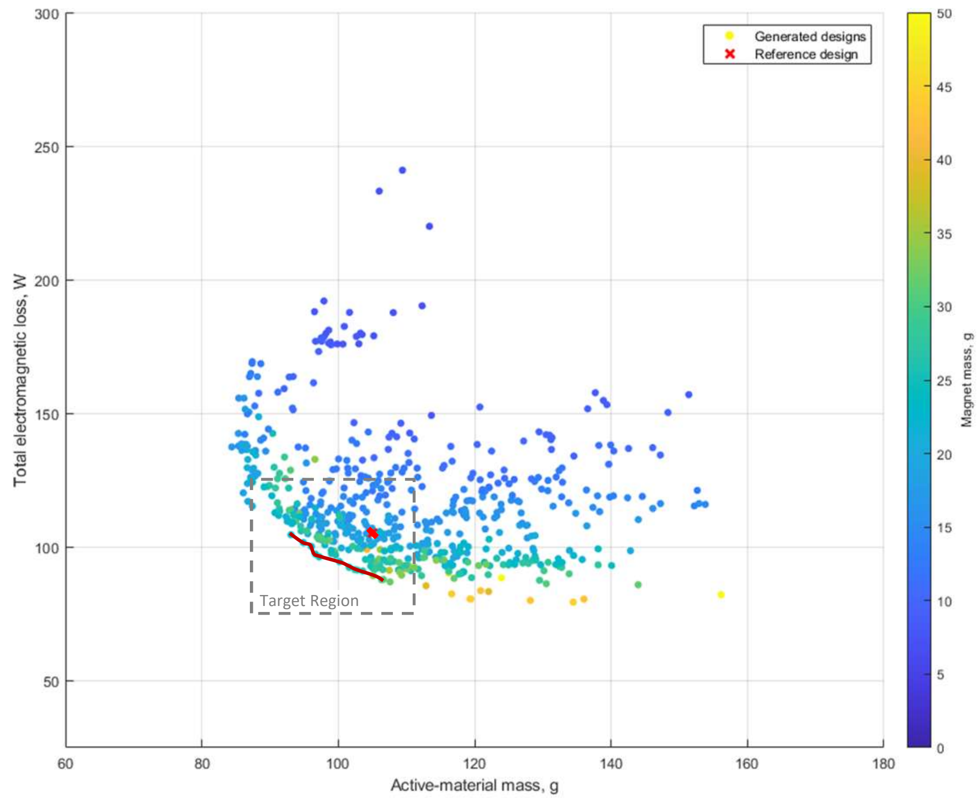
Use the suggested settings, ranges, and parameters.
Create the optimization scenario and evaluation function M-files in
"***[local computer path]***\CustomScripts\Webinar_Sept2026"
If possible, do not create more than two M-files for this optimization study.

Pareto Fronts for Two Optimization Formulations

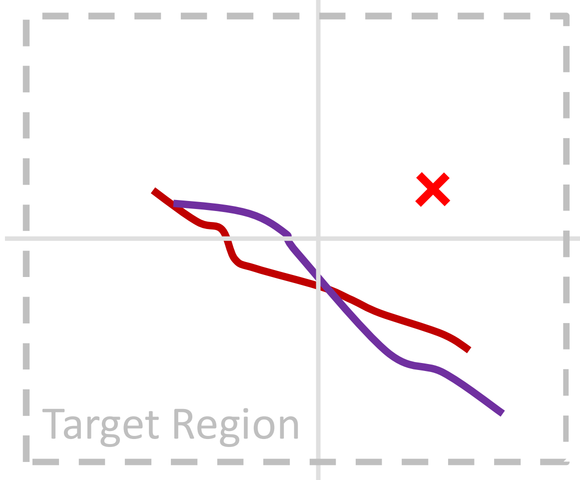
Current-Density-Constrained With Penalty Function



Fixed-Current-Density With Dependent Stator Height



Pareto Fronts in the Highlighted Target Region



Current-Density-Constrained Optimization With Penalty Function

Fixed-Current-Density Optimization With Dependent Stator Height

Reference design

The Pareto fronts cross, so neither formulation dominates across the target region.

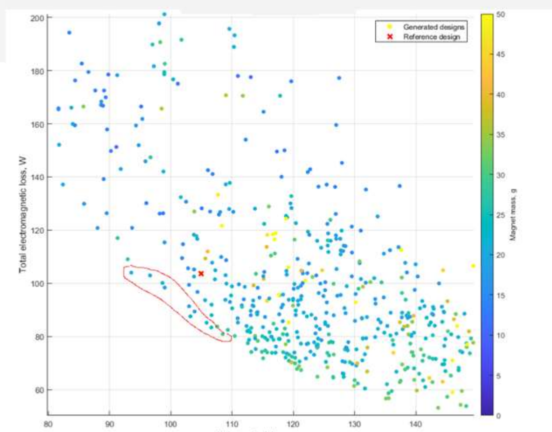
Prompt-Ready Task Statement for Focused Optimization Scenario

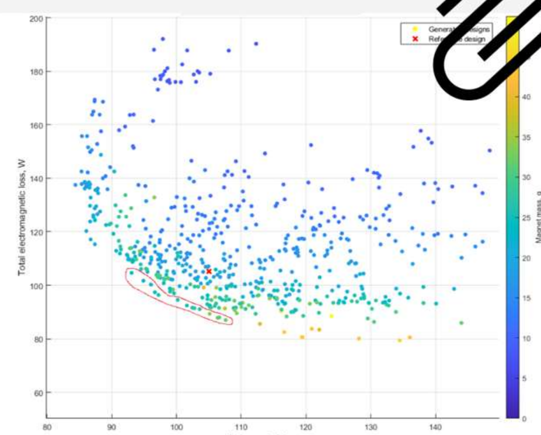
Prompt 5

Prepare a focused optimization study based on two previous optimization studies:

- Current-Density-Constrained Optimization with Penalty Function and Fixed-Current-Density Optimization with Dependent Stator Height:
- Use the optimization variables from the first study (Current-Density-Constrained Optimization with Penalty Function).
- For design candidates with current density below 40 A/mm², perform the optimization without additional adjustment. For design candidates with current density above 40 A/mm², increase the stator height as needed to maintain a fixed current density of 40 A/mm², using the same approach as in the Fixed-Current-Density Optimization with Dependent Stator Height.
- Extract the optimization-variable values for the designs selected on the attached Pareto plots from both optimization studies. Based on the extracted values, propose focused variable ranges with small margins around the selected designs. Note that some of the selected designs are not nondominated.
- For each extracted design, show its position within the proposed variable ranges and report its objective values for verification.
- Use the extracted designs as deterministic seed points in the initial surrogate-model training dataset, together with the remaining LHC-generated initial designs.
- Use the baseline design as a reference point on the Pareto plot for comparison and assessment of the improvements.

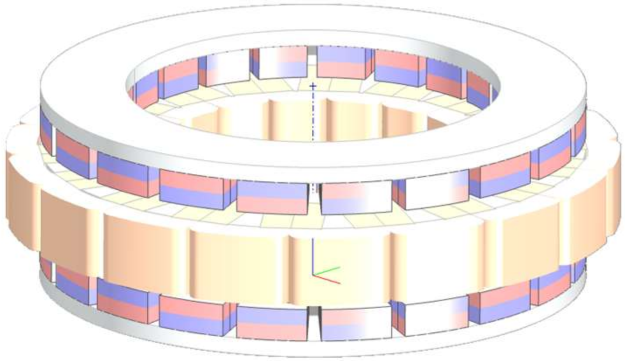
Do not create any M-files before receiving approval.



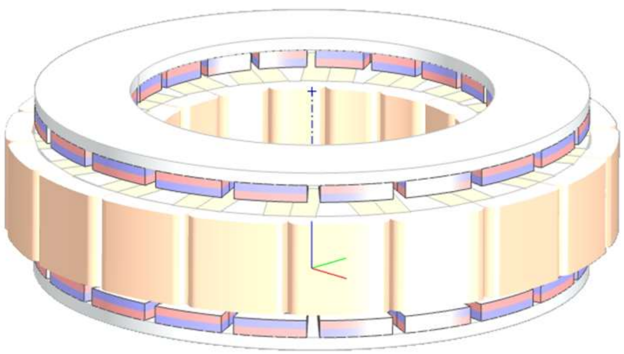


Focused Optimization Study Results

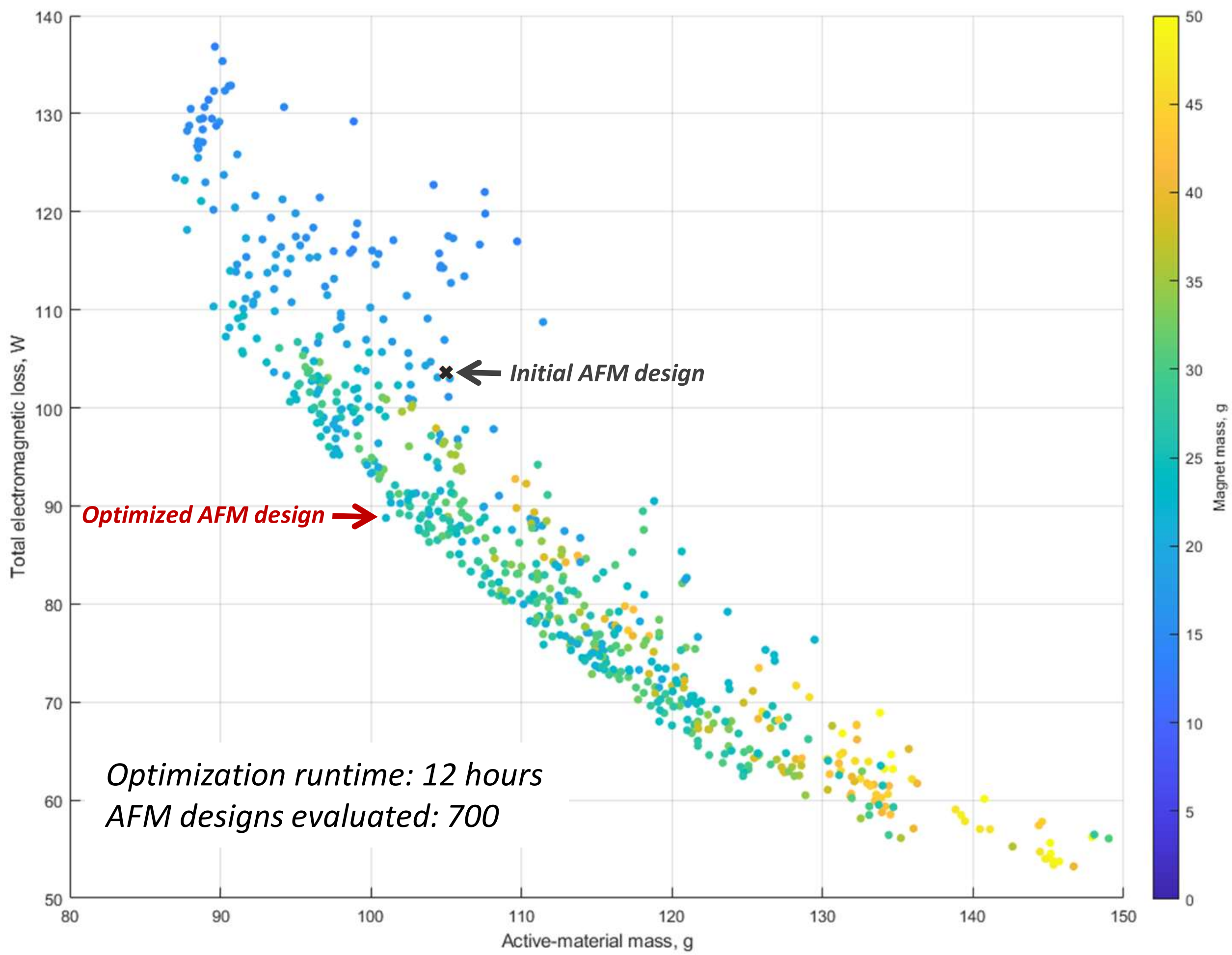
Initial AFM design



Optimized AFM design



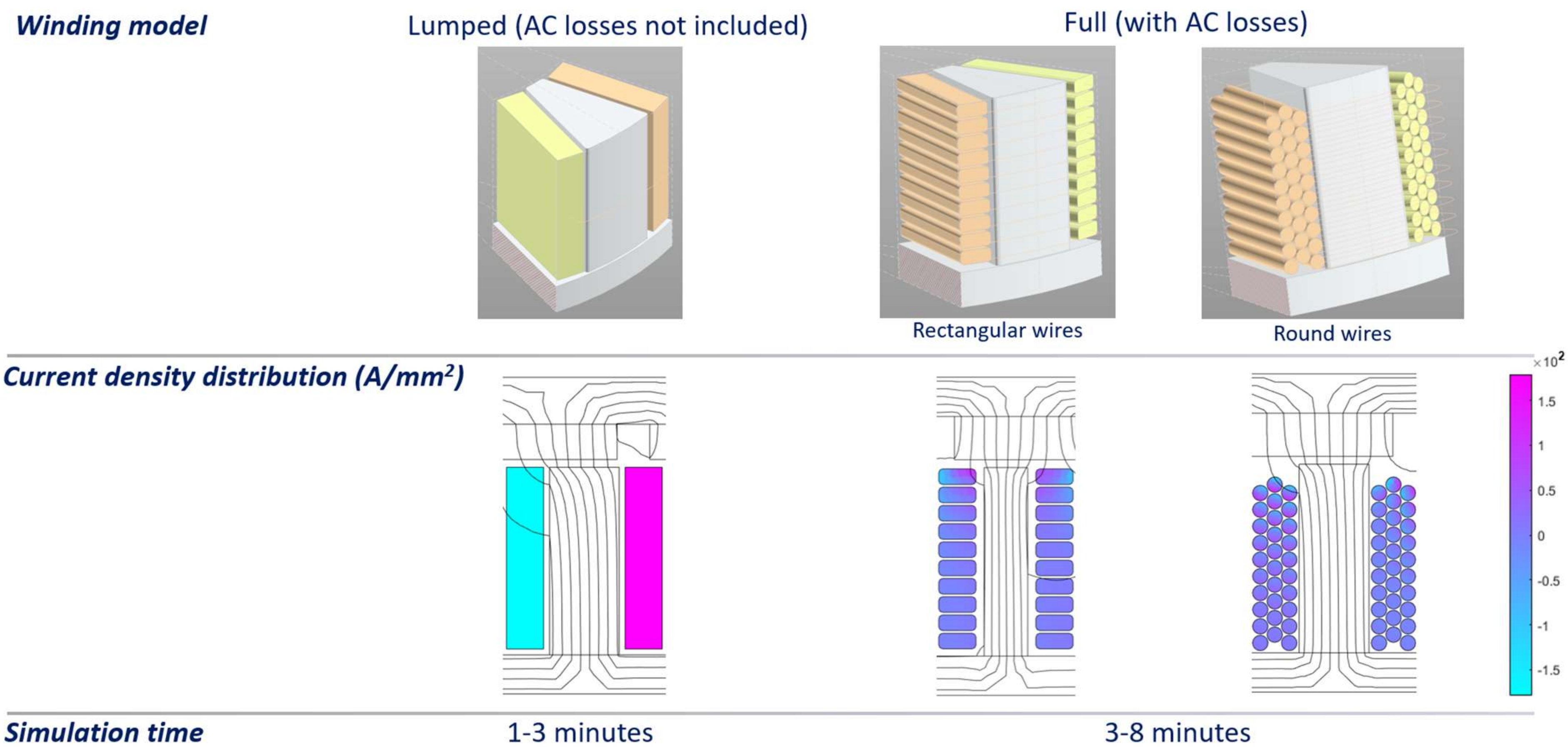
Focused optimization Pareto plot



Initial AFM design vs. optimized AFM design comparison (@ 0.5 Nm, 3200 RPM)

	Active-material mass (g)	Magnet mass (g)	Losses (W)	Efficiency (%)
Initial AFM design	105	39	104.0	61.7
Optimized AFM design	101	22	88.8	65.4
Improvement	3.8 %	**43.6 %**	14.6 %	3.7 pp.

Dynamic Finite Element Analysis: AC Winding Losses Calculation



For more details: https://motorxp.com/docs-category/mastering-ac-loss-calculation/

Thank you!

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motorxp.com