ALVIER MECHATRONICS

AN ENGINEERING COMPANY

System model generation of traction machines using JMAG

Prepared by:

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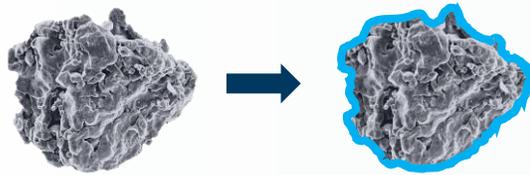PRESENTATION FOR: JMAG User Conference, Stuttgart

DATE: 2024-10-23

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MECHATRONICS

SCANNING

Höganäs AB
and
Alvier Mechatronics

Höganäs AB

EMM Division → From powder to system

Somaloy® raw material
(1P, 3P, 5P, 7P)
Pure iron powder with insulating coating

SMC component

Drive systems

EMM powder manufacturing (Höganäs)

Component production (customer)

OEM, TierX

| Raw material | | Atomizing | Milling/ Annealing | Coating | Lubricant & Mixing | | Compaction | Heat treatment | Final part quality | | System |

Höganäs ㅐㅣ

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100% owned

ZeBeyond
50/50 Joint venture with DRIVE SYSTEM DESIGN

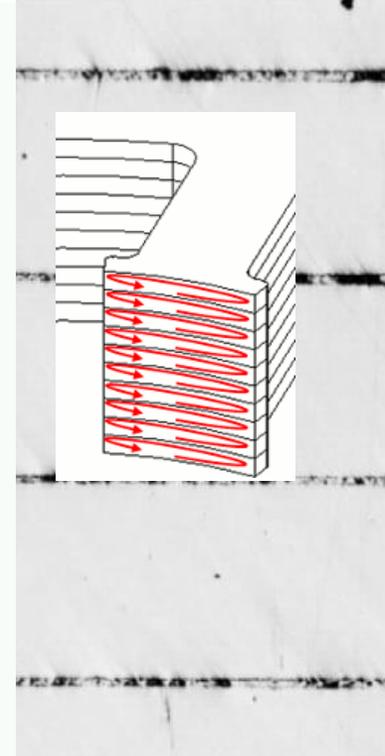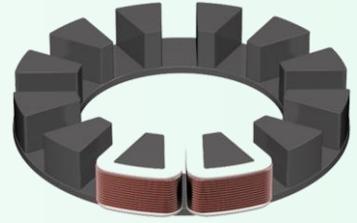SMC = Soft Magnetic Composite

Soft Magnetic Composites

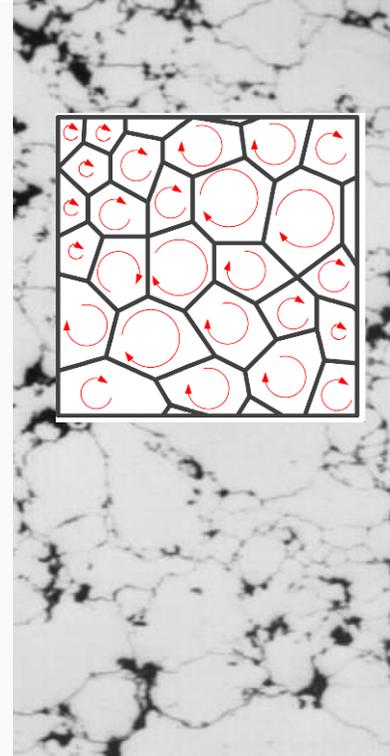**SMC vs laminated electrical steels.**

Benefits of SMC

- 3D shaping possibility with minimized scrap in productio

- 3D flux capability as an enabler for electromagnetic des

- High frequency losses are lower
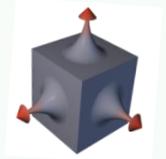
Challenges

- SMC technology is less mature
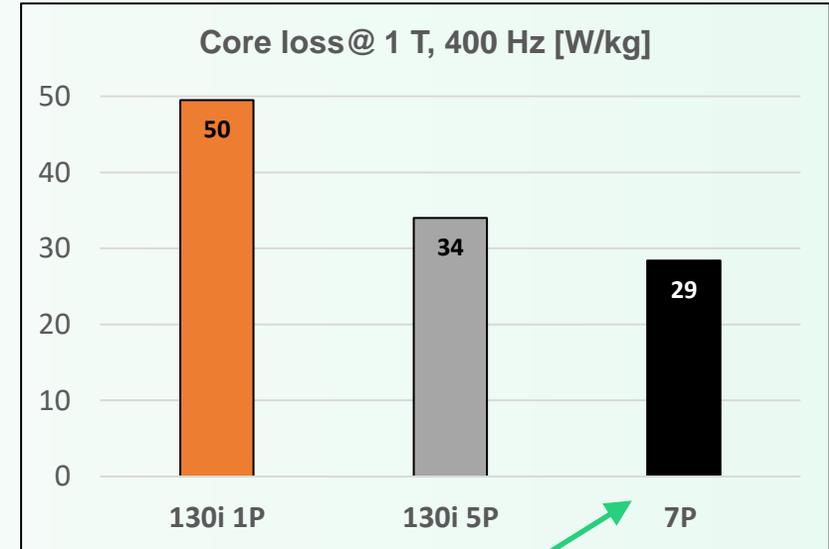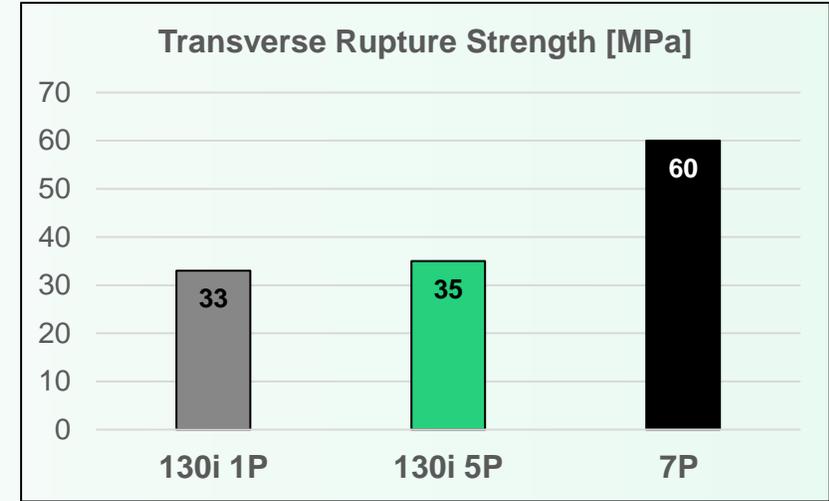
- Low frequency losses higher

- Lower mechanical strength

Laminated
sheet metal

Somaloy®

Evolution of Somaloy

Material Performance / Year

- S500 1P — Baseline
- S700 1P
- 3P — High strength, High permeability
- 5P — Low losses
- 7P — Lower losses, Strength > 5P

1997   2004   2006   2009   2014   2025

Transverse Rupture Strength [MPa]

130i 1P	130i 5P	7P
33	35	60

Core loss @ 1 T, 400 Hz [W/kg]

130i 1P	130i 5P	7P
50	34	29

Generally competitive with 0,35mm laminations.
In some designs even thinner.
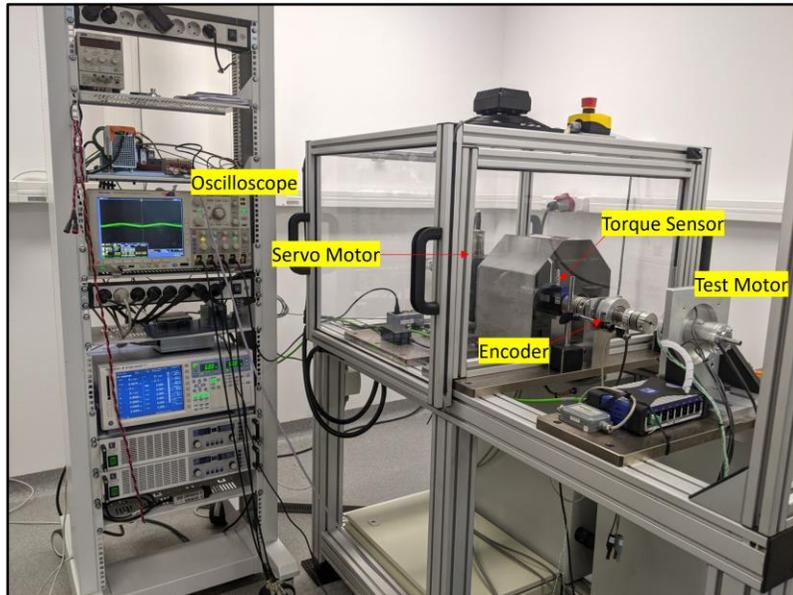
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Alvier AFM R&D – OD100

Development status: In-house detailed validation.

Single SMC-piece stator: 0.53 kg

Single SMC-piece rotor disc: 0.20 kg

OD100 Specifications

Parameters	Value
Motor type	Single Sided Axial Flux Permanent Magnet Motor
Number of phase	3
Number of poles	10
Number of slots	12
Number of turns	62
Winding	Concentrated + Delta
Parallel circuit	1
Phase resistance	0.321 Ω (@ 20 degC)
Outer / Inner diameter	110 mm / 50 mm (+ coil extension)
Air gap	1 mm
Magnet span	130 elec. degree
Magnet thickness	3.05 mm
Magnet segment	4 (radial segmentation)

Detailed application measurements

✓ Shaft torque & speed measurement

✓ 3-phase motor input electrical power

✓ Thermal measurements in selected nodes

✓ Calibration of test-bench parasitic drag losses

✓ Evaluation of optimal control strategy

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Alvier traction machine R&D

Development status:

In-house build and verification.

Target specifications

- Voltage: 400 V_{DC}
- Peak Power: 150 kW
- Peak Torque: 440 Nm
- Weight: 25 kg
- Max Speed: 9000 rpm
- Rotor OD: 280 mm
- Housing OD: 330 mm
- Axial Length: 80 mm
- Peak Phase Current: 500 A_{RMS}
- Oil Coolant Flow: 12 l/min

➢ Total weight of SMC stator parts 4,8 kg
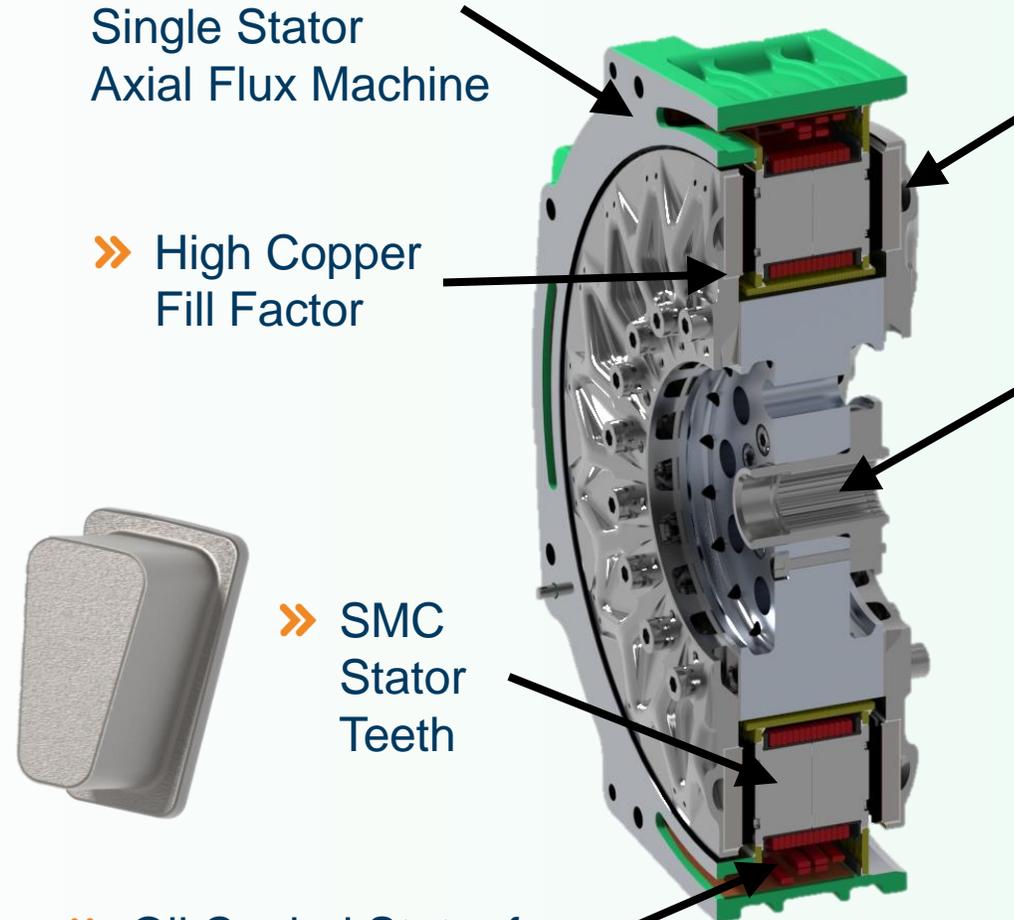
» Double Rotor, Single Stator Axial Flux Machine

» Oil Cooled Rotor Discs for High Continuous Power

» High Copper Fill Factor

» Transmission Spline Interface

» SMC Stator Teeth

» Oil Cooled Stator for High Continuous Power

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Alvier's FEA-capabilities

JMAG EM-FEA automation

Customer requirements
Traction machine design
(RX or AX)

Boundary conditions:
- Max size/volume/weight
- Max inverter current & voltage
- Material selection
- Target torque & power
- Speed range

Engineering judgement

EM-APP

Low effort

1 hr (2D)
10 hrs (3D)

Material database APP

Automated pre-processing → JMAG project → Full study (100+ cases) → Post-processing, automatic design validation → Web based intermediate report → Optimal operating point finder → **Efficiency map, ePOP model, ECM, BoM**

CAD templates

Multi-physics co-simulations

Thermal networks
Structural mechanics
Advanced losses

Pre-processing examples:
- AFM CAD templates
- Meshing rules
- Movement and torque regions
- Symmetry regions
- Flexible FEM time stepping
- Winding layout and conductor sizing
- Material properties and settings
- Iron loss configuration

Post-processing examples:
- Data validation, phase balance
- dqz-transform
- MTPA/MA
- Field weakening
- Maximum performance, T/w and P/w envelopes
- Demagnetization risks in all operating points

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Full FEM of 3D-models!?

Obsoletely view on advanced FEA:

"3D FEM simulations will take several hours per case,
running hundreds of cases in a study is unthinkable!"

Example cases using JMAG
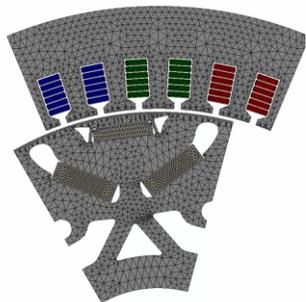
(full transient with eddy currents):

3D axial flux machine:

10 minutes per case @ 36 time steps

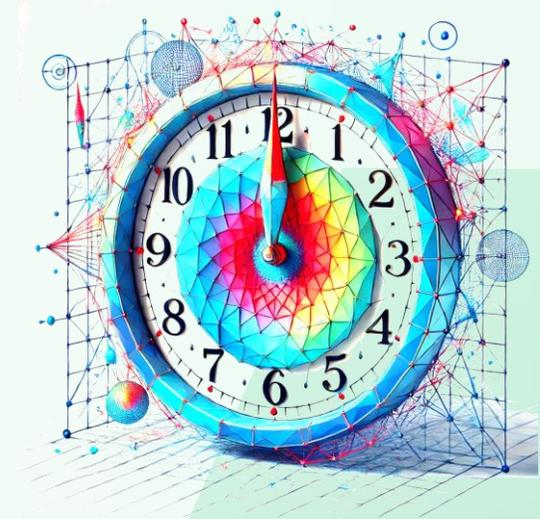→ A few hundred cases in 10 hours = "overnight batch"

Assuming running 4 parallel cases using in total 16 CPU cores.

2D traction machine:

12 seconds per case @ 200 time steps

→ One thousand cases in 1 hour = "lunch break batch"

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Highly parametrized model

Alvier's FEA pre-processor is making sure the 2D/3D-model is parametrized using JMAG's equation system.

This can be achieved either through:

- Use of JMAG's analysis templates
- Automated re-configuration through JMAG's Python API

Examples on parametrization:

- Geometry, winding
- Mesh rules
- Time stepping
- Output data format

3D FEA procedures

Example with a DRAX 3D model (**D**ouble-**R**otor, **A**xial-flu**X**)

EM-model

Meshing

Full model of machine
(Illustration from YASA Limited)

Make a FEA model with only
magnetically active parts

Apply a mesh = divide it into many
sparsely connected polygons
E.g. ca **2 million** polygons for a DRAX

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3D FEA model refinement

3D model reduction through symmetries

Full 3D model

Symmetry slicing

Reduced symmetric model

Full 3D FEA model.
Several hours CPU time
needed per operating point.

Slicing

Axial slicing

Axial model slice

Axial symmetric mirror

Circumferential model slice

Circumferential slicing

Model reduction & meshing

Mesh elements

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Case setup: Time stepping

Time stepping rules

- Use equidistant time stepping.

- Compensation for initial transient steps.
  - Typ. 1-20 initial steps to discard (configurable).

- Same number of **active steps** regardless of speed.

- Length of simulation is determined in electrical degrees.
  - E.g. 360° el means one electrical period.

- Time resolution is configured in **number of steps per electrical period.**
  - E.g. 100 steps/period means medium-high resolution.
  - This input automatically updates relevant mesh rules.

- Initial angle of rotor is automatically calculated to compensate for settings above.

→ First active step is **always aligned with d-axis.**

Operating points

Pre-processing sets up the operation points defined as **speed, current magnitude, current angle.**

A typical configuration could be;

Speed range:

4-6 points from 1 krpm – 1.2*max speed

Current magnitude range:
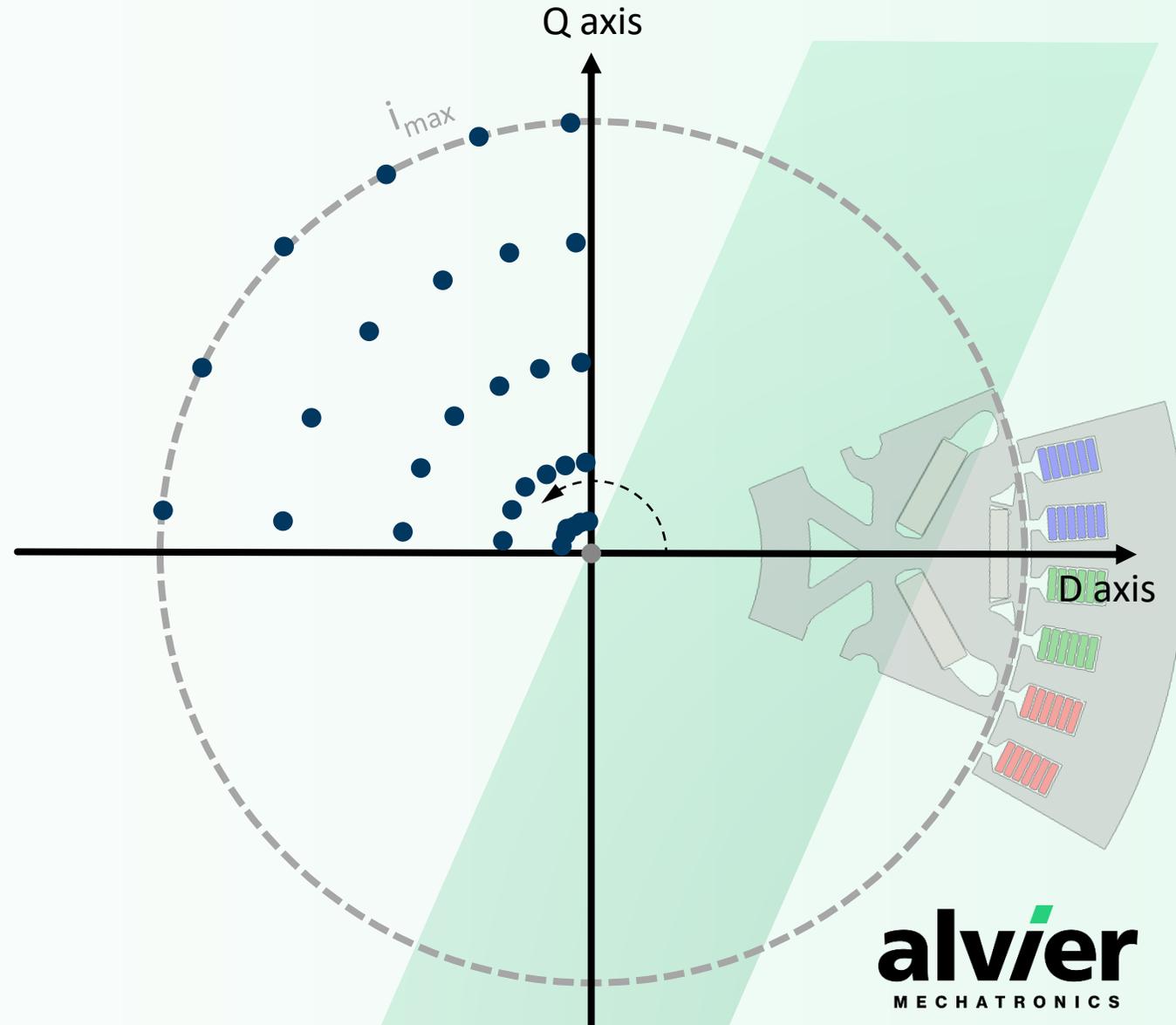
5-8 points.

(0) + [0.05 – 115%] * i_max

Current angle:

5-9 points.

91 – 179 degree ahead of d-axis.

Example of small scan of entire operating space:
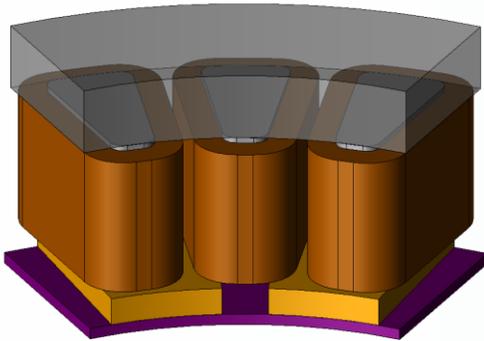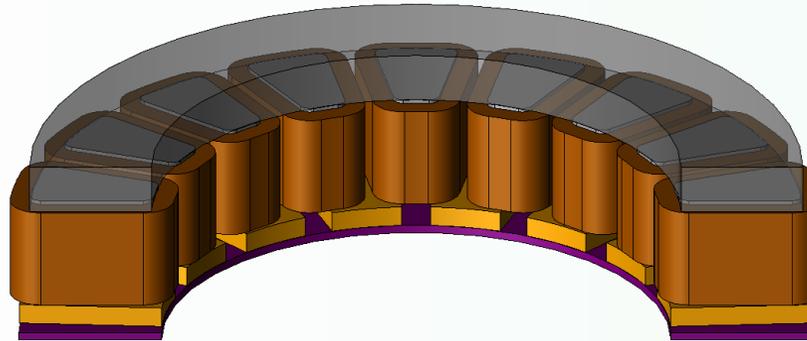4 speeds * 5 currents * 5 angles = 100 operating points.

Demo

Example: AFM case setup

Case	Label	Geometry	Groups	SLOTS	POLES	SPEED_RPM	i_rms	i_beta	steps_active_per_period	steps_pre	end_position_deg_e	AFM_ID	AFM_OD	STATOR_COIL_WIDTH	STATOR_COIL_HEIGHT
1	1;1000;50;90			24	16	1000	50	90	54	4	360	120	200	5	25
2	2;1000;50;90			24	20	1000	50	90	54	4	360	120	200	5	25
3	3;1000;50;90			18	16	1000	50	90	54	4	360	120	200	5	25
4	4;1000;50;90			24	22	1000	50	90	54	4	360	120	200	5	25

Example of parameter view. A limited set of parameters are shown in this demo picture.
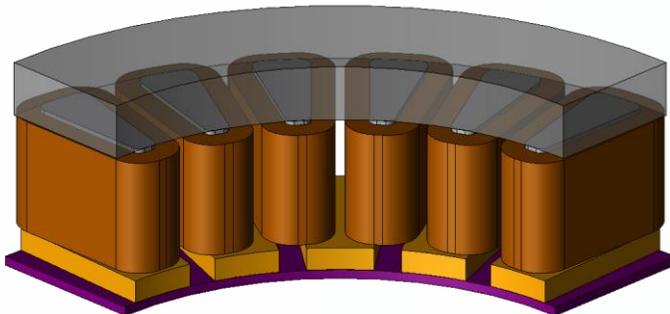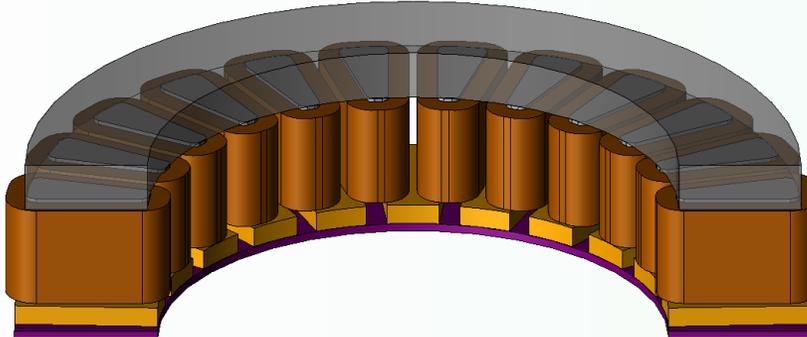
Case 1: 24s16p

Case 3: 18s16p

Case 2: 24s20p

Case 4: 24s22p

Both geometry and operating point is fully configured in JMAG Analysis Parameter View.

The Geometry is updated within seconds via JMAG Geometry Editor.

Settings for time stepping, mesh density, materials, magnetization, symmetry boundaries, initial angle, winding layout are automatically updated.
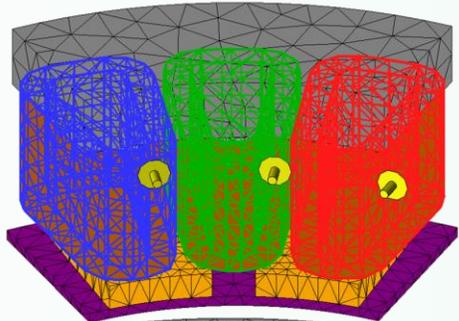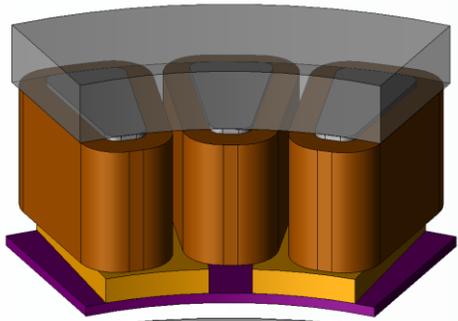
Supported AFM layouts
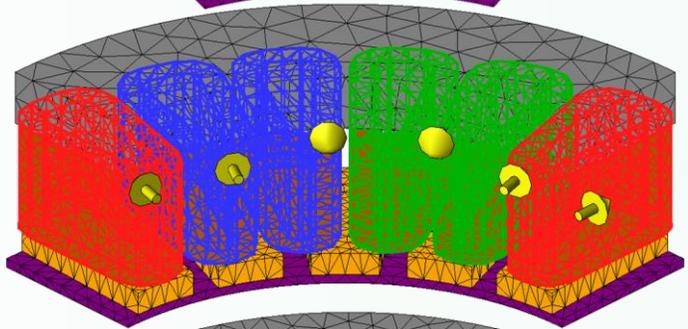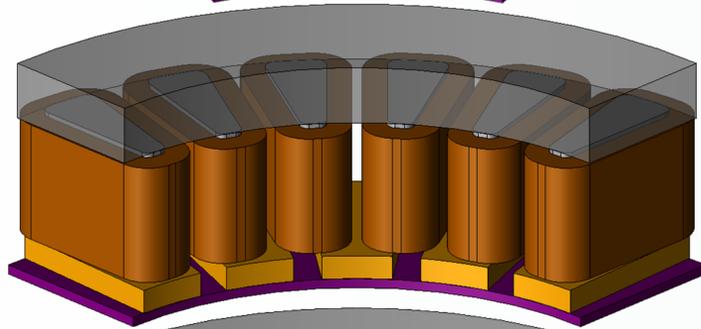
Tooth-coil stator winding, PMSM rotor:

• Dual-stator, single-rotor

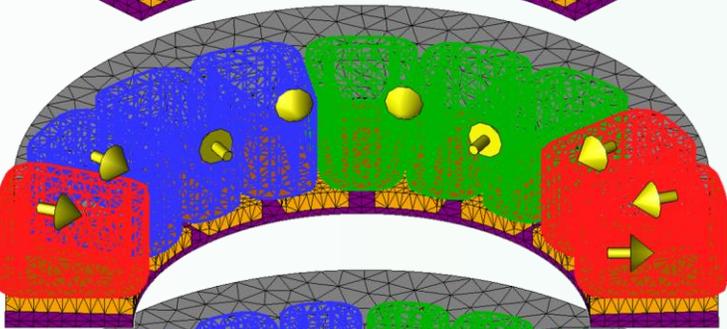• Dual-rotor, single-stator

• Single-stator, single-rotor

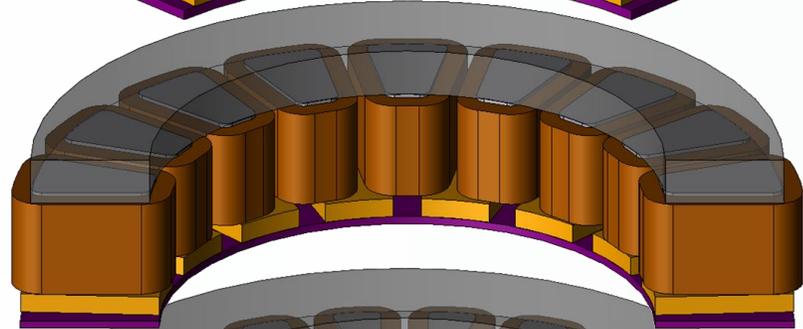**alvier**
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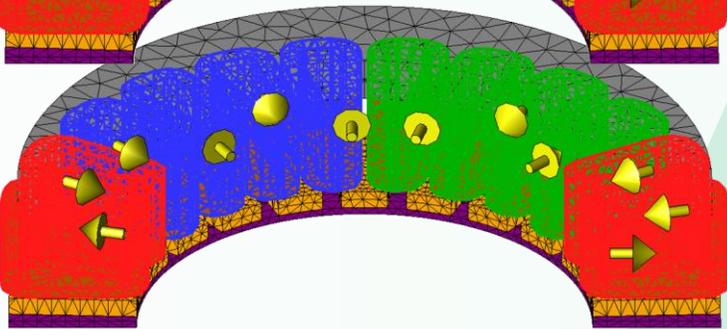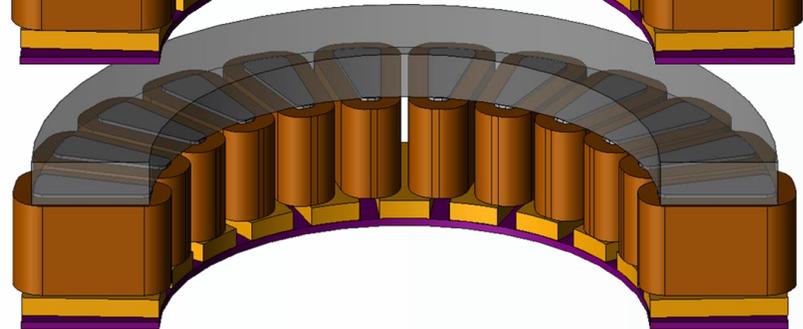
FEM time

Case 1: 24s16p

Case 2: 24s20p

Case 3: 18s16p

Case 4: 24s22p

Study settings:
59 time steps per case, full transient 3D, magnet eddy currents enabled.

Case	Layout	Mesh elements	FEM-time (mm:ss)
1	24s16p	65 k	02:07
2	24s20p	57 k	01:28
3	18s16p	66 k	04:20
4	24s22p	70 k	03:30

Executed on an Intel i9-13900 using JMAG v23.2 and 4 CPU-cores per case.
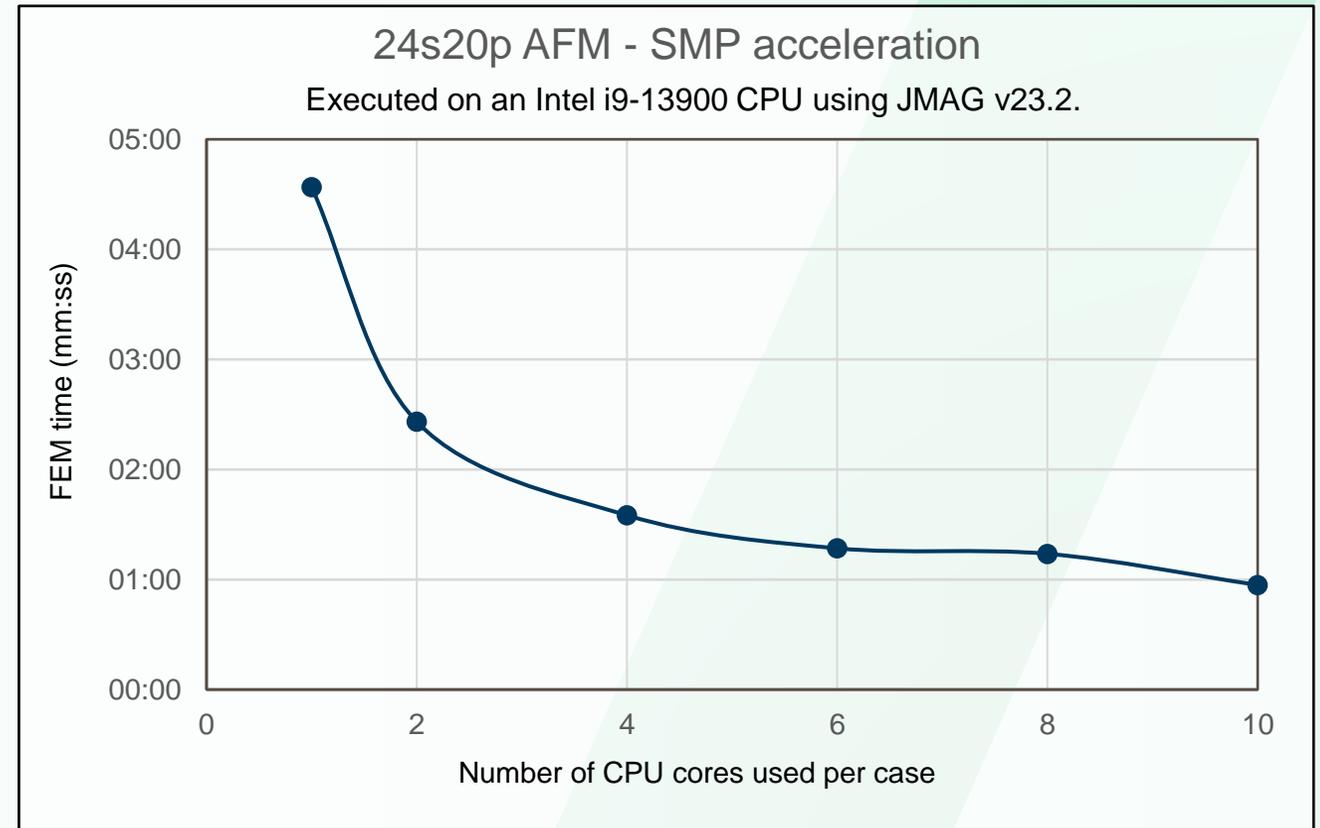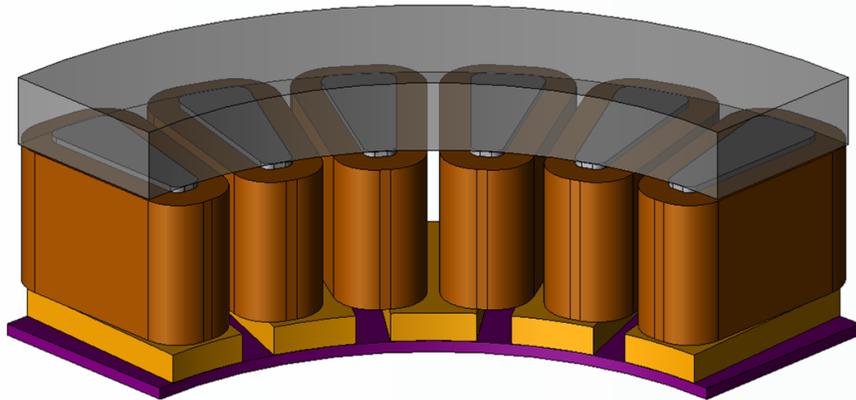
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FEM SMP acceleration

Using the parallel computing module (SMP) in JMAG, FEM time can be further reduced when simulating 3D cases.

Example case 2: 24s20p AFM
Study settings:
59 time steps per case, full transient 3D, magnet eddy currents enabled.

24s20p AFM - SMP acceleration
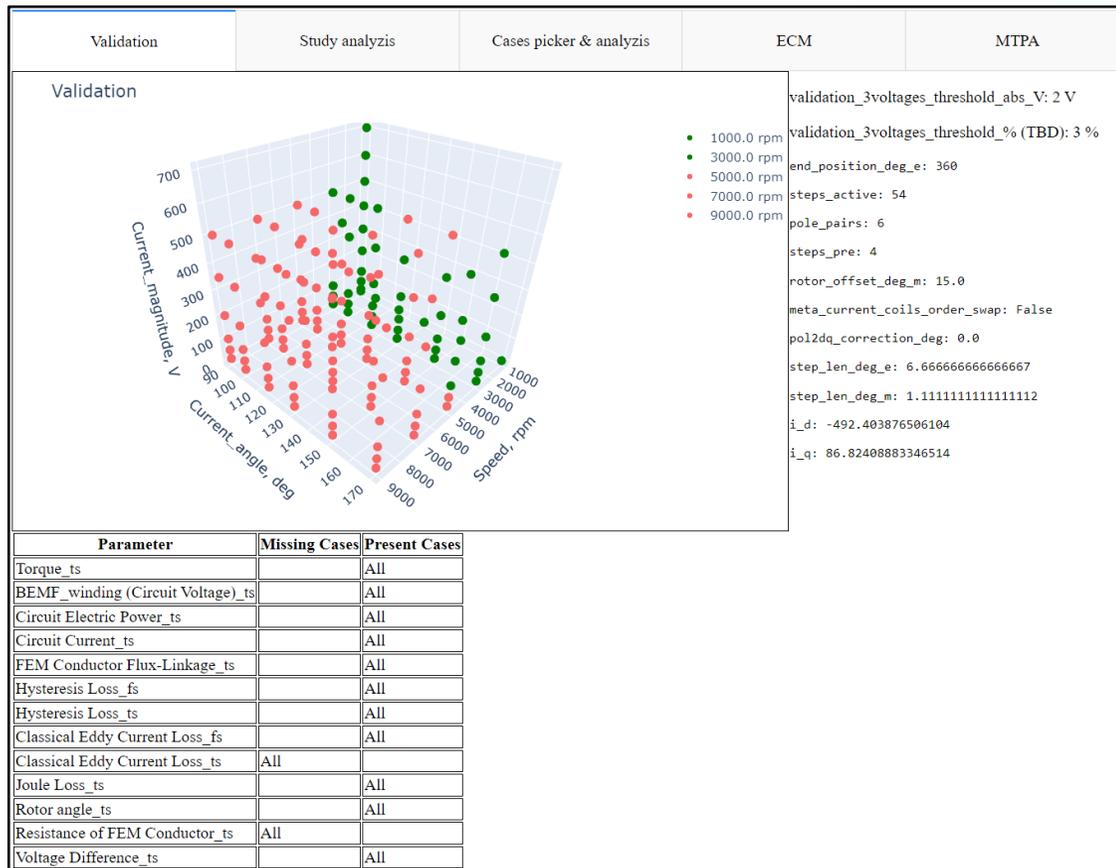Executed on an Intel i9-13900 CPU using JMAG v23.2.

Post-processing of full operating area

Using JMAG analysis parameter view to generate cases to cover the entire operational area in speed, current magnitude, current angle.

→ 100 - 400 cases needed

Alvier's post-processing tool will handle the raw data from JMAG directly!

Parameter	Missing Cases	Present Cases
Torque_ts		All
BEMF_winding (Circuit Voltage)_ts		All
Circuit Electric Power_ts		All
Circuit Current_ts		All
FEM Conductor Flux-Linkage_ts		All
Hysteresis Loss_fs		All
Hysteresis Loss_ts		All
Classical Eddy Current Loss_fs		All
Classical Eddy Current Loss_ts	All	
Joule Loss_ts		All
Rotor angle_ts		All
Resistance of FEM Conductor_ts	All	
Voltage Difference_ts		All

Post-processing step 1:

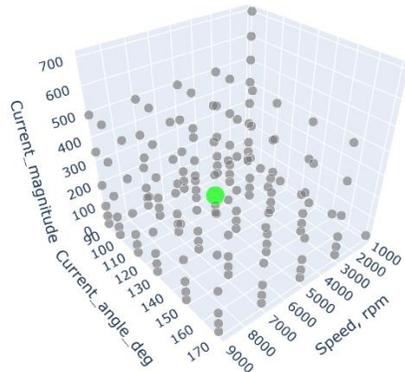Import of raw data, parsing and 3D overview.

Automatic sanity-checks of:

✓ Phase balance of multiphase signals

✓ dqz-transform of multiphase signals

✓ Time- & rotational alignment of d-axis

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Post-processing, step 2

Post-processing step 2: Interactive 2D-plots of time & frequency series.

A

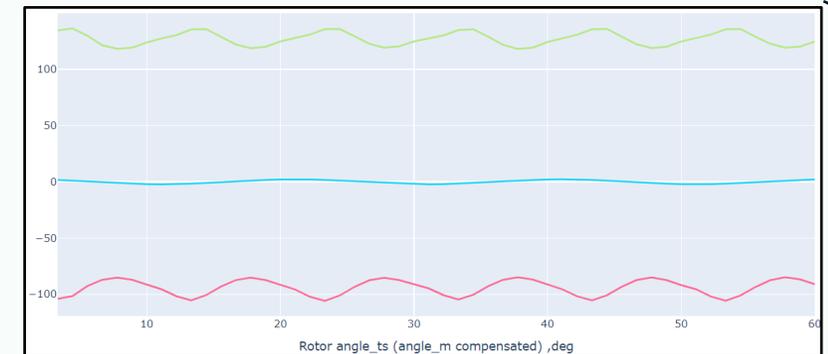Pick one or several operating point in interactive 3D-map.

B

Choose any signal to review, e.g. phase voltage.

C

View αß- & dqz-transform in the time-domain.

D

Review all pre-computed signal norms

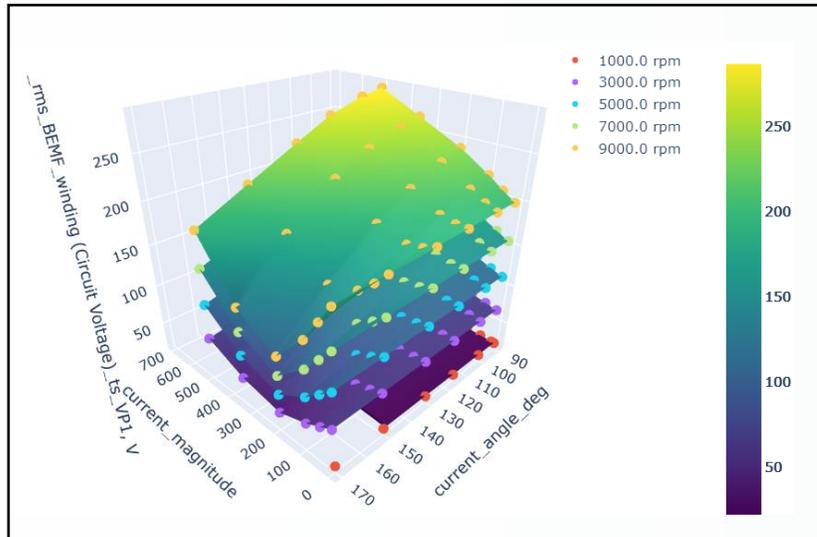| case #	speed_rpm	current_magnitude	current_angle_deg	column_name	min	peak	avg	rms	pk2pk	ripple	crest
61	5000.000000	100.000000	115.000000	VP1	-157.155754	157.361105	4.517439	111.639387	314.516859	69.622825	1.409548
61	5000.000000	100.000000	115.000000	i_beta	-172.062103	171.845261	-4.236020	112.343400	343.907365	-81.186431	1.529643
61	5000.000000	100.000000	115.000000	_d_pk	-105.906098	-84.914926	-93.991288	94.238336	20.991172	-0.223331	-0.901066
61	5000.000000	100.000000	115.000000	i_alpha	-154.948648	155.142594	4.601068	111.549646	310.091242	67.395492	1.390794
61	5000.000000	100.000000	115.000000	_z_avg	-2.258847	2.218512	-0.083629	1.508755	4.477358	-53.538270	1.470426
61	5000.000000	100.000000	115.000000	VP2	-156.816992	155.650590	-6.052664	110.043468	312.467582	-51.624800	1.414446
61	5000.000000	100.000000	115.000000	_q_pk	118.230698	136.421806	127.071722	127.214382	18.191108	0.143156	1.072377
61	5000.000000	100.000000	115.000000	VP3	-157.281957	157.631844	1.284338	114.151022	314.913801	245.195424	1.380906

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Post-processing, step 3

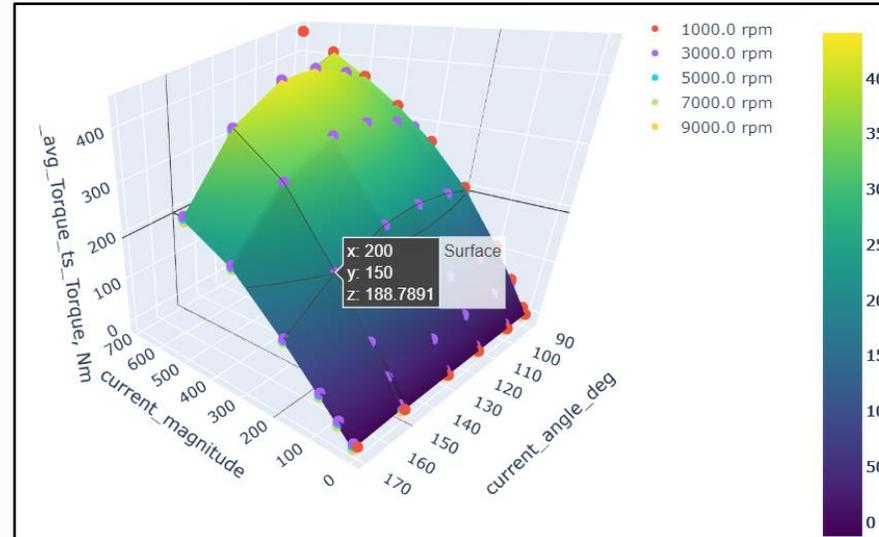**Post-processing step 3:** **Interactive 3D-maps of response values.**

Pick any norm (e.g. average, rms, difference, sum) from a time- or frequency series and plot versus operating point.

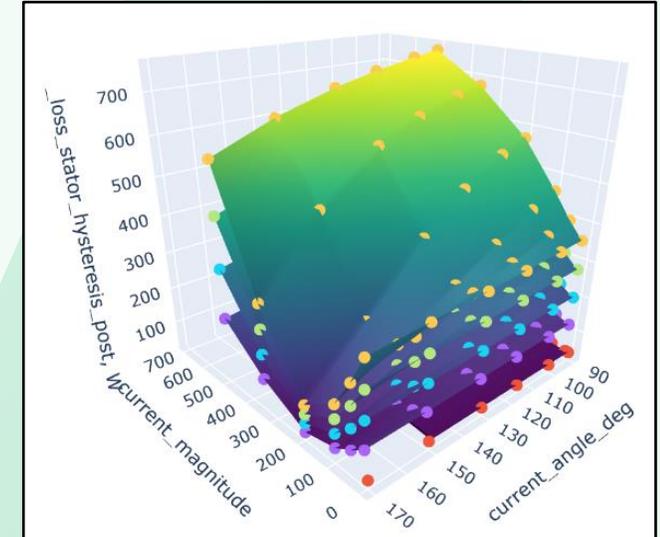The application can optionally render a regression surface between simulated operating points.

Phase rms voltage

Average torque

Stator hysteresis losses

Post-processing, step 4

Post-processing step 4: Export all raw data

- ✓ Select any signal, or all, to export.
- ✓ Exports data for all simulated operating points.
- ✓ Including internally processed norms (e.g. average, rms, difference, sum).
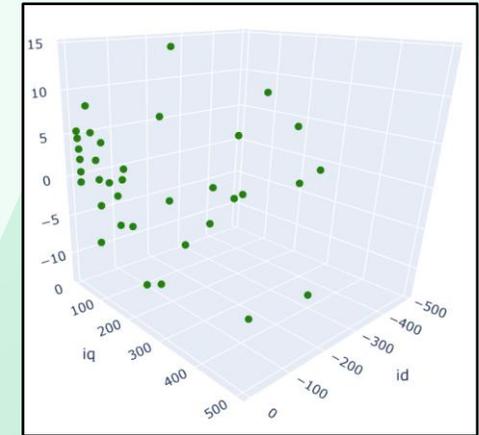- ✓ Export all data mat-format, including physical units.

name
☑ ecm_id_rms_ref
☑ ecm_iq_rms_ref
☑ ecm_speed
☑ ecm_pole_pairs
☑ ecm_I_d
☑ ecm_I_q
☑ ecm_V_dm
☑ ecm_V_qm
☑ ecm_r_s
☑ ecm_flux_linkage_d
☑ ecm_flux_linkage_q
☑ ecm_flux_linkage_pm
☑ ecm_L_d
☑ ecm_L_q
☑ ecm_L_d_102pct
☑ ecm_L_q_102pct
☑ ecm_L_dm
☑ ecm_L_d_ls1
☑ ecm_L_d_ls2
☑ ecm_L_qm
☑ ecm_L_q_ls1
☑ ecm_L_q_ls2
☑ ecm_loss_stator
☑ ecm_loss_rotor
☑ ecm_loss_winding
☑ ecm_loss_magnets
☑ ecm_loss_total

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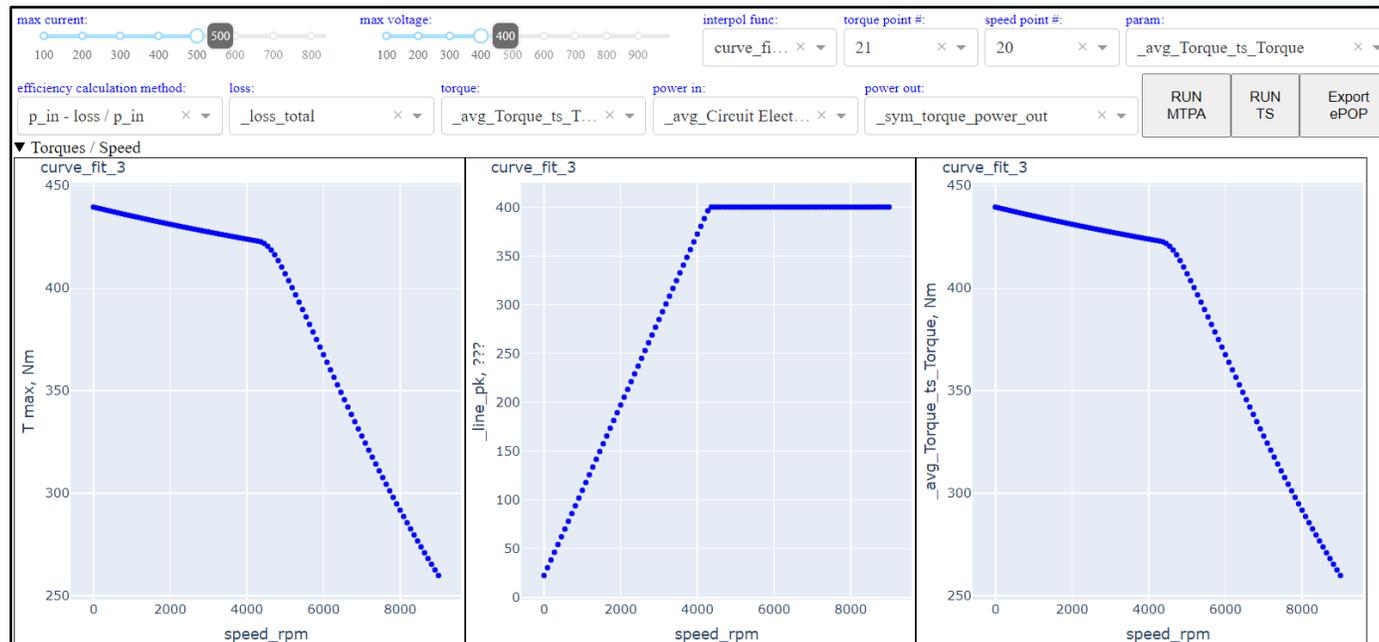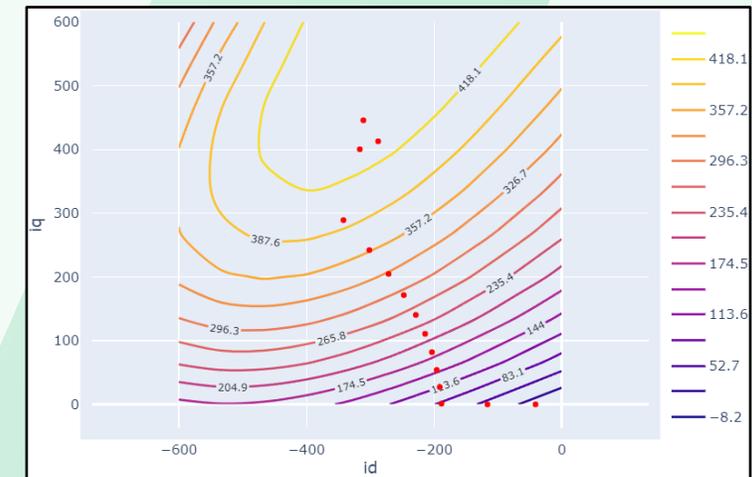
Post-processing, step 5

Post-processing step 5: Calculate optimal-control and generate efficiency maps

- ✓ Adjust maximum phase current and maximum supply voltage.

- ✓ Fine-tune regression model parameters to apply to FEM-data.

- ✓ Review regression model goodness-of-fit.

- ✓ Select optimization criteria (e.g. minimum-loss).

- ✓ View live results of maximum-torque & power envelopes.

- ✓ View computed efficiency maps and current trajectory in id-iq.

- ✓ Export data to 3rd party system modeling software (e.g. Matlab).

Absolute error in regression model for total stator losses (W) at 5 000 rpm.

Optimal current trajectory at 3 000 rpm, max 500 A, max 400 V.

THANK YOU!

ALVIER MECHATRONICS –

AN ENGINEERING COMPANY

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EMAIL: Stefan.Skoog@ALVIERMECHATRONICS.COM

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