ECCE 2023

IEEE ENERGY CONVERSION CONGRESS & EXPO Nashville, TN | OCT.29-Nov.2

Future of Electric Machines Design: Computational Advancements

Facilitators:

Pete Wung University of Dayton and Marquette University (USA)

Greg Heins Regal Rexnord (Australia)

Mircea Popescu Ansys, (U.K.)

Panellists:

Gianmario Pellegrino Politecnico di Torino (Italy)

Ian Brown Illinois Institute of Technology (USA)

Keld Rasmussen Grundfos (Denmark)

Alireza Fatemi GM (USA)

Joel Van Sickel Mathworks (USA)

Philippe Wendling Altair (USA)

Takashi Yamada JMAG

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PANELLIST INTRODUCTION

8:30AM – 10:10AM

Pete Wung	University of Dayton and Marquette University (USA)
Greg Heins	Regal Rexnord (Australia)
Mircea Popescu	Ansys, (U.K.)

Gianmario Pellegrino	Politecnico di Torino (Italy)
Ian Brown	Illinois Institute of Technology (USA)
Keld Rasmussen	Grundfos (Denmark)
Alireza Fatemi	GM (USA)
Joel Van Sickel	Mathworks (USA)
Philippe Wendling	Altair (USA)
Takashi Yamada	JMAG

Panelists: Customers

Gianmario Pellegrino ***Politecnico di Torino (Italy)***	Gianmario Pellegrino (M'03, SM'13, F'22) received the MSc and PhD degrees in electrical engineering from Politecnico di Torino, Turin, Italy in 1998 and 2002, respectively. He is currently a Professor of Power Converters, Electrical Machines and Drives at the same university. Dr. Pellegrino is engaged in several research projects with the industry, and one of the authors of the open-source project SyR-e for the design of electrical motors and drives. He was a visiting fellow at Aalborg University, DK, the University of Nottingham, UK, and the University of Wisconsin-Madison, USA. Dr. Pellegrino is an Associate Editor for the IEEE Transactions on Industry Applications and has 55+ IEEE journal papers, three patents and nine Best Paper Awards. He is a member of the Power Electronics Interdepartmental Laboratory (PEIC) established in 2017 at the Politecnico di Torino and a member of the Advisory Board of PCIM (Power Conversion and Intelligent Motion) Europe. He is currently the Rector's Advisor for Interdepartmental Centres of Politecnico di Torino
Ian Brown ***Illinois Institute of Technology (USA)***	Ian P. Brown (Senior Member, IEEE) received the B.S. degree in engineering from Swarthmore College, Swarthmore, PA, USA, in 1999, and the M.S. and Ph.D. degrees in electrical engineering from the University of Wisconsin, Madison, WI, USA, in 2003 and 2009, respectively. Since 2012, he has been with the Illinois Institute of Technology. Previously, he was with the Corporate Technology Center, A. O. Smith Corporation, Milwaukee, WI, USA. His main research interests are high- performance electrical drives, the design of electric machines, and power electronics.
Keld Rasmussen ***Grundfos (Denmark)***	Keld Folsach Rasmussen has worked for Grundfos for 30 years, starting as an industrial Ph.D. working on Energy Efficient Motors for Pumps. The work includes both development of motors but also simulation tools for motor design. In the beginning the focus was on evaluating energy efficient motors for small pumps for central heating system. This also included development of motor design tools for these types of motors. From year 2000 Grundfos has been implementing these new energy efficient motors (Permanent motors) in many of their products, always with focus on the application and the energy use by the application. As example it is estimated that the introduction by Grundfos of the variable speed, permanent magnet-based heating pumps in EU in 2021 has saved 11.4 TWh, equivalent to the average consumption of more than 6 million average EU citizens. Keld's current responsibilities includes evaluation of new motor types and magnetic materials that can be used for future electrical motors for pump and pumps systems.
Alireza Fatemi ***GM (USA)***	Alireza Fatemi (Senior Member, IEEE) received the Ph.D. degree in electrical engineering from Marquette University, Milwaukee, WI, USA, in 2016. He is currently a Senior Researcher with the Propulsion Systems Research Laboratory, Global Research and Development Department, General Motors Company, Warren, MI, USA. His research interests include performance optimization of electromechanical energy conversion systems, design and control of power electronics converters, and computational electromagnetics in machines and drives. Dr. Fatemi is affiliated PES, IAS, IES, PELS societies, and a member of SAE. He has authored or coauthored more than 40 technical papers including two Prize Papers from IEEE IAS Electric Machines Committee

Panelists: Vendors

Joel Van Sickel ***Mathworks (USA)***	Joel Van Sickel is a principal application engineer at MathWorks working with customers developing electric vehicles, renewable energy systems, industrial drives, and other high-energy equipment. He brings 13 years of expertise in modeling and design of power electronics and motor drive systems. Prior to joining MathWorks, he was a hardware design engineer for medium and high voltage power systems and converters at Raytheon. He received his Ph.D. in electrical engineering from the Pennsylvania State University in 2010.
Philippe Wendling ***Altair (USA)***	Philippe Wendling (Senior Member, IEEE) graduated from Ecole Centrale Lille (Lille, France) in 1979 and received his Master of Science degree in 1982. He co-founded Magsoft Corporation, Ballston Spa, NY, USA. Previously, he was Director and Executive Officer of Magsoft Corporation and Director of Cedrat SA, France. Since 2016 he is Vice President at Altair Engineering, USA.
Takashi Yamada ***JMAG***	Takashi Yamada received Ph.D degree in computational mechanics from Portsmouth University, UK. He joined JSOL Corporation in 1987 and has been leading several developments of CAE software for electrical engineering. Currently, he is CTO at JMAG division of JSOL Corporation, Tokyo Japan. He has also been serving as a member of Investigation Committee on Electromagnetic Field Analysis for Rotating Machines of IEEJ (Institution of Electrical Engineering of Japan).

TOPICS_AND_STRUCTURE

Model type (15 mins presentation + 15 mins discussion) [8:30 - 9:00]

1. Completely trusted results vs experimental validation?
2. Accuracy vs Time (inc 2D vs 3D)
3. Subsystem Focus vs Multiphysics
4. Empirical vs Physics based

Model implementation (15 mins presentation + 15 mins discussion) [9.00 - 9:30]

5. Open Source vs Commercial (inc customer/ developer relationship)
6. Local vs Cloud Computing
7. AI vs Human
8. Traditional Simulation vs Digital twin (inc real time modelling)

Open discussion (15 mins presentation + 15 mins discussion) [9.30 - 10:00]

9. What is the next big Computational Advancement?

COMPUTATIONAL ADVANCEMENTS: MODEL TYPE

15 mins presentation,
15 mins open discussion

[8:30 - 9:00]

COMPLETELY TRUSTED RESULTS VS EXPERIMENTAL VALIDATION?

Keld Rasmussen

COMPLETELY TRUSTED RESULTS VS EXPERIMENTAL VALIDATION

What do Grundfos do

- Motors for pumps or pump systems
- Motors from 5W to 22kW shaft power (few special motors above 22kW)

Simulation and validation at Grundfos

- We have a +50 years of motor simulation experience at Grundfos
- Target with simulations:
  - More simulation instead of test
  - Improve process of making test, as test could not be avoided
  - Link simulation to production and product data.

Testing is still mandatory

- Approval for UL/VDE still requires testing, so Grundfos have an UL approved lab.

Simulations are not for free

- Use test when it is the best option and simulation when it is the best option
- We do replace more test with simulations.

Grundfos Alpha2

Pump with integrated motor and frequency converter.

Requirement from UL for US marked introduction of standard motor

If efficiency and/or efficiency class is put on motor nameplate, 5 motors of each variant must be tested for validation of efficiency/efficiency class

Grundfos standard motor program

- MG/ML is a standard single speed induction motor meeting IE3 and MGE/MLE is a variable speed Permanent Magnet motor with integrated VFD meeting IE5
- Each Motor comes in a low speed (4 pole) and medium speed (2 pole) variant.
- For MG/ML there is also a high voltage variant.
- Each variant comes in a range from 0.75kW to 22kW (1-30HP) with 12 different power size.

Test requirements for MG/ML

3 variants X 12 power size X 5 samples = 180 test

Standard single speed induction motor, MG/ML

Standard variable speed PM motor, MGE/MLE

ALTERNATIVE EFFICIENCY DETERMINATION METHOD

Alternative Efficiency Determination Method

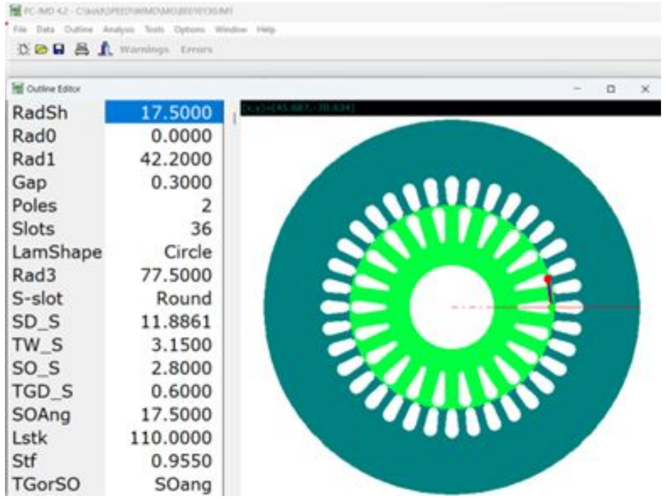
UL selects 5 out of the 3x12=36 variants. 5 samples of each variant is tested, giving 25 test in total. The rest can be verified by simulation under these conditions.

Conditions

- Understanding of the simulation tool must be given.
- Version control of software must be ensured and validated on request.
- Losses must be simulated within 10% accuracy.
- Variations within designs must be evaluated and limitations set up (Grundfos requirement).

The simulation tool used is based on analytical calculation. Models are improved/tuned with FEA in relevant areas and against physical test on the motor.

Standard single speed induction motor, MG/ML



Accuracy vs Time (inc 2D vs 3D)

Gianmario Pellegrino

(x,b) Design Plane and FEAfix

The (x,b) design plane allows the quick preliminary design of PMSMs

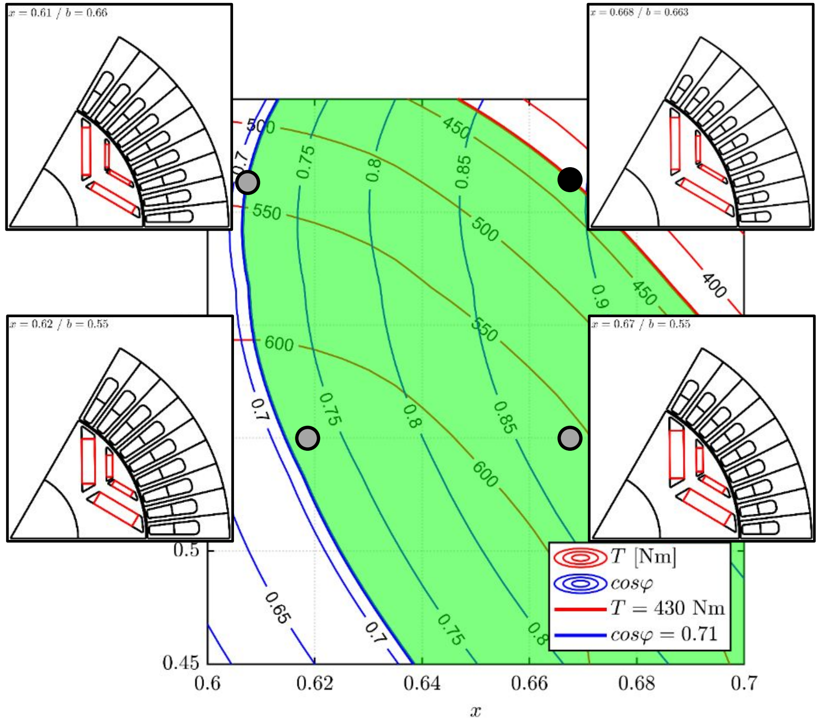
- Design rules for the geometry definition
- Analytical equations for performance figures
- FEAfix correction of equations

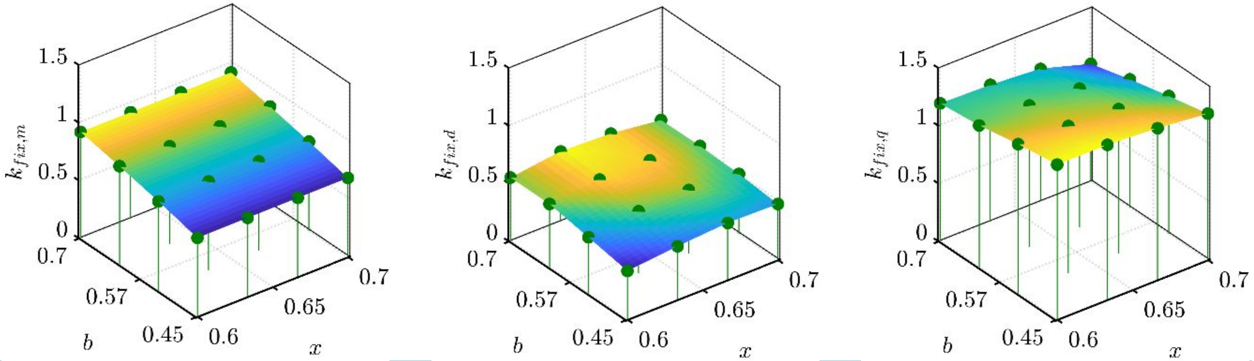
FEAfix is a strategy to correct the design plane output figures

Standard FEAfix approach

- FEMM run of 16 designs in MTPA
- Workload: 16 designs x 6 current angles x 6 rot. positions = 576 FEMM runs **5 min typ**

More KPIs can be added to the plane



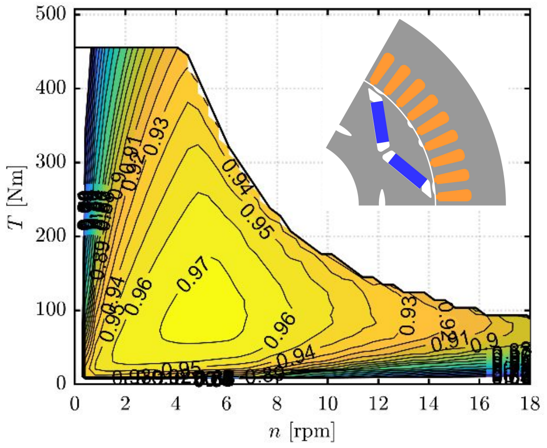


P. Ragazzo, G. Dilevrano, S. Ferrari and G. Pellegrino, "Design of IPM Synchronous Machines Using Fast-FEA Corrected Design Equations," 2022 International Conference on Electrical Machines (ICEM), Valencia, Spain, 2022, pp. 1-7, doi: 10.1109/ICEM51905.2022.9910753.

Efficiency Map with SIN Supply

Fast computation of PMSM effy maps

- **Magnetostatic, 2D FEA**
- **Flux maps (id, iq)**
  - control trajectories, torque vs speed
- **Iron and PM loss maps (id, iq) at a single speed value**
  - 3D effects and PM segmentation accounted for
- **Use of time symmetry** (60° or 180° sim for 360°)
- AC loss characteristic (AC FEA model of slot)
- Inverter limits and temperature considered
- Mechanical loss easily modeled



Simil Tesla Model 3 specs		
Peak torque	[Nm]	430
Peak power	[kW]	192
Maximum speed	[rpm]	18100
Peak phase current	[Arms]	1000
DC link voltage (min)	[V]	231
Stator outer diameter	[mm]	225
Stack length	[mm]	134
Base speed	[rpm]	4200

Total computational time
Ref to Intel Xeon E5-2690 v4 CPU, 14 cores and 32GB RAM

Flux Maps	Grid Points	# Rotor positions	# FEMM runs	Time (min)
Flux Maps	15x15	10 on 60° elt	15x15x10	10
Loss Maps	5x5	180 on 180 °elt	5x5x180	60
Effy Map	51x51	/	/	~2
Total Time	~ 70 min			

syre

S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino, "Flux and Loss Map Based Evaluation of the Efficiency Map of Synchronous Machines," in IEEE Transactions on Industry Applications, vol. 59, no. 2, pp. 1500-1509, March-April 2023, doi: 10.1109/TIA.2022.3221381.

NEW

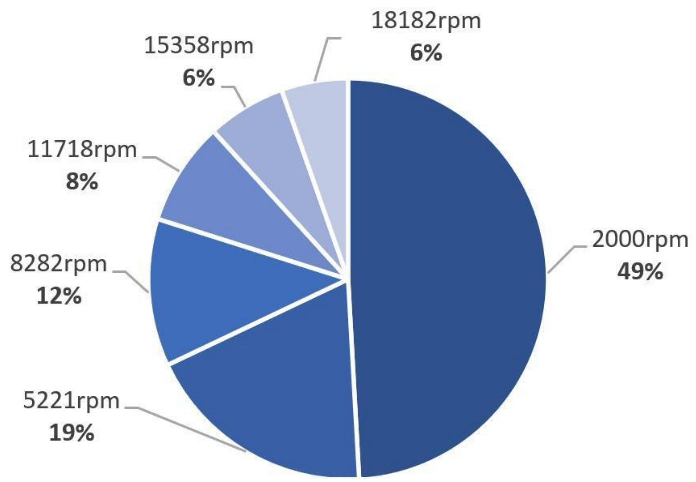
PWMfix: PWM supply fix of effy map

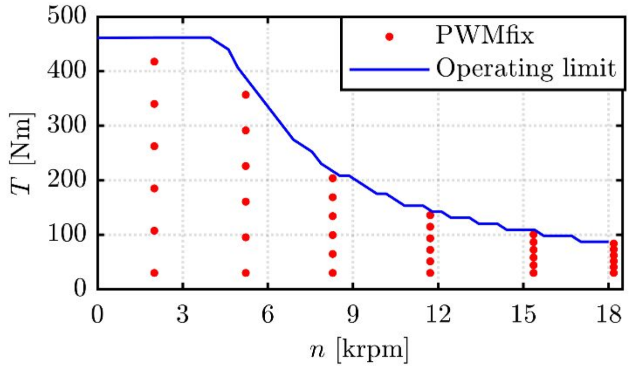
PWM supply 6x6 torque-speed grid:

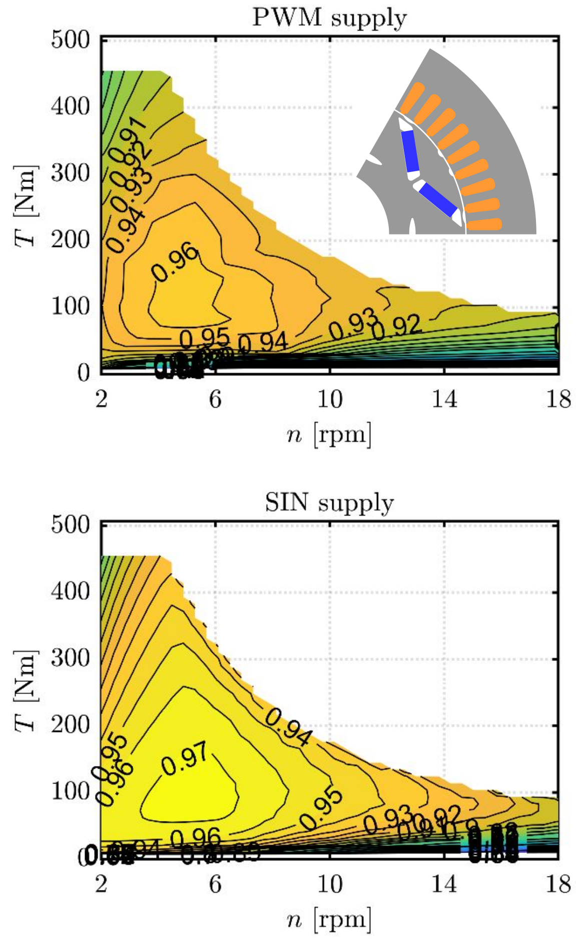
- PWM current waveforms from embedded 1D model (syreDrive)
- Static FEA run again for iron and PM loss
- Copper loss is calculated by decomposing the current harmonics via FFT and by quiring a pre-calculated AC copper loss map
- Correction factors are interpolated over the entire torque-speed domain

Unevenly dist. extra computation time 80 min

Breakdown of the FEA computational time – Total: 80min



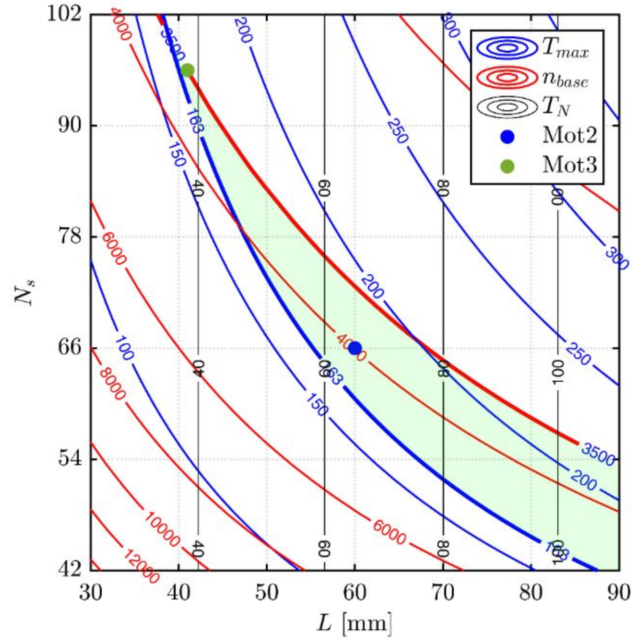


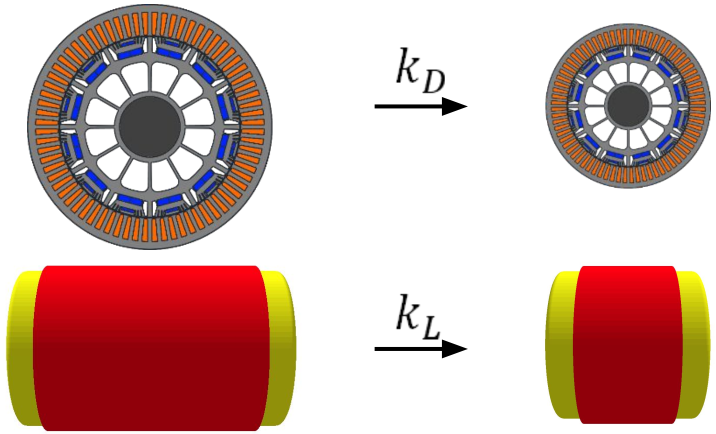


Scaling

Flux-map based method for scaling:

- **FEA maps** of the initial machine **scaled instantaneously**
- **Mechanical, magnetic and thermal** aspects are accounted for
- **Inverter voltage and current** specs are flexible
- **Length and turns scaling plane** axial and rewind factors chose





		i3	Prius MG2	
Max current	I_{max}	530	226	[Apk]
Max torque	T_{max}	250	163	[Nm]
DC link voltage	V_{dc}	355	600	[V]
Nominal speed	n_{base}	4500	3500	[rpm]
Max speed	n_{max}	11400	17000	[rpm]
Max power	P_{max}	125	53	[kW]
Pole pairs	p	6	4	
Outer diameter	D	242	215	[mm]
Stack length	L	132	60	[mm]
Volume	V	6.1	2.2	[L]
Turns	N_s	18		

G. Dilevrano, P. Ragazzo, S. Ferrari, G. Pellegrino and T. Burress, "Magnetic, Thermal and Structural Scaling of Synchronous Machines," 2022 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, MI, USA, 2022, pp. 1-8, doi: 10.1109/ECCE50734.2022.9947472.

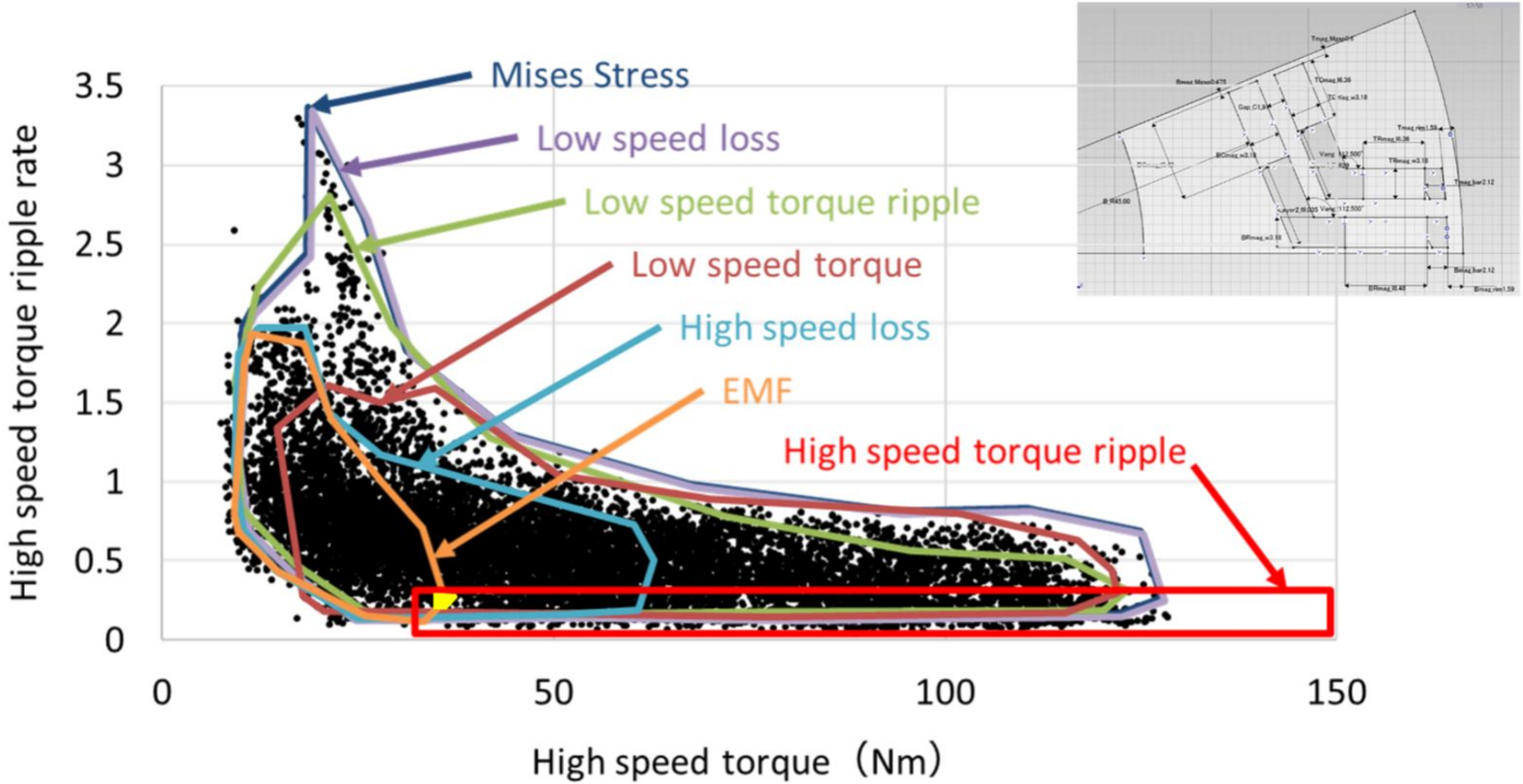
Accuracy vs Time (inc 2D vs 3D)

Takashi Yamada

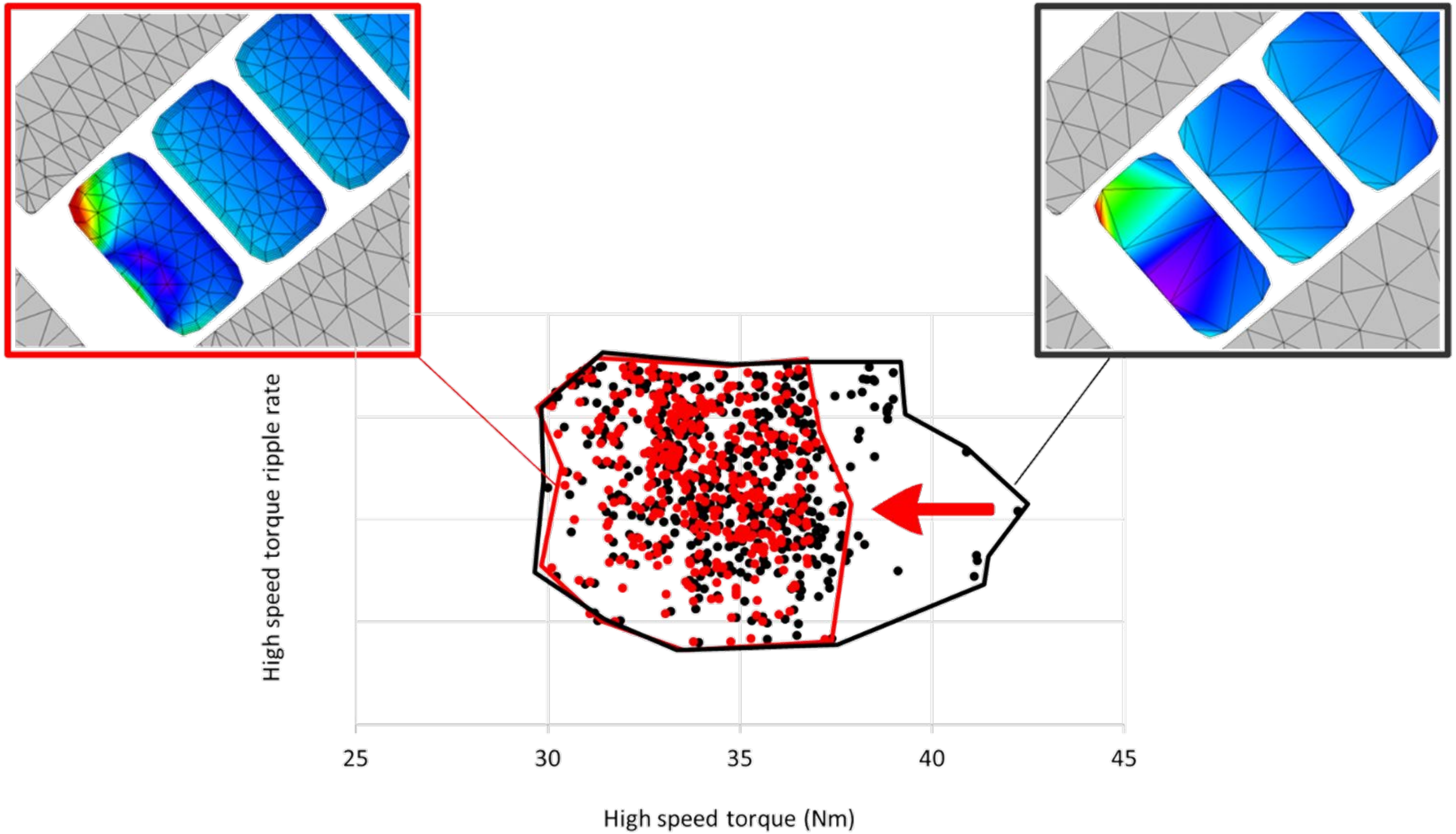
Accuracy vs Time (inc 2D vs 3D)

- The accuracy is the priority in complex problems where multi-objective optimization or MDB is necessary.
  - Solution space is so small that the error leads to non-optimized solution.
  - ECU cannot be cheated with "experiences".
- The computational time to achieve the necessary accuracy is the necessary investment.
  - Large machine designs employ high fidelity modeling including 3D.
- The computational time has been improved a lot.

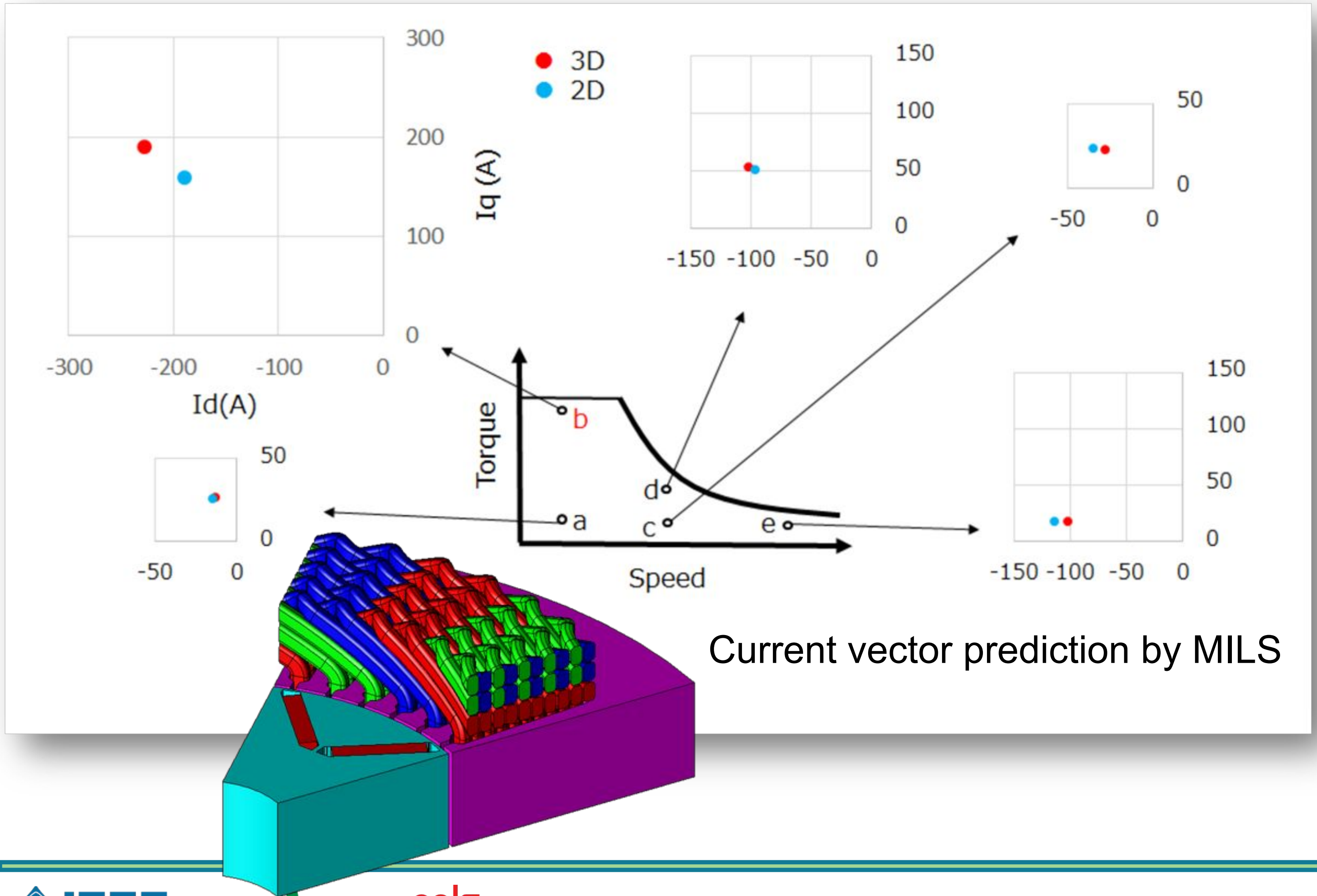
The solution space is tiny



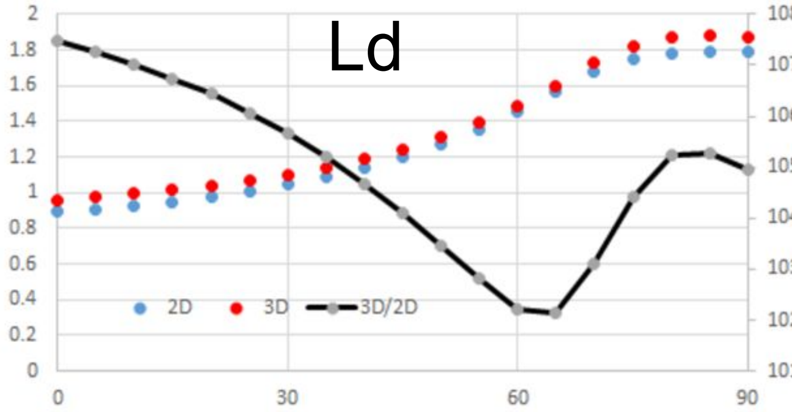
The low accuracy misleads designs

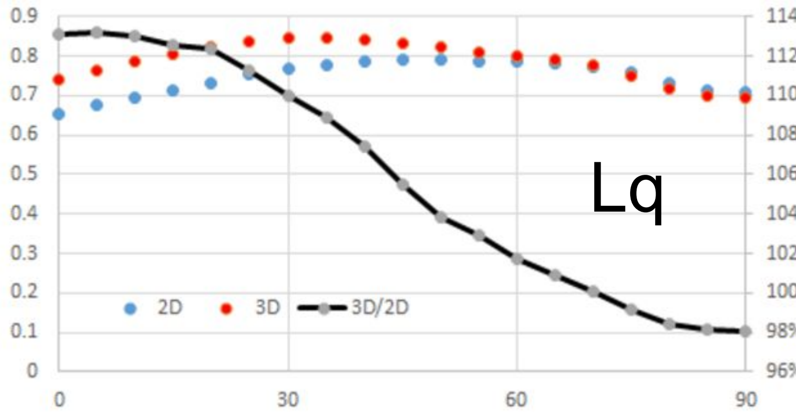


Calibration needs accurate models

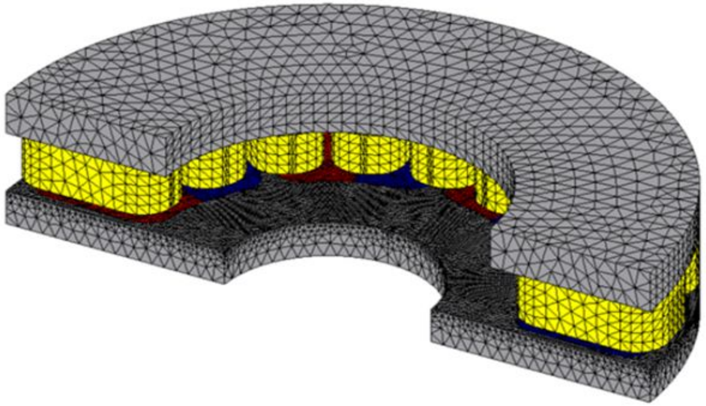


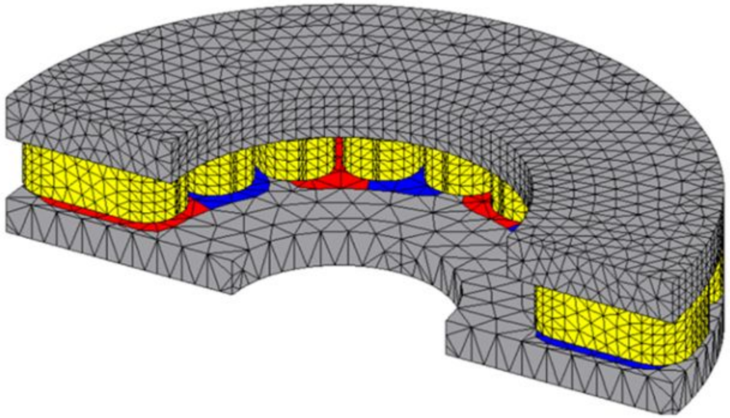
Current vector prediction by MILS





3D is not so time consuming





Can be <1 min. with 64 cores

x 32 64 cores
x 60 128
x 256 1,000
x 400 2,000

Calc. Time	24min
Number of cores	Single
Number of elements	272K
Number of steps	72
Average torque error	0.1%
Torque ripple error	0.86%

Calc. Time	4min
Number of cores	Single
Number of elements	90K
Number of steps	36
Average Torque error	0.5%
Torque ripple error	18%

Accuracy vs Time (inc 2D vs 3D)

Philippe Wendling

Accuracy vs. Time

- Design phase:
  - Equivalent Magnetic Circuits
  - Full DQ tables
  - Enhancement through Static 2D FEM
  - Enhancement through Transient 2D FEM

- Each feature brings a new level of details and accuracy

Skewed Machine

- Parameterized 2D (Multipositon): add solutions (only current input or non energized) – fastest, minutes
- Skewed applications: multilayer approach (can support voltage input): full 3D postprocessing of 2D approximation, no end effects – a few hours
- Full 3D – several hours
- Indication of time single CPU no distribution

Mixed methods

- Advanced elements to model special features:
  - Line/surface airgap
  - Line/surface conducting regions
  - Surface impedance
- Replace air in FEM by IM region
- Use circuit connections to describe 3D features

Subsystem Focus vs Multiphysics

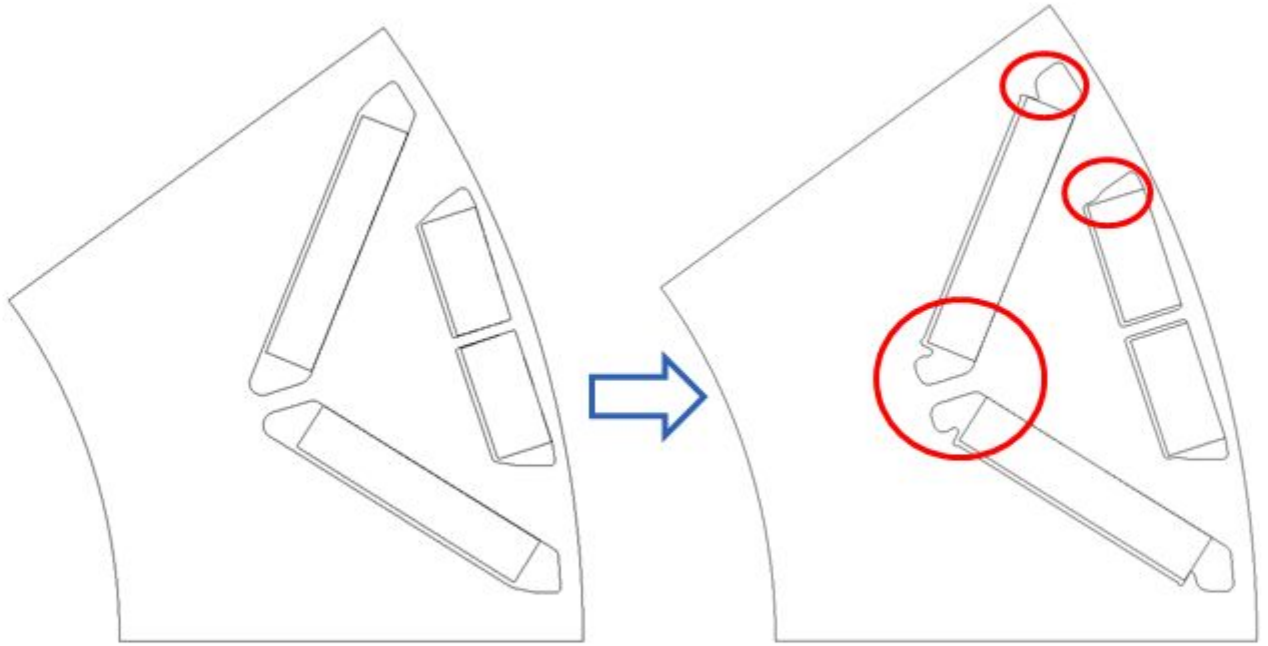
Ian Brown

Subsystem Focus vs Multiphysics

- True multiphysics design is needed to push the state-of-the-art performance of electric machines
- Optimizing electromagnetic only with secondary structural and thermal checks leaves significant unrealized potential performance or unrealistic designs
- Electromagnetic, structural, thermal, acoustic, rotor dynamics, all impact the design and have significant performance implications
- Small features matter if the best designs are to be found, subject to stress, torque ripple, and thermal constraints
- Significant gains in thermal performance can be made through small changes that would likely not be carried out in a standard template, e.g. jet impingement optimization or water jacket flow path optimization

Subsystem Focus vs Multiphysics

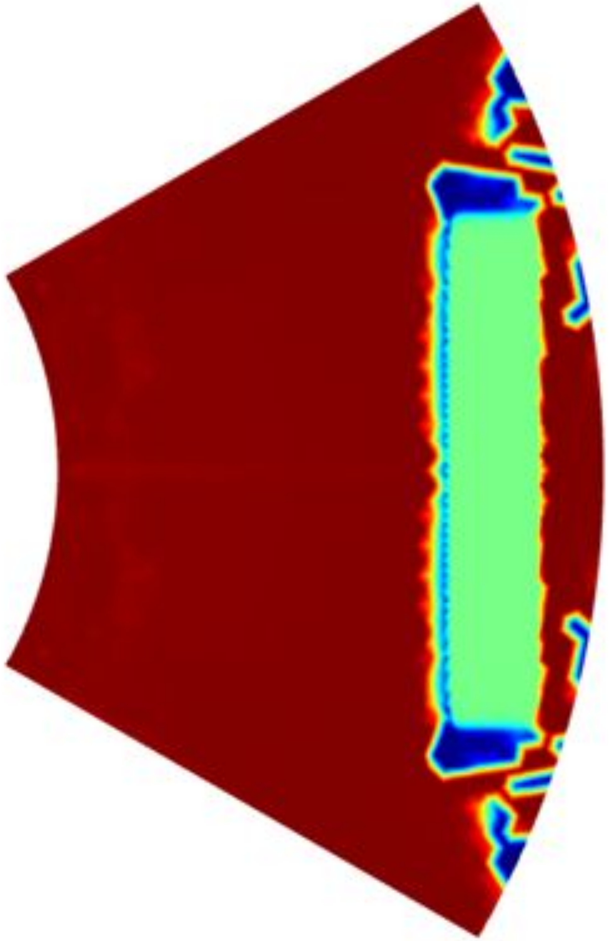
- Example result from a combined electromagnetic and structural optimization using a standard template
- Small features, e.g. multiple small radii can reduce the peak stress by more than 50 MPa, in some cases 100 MPa
- In reality real peak stress will likely be even lower due to stress redistribution due to nonlinear and deformation effects
- Potentially missed opportunity for electromagnetic performance improvement, e.g. smaller bridges, etc.



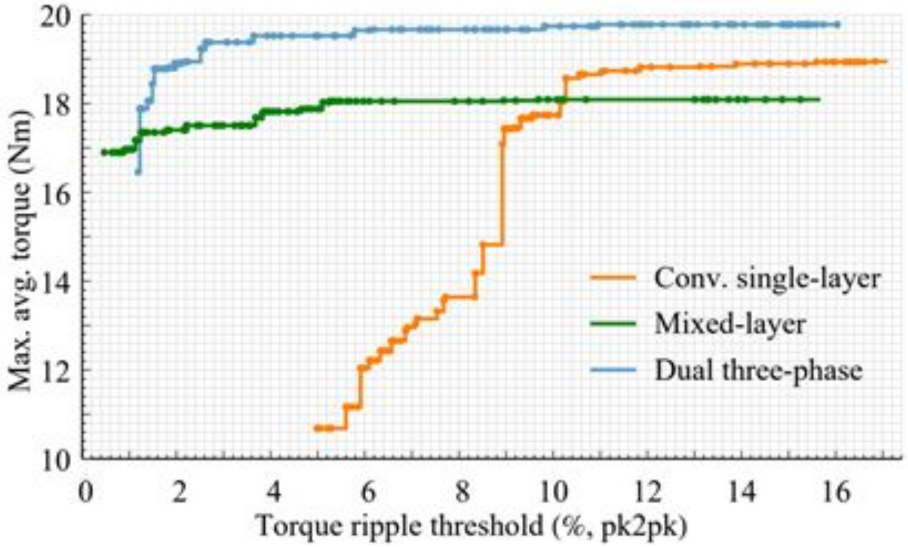
Subsystem Focus vs Multiphysics

- Examples of small features making a difference on the achievable design or Pareto front

- Small features introduced by topology optimization to meet combined stress, torque ripple, and average torque constraints



- Larger design decisions also have a major impact on the achievable Pareto front, e.g. the winding for the same slot pole combination subject to a torque ripple constraint



EMPIRICAL VS PHYSICS BASED

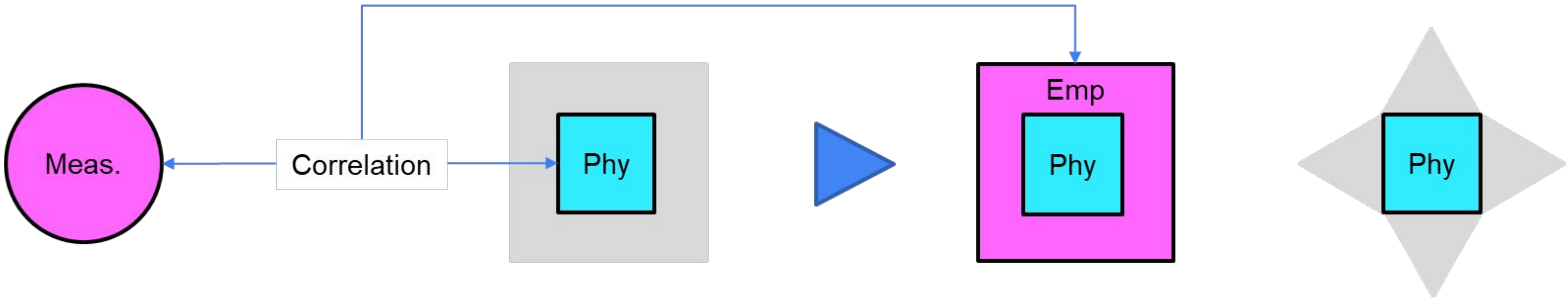
Takashi Yamada

EMPIRICAL VS PHYSICS BASED

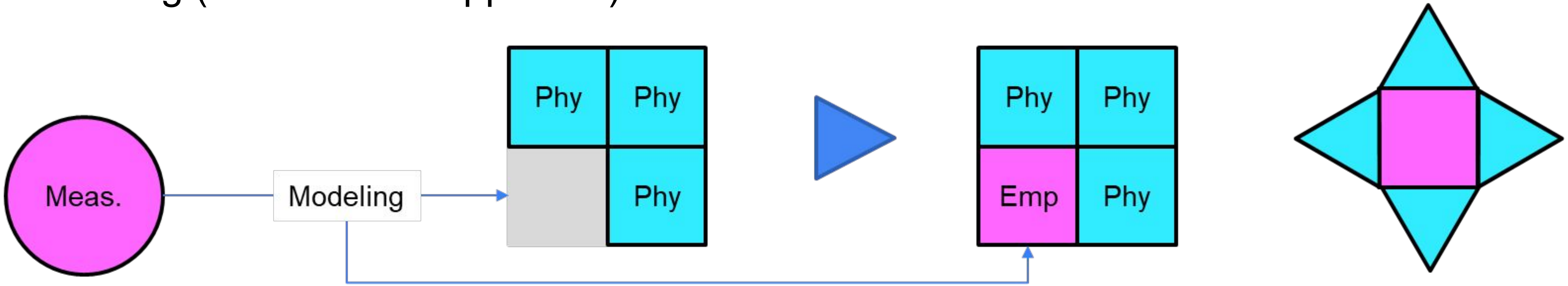
- The physics based modeling is ideal
  - for wide applicability
- However, the empirical modeling is necessary
  - because the physical based modeling is not always possible
    - Material, Manufacturing effects, …
  - They are complementary.
- The empirical modeling should be applied not to whole but to parts only for which the physics based modeling is not available.
  - for wide applicability.
    - BH curve
- More detailed and sophisticated measurements are encouraged to construct good empirical models.

Model tuning vs Empirical modeling

Model tuning (Differential approach)



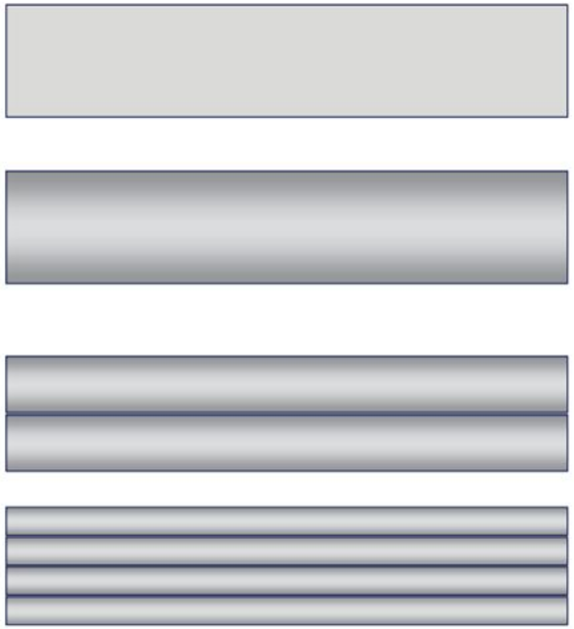
Empirical modeling (Constructive approach)



Ex. Empirical modeling of punching effects

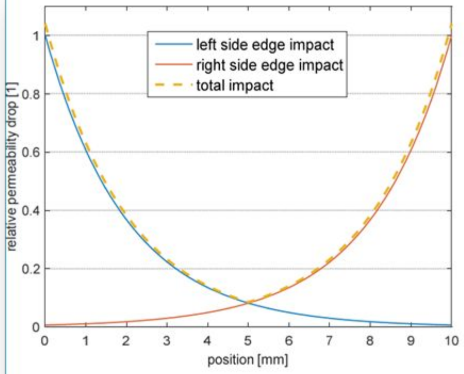
Generation of material data

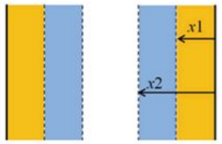
- Sample preparation:
  - 1 sample without cut edge effect (wire cut technique)
  - Same sample with cut edge effect (the impact of the tool for cutting the sample should be similar to the one produced by the manufacturing cutting tool used for the magnetic circuit of the machine understudy)
  - Cut the former sample into 2 parts
  - Split the previous sample into 2 again (an so on)



- On each configuration, the cut edge impact is different and will help identify the model parameters.

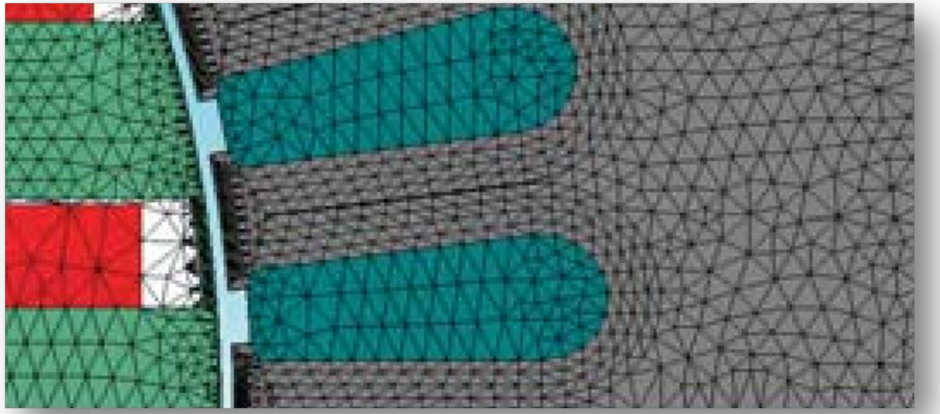
Leroy-Somer EMERSON Industrial Automation





The cutting process also impacts the material specific losses:
The hysteresis and Eddy-current parameters of the material will depend on the distance from the cut edge.

Leroy-Somer EMERSON Industrial Automation



X. Jannot, "Evaluation of performances of a PMSM taking into account the impact of the lamination cutting", JMAG User Conference 2015

EMPIRICAL VS PHYSICS BASED

Keld Rasmussen

EMPIRICAL VS PHYSICS BASED

In 1972, the IBM system in the Data Processing Department was replaced by a new and better system with a capacity that was three times larger than the old one.

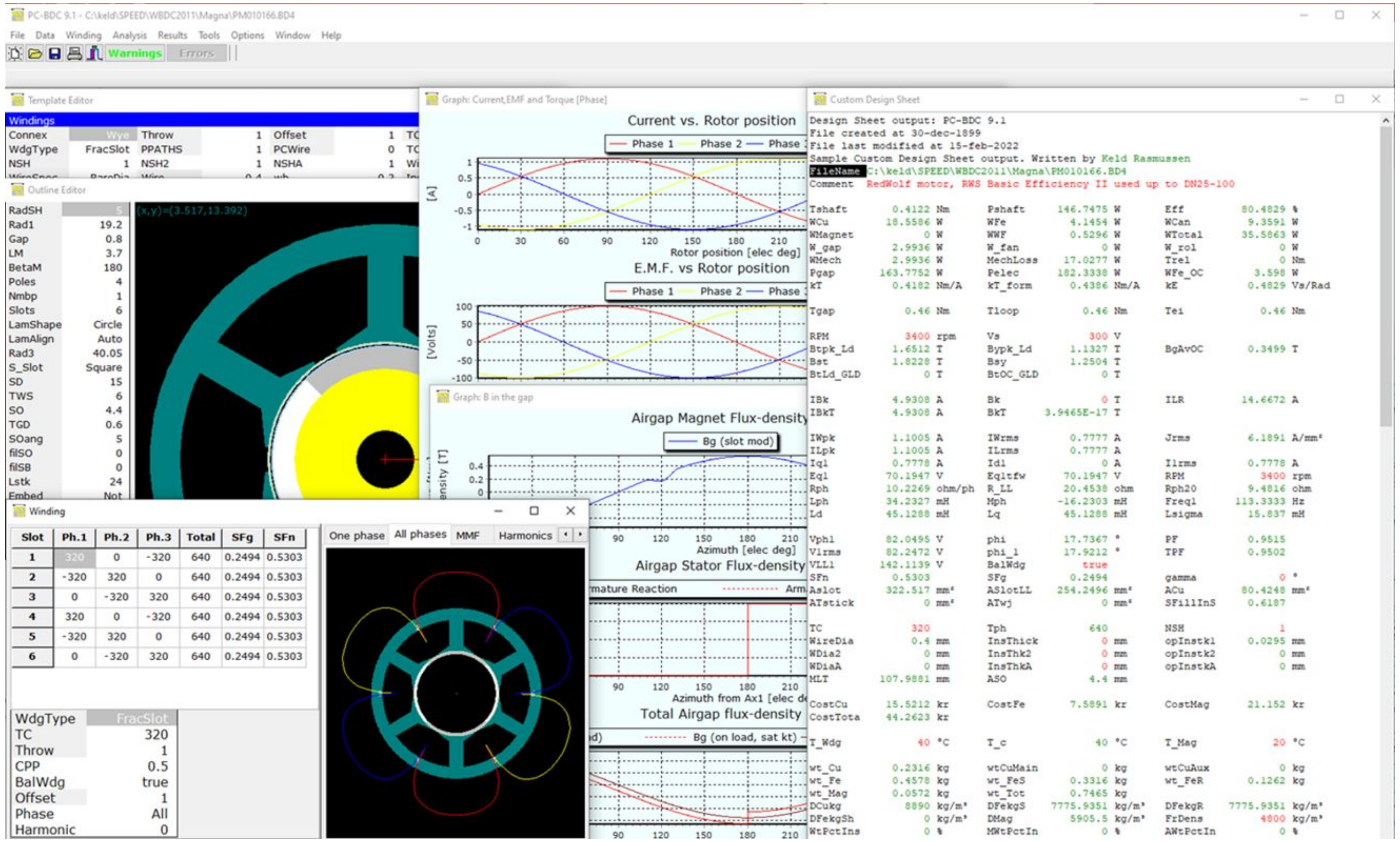
```
01 BEREGNING MOTORDATA  VED BEREGNINGSNUMMER  PANEL
03 BEREGNING MOTORDATA  FRA  MBMIN TIL MBMAX  WRITE
04 BEREGNING BERG-KORT  FRA  MBMIN TIL MBMAX  WRITE
05 MOTORDATA STEMPLINGSDATA  PRODUKTKODE      PRINT
06 MOTORDATA STEMPLINGSDATA  PRODUKTKODE   PRINT OG WRITE
07 MOTORDATA STEMPLINGSDATA  SORTERET      PRINT
08 MOTORDATA STEMPLINGSDATA  SORTERET      PRINT OG WRITE
09 MOTORDATA VIKLINGSDATA    SORTERET      PRINT
10 MOTORDATA VIKLINGSDATA    SORTERET      PRINT OG WRITE
11 STEMPLING VIKLING  MASKINK SORTERET TESTDATA PRINT OG WRITE
12 STEMPLING VIKLING  MASKINK SORTERET DIAMETER PRINT OG WRITE
13 STEMPLING VIKLING  MASKINK SORTERET ETA      PRINT OG WRITE
14 STEMPLING VIKLING  MASKINK OPTIMER. ETA      PRINT OG WRITE
15 MOTORDATA  ãNDRING AF  DATA  USORTERET       PRINT OG WRITE
16 MOTORDATA  ãNDRING AF TEKST  USORTERET       PRINT OG WRITE
17 PROGRAM INFORMATION FOR BEREGNINGER          PRINT OG WRITE
18 STOP PROGRAM

MENU Number > 01
Indtast beregningsnummer > 2036

**** LãSER FRA DATA-BASE KONSTRUKTION BEREGN02 ****

 01  BEREGNING  MOTORDATA        INGEN     WRITEFILE

**** BEREGNING AF 1-FASET MOTOR  ****

Edit, save and close file axjtemp.m
Press enter when finished >
```

- Inhouse developed simulation program for Induction motors, single phase and 3 phase
- Analytical models
- Close coupled to motor production
- Around 1990 PC started replacing Workstations -> enabled use of electromagnetic FEA

Empirical vs Physics based

SPEED software

- Introduced in 1995 in Grundfos
- Induction and Permanent magnet motors.
- Graphical interface
- Analytical based with link to Finite Element, PC-FEA
- Integration with Matlab through ActiveX (for e.g., optimization)

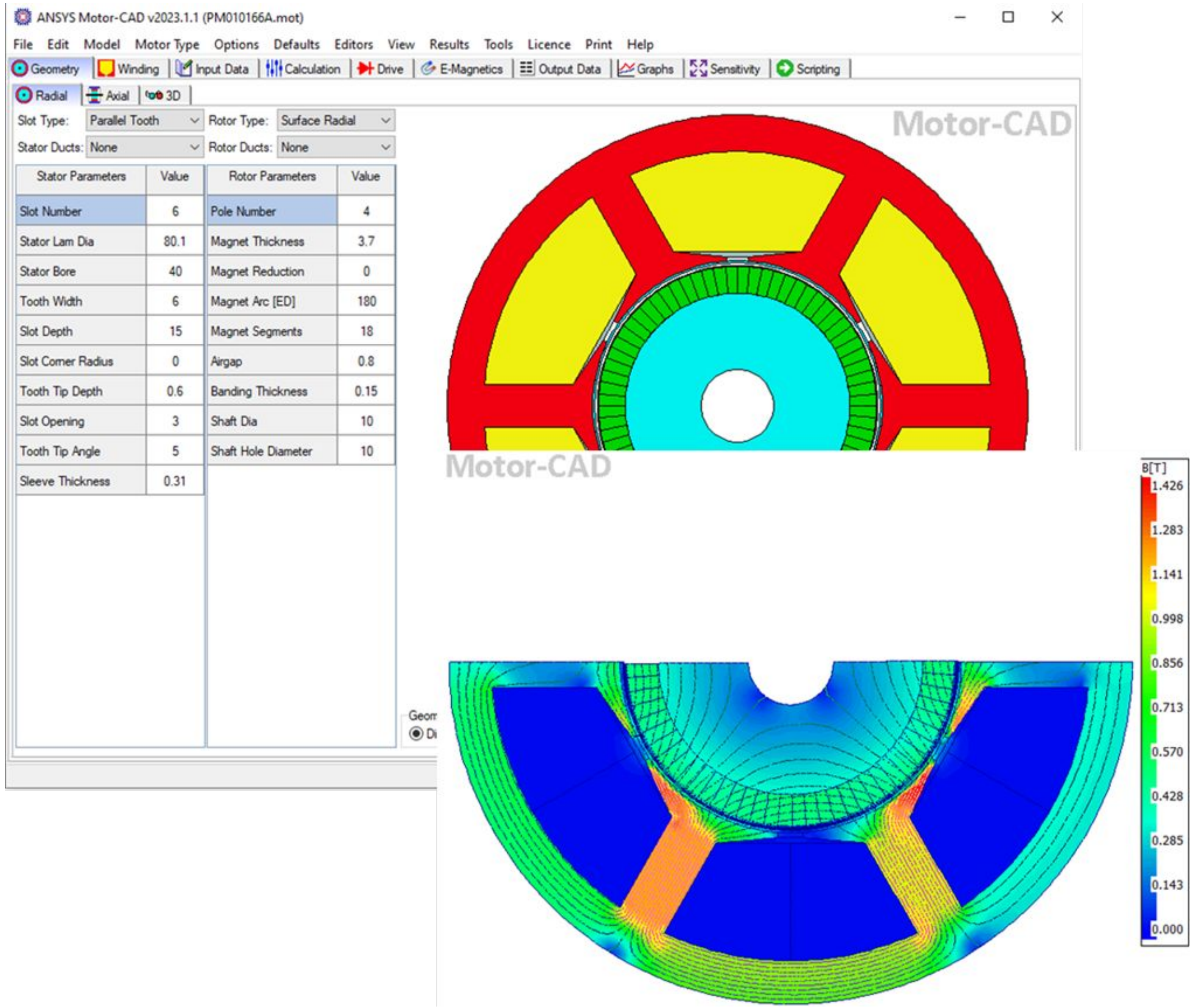


Co-development between SPEED consortium and Grundfos for implementation of pump specific solutions.

EMPIRICAL VS PHYSICS BASED

ANSYS MotorCad software

- Introduced in 2010 in Grundfos
- Originally used for some thermal verification of motor designs made in SPEED software.
- Introduction of E-Magnetic has enabled the use of Motor-CAD on especially Permanent Magnet motors.
- Ansys is the preferred simulation suite for mechanical and electronics in Grundfos -> best option for Multiphysics simulation.
- Tool made for electrical motor design, with increased focus on Multiphysics. E.g., optimization of Interior Permanent Magnet motors.
- The easy use/implementation of custom designs and still have the motor output data.
- Last but not last least. Long term personal relationship between Grundfos and Ansys Motor-CAD.
-



Computational Advancements: Model implementation

15 mins presentation,
15 mins open discussion

It should be about 9am now - how are the facilitators going keeping the panelists in order?

Open Source vs Commercial (inc customer/ developer relationship)

Gianmario Pellegrino

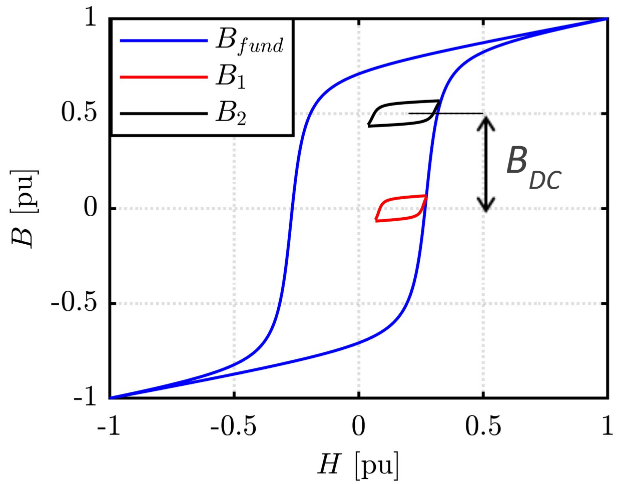
Preliminary Design: SyR-e Vs Commercial

	Open	Commercial						
Feature	**SYRE**	**ANSYS RMxprt**	**ANSYS Motor-CAD**	**JMAG Express**	**Simcenter SPEED**	**Simcenter MotorSolve**	**Altair FluxMotor**	**MotorXP**
DXF and scriptable Geometries	✓	✓	✓	✓	✓	✓	✓	✓
FEA Solver	Magnetostatic FEA coupled with analytical solution	–	Magnetostatic FEA coupled with analytical solution	Magnetostatic FEA coupled with analytical solution	Magnetostatic FEA coupled with analytical solution	FEA	Magnetostatic FEA coupled with analytical solution	Magnetostatic FEA coupled with analytical solution
Compatibility	Motor-CAD ANSYS Maxwell Magnet	ANSYS Maxwell	ANSYS Tools	JMAG Designer	Simcenter MAGNET Star-CCM+	Simcenter Flomaster and Amesim	Altair Flux	–
Embedded automation features								
Preliminary sizing	✓	✓	–	✓	–	✓	–	–
Scripting and workflow automation	MATLAB	MATLAB Python JavaScript, VB, Excel	MATLAB, Phyton, VB	MATLAB, Python	JavaScript, Python	Excel	Python	MATLAB
Design Space Exploration	✓	–	–	–	✓	–	–	–
Performance Metrics								
Efficiency and Loss Map Calculation	✓	–	✓	✓	✓	✓	✓	✓
Electromagnetic-Thermal Co-Simulation	Via Motor-CAD	–	✓	✓	Via Motor-CAD or STAR-CCM+	Embedded 3D thermal FEA	Via Altair HyperStudy	–

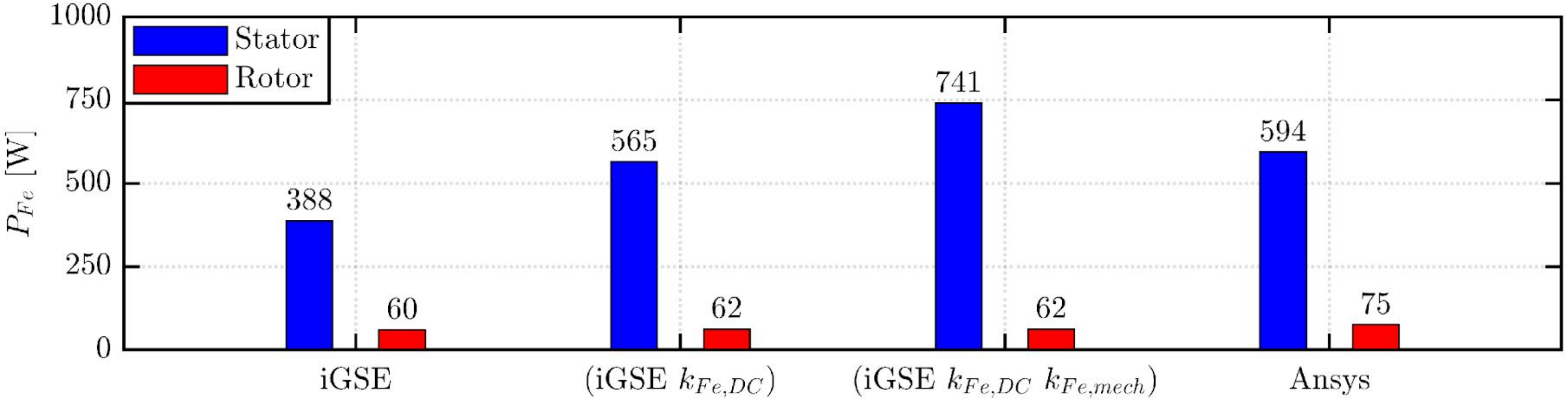
Iron Loss Computation Accuracy

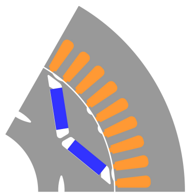
Magnetostatic field solutions manipulated via scripting:

- Improved Generalized Steinmetz Equation (**iGSE**)
- minor and major **hysteresis loops** are detected
- the **DC flux density bias** effect is considered via a parametric approach
- the impact of **compressive mechanical stress** in the stator can be addressed



700Apk MTPA – 4000rpm (sinusoidal supply)



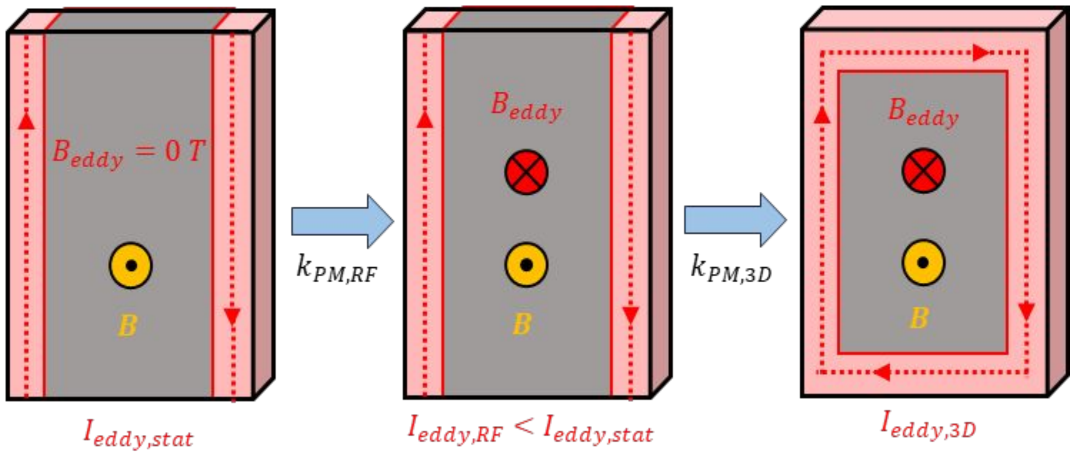


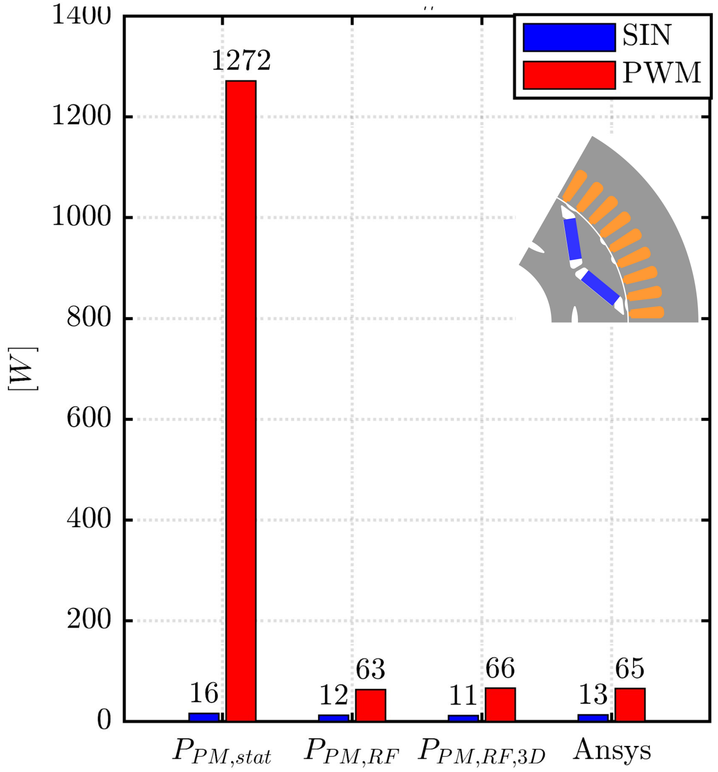
S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino, "Flux and Loss Map Based Evaluation of the Efficiency Map of Synchronous Machines," in IEEE Transactions on Industry Applications, vol. 59, no. 2, pp. 1500-1509, March-April 2023, doi: 10.1109/TIA.2022.3221381.

Magnet Loss Model Comparison

Magnetostatic field solutions manipulated via scripting:

- eddy current reaction field impact
- **3D effect on the PM axial end-side**





M. Hullmann and B. Ponick, "General Analytical Description of the Effects of Segmentation on Eddy Current Losses in Rectangular Magnets," 2022 International Conference on Electrical Machines (ICEM), Valencia, Spain, 2022, pp. 1757-1762, doi: 10.1109/ICEM51905.2022.9910629.

AI vs Human

Joel Van Sickel

Some AI Types

- Offline Optimization - Genetic Algorithm
- Real-time Optimization - Machine Learning, Neural Networks
- Generative - Large Language Model

How will AI affect Engineers?

- Who will set up problems where the AI can evaluate itself with minimal effort from a human?

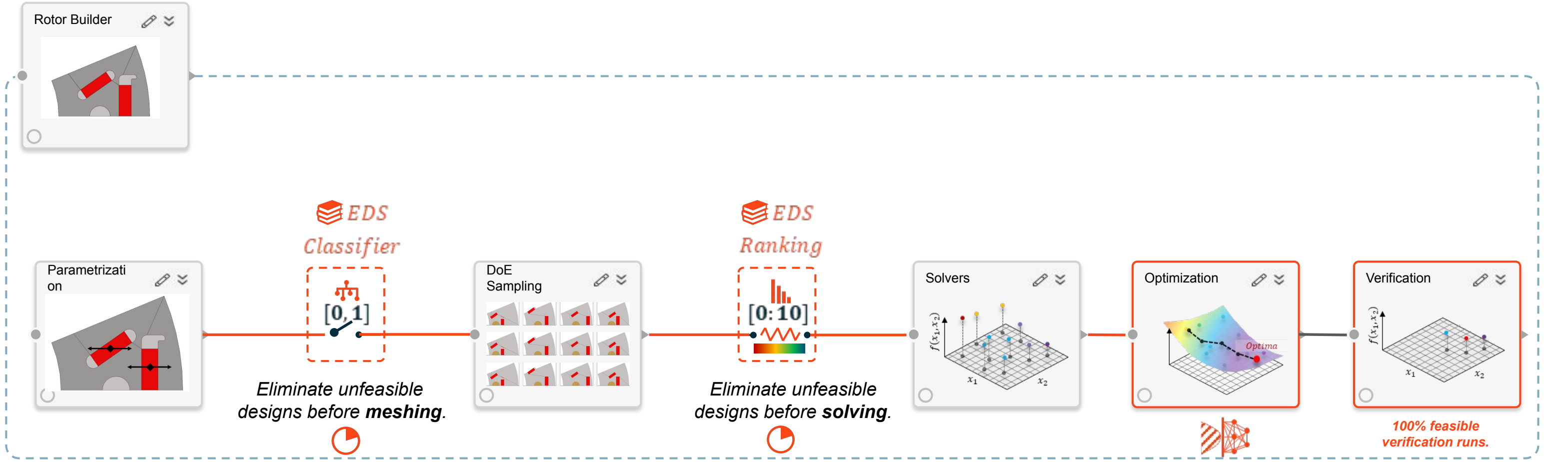
- We are going to start logging more data and adding sensors

AI vs Human

Philippe Wendling

Add Intelligence in Optimization Schemes

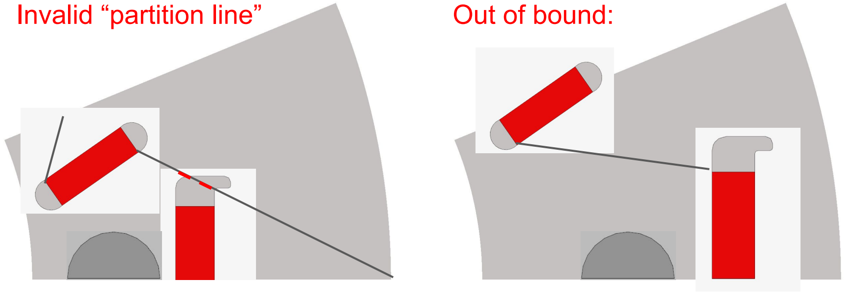
- Enhance Solution with Engineering Data Science



- *Allows sampling of large design spaces*
- *Modularized Solution*
- ***20~30%** faster than conventional approach*
- *Instant evaluation of geometric feasibility*
- *Increased confidence on optimization results (Classifier accuracy = 0.89)*
- ***Optimization results faster and more reliable***

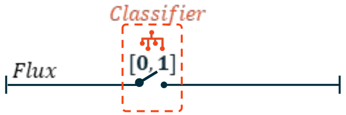
Add Intelligence in Optimization Schemes

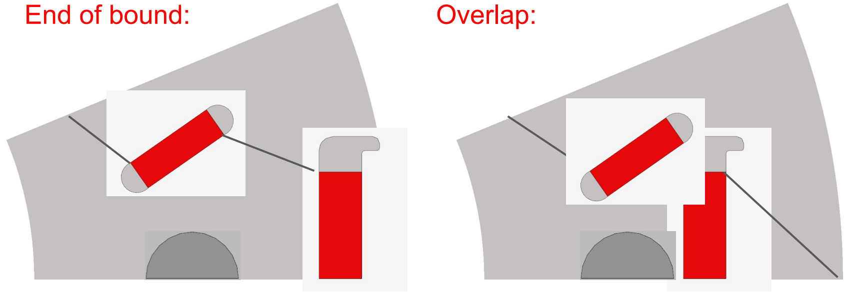
- The geometrical parametrization of the position of the center and magnets might lead to unfeasible designs.



INVALID GEOMETRY

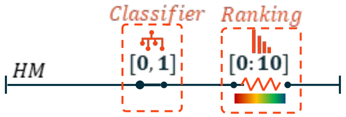
- This designs contain heavily distorted surfaces
- Geometric operations not possible
- Captured by Flux geometric check
- Provide a discrete output e.g. (0 feasible / 1 not feasible)





HEALTHY GEOMETRY

- Geometric operations are possible
- CAE operations end up in errors (e.g. meshing/solving)
- Not captured by Flux geometric check
- Tcl script built to provide a **scalar output** (e.g. distance between magnets).



Add Intelligence in Optimization Schemes

- Data review
- Prepare datasets (measures, computations)
- Train ML models
- Predict and evaluate

- Reduced Order Models

- Selection of predesign in library

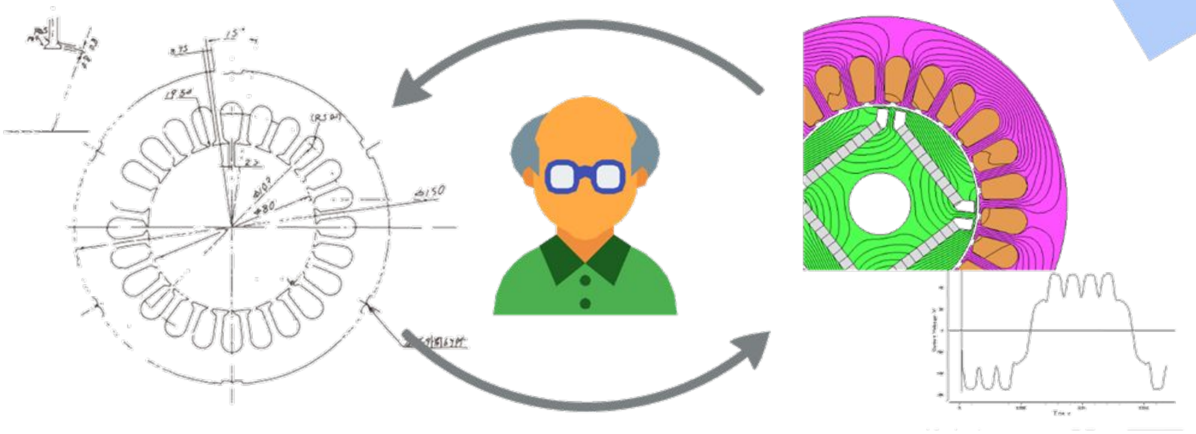
AI vs Human

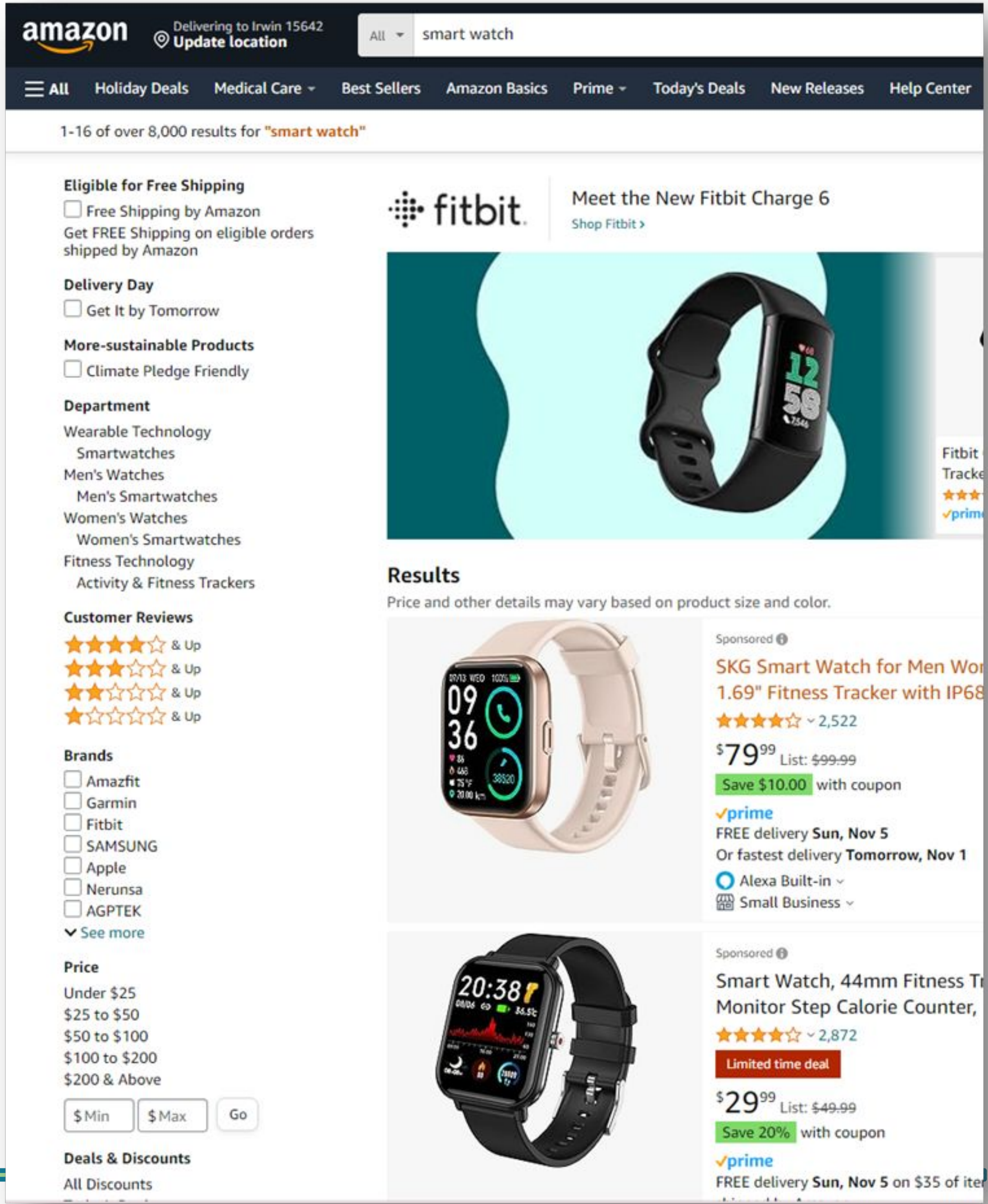
Takashi Yamada

AI VS HUMAN

LLM…?

?





Traditional Simulation vs Digital twin (inc real time modelling)

Joel Van Sickel

TRADITIONAL SIMULATION VS DIGITAL TWIN (INC REAL TIME MODELLING)

- Traditional Simulation
- Real-time Simulation
- Digital Twin

What is a Digital Twin

- IBM
  - A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision making
- Opal-RT
  - Digital Twins are virtual representations of physical assets and processes used to understand, predict, and optimize their operation.
- MathWorks
  - A digital twin is an up-to-date representation, a model, of an actual physical asset in operation.
- Amazon
  - A digital twin is a virtual model of a physical object. It spans the object's lifecycle and uses real-time data sent from sensors on the object to simulate the behavior and monitor operations.

COMPUTATIONAL ADVANCEMENTS: OPEN DISCUSSION

15 mins presentation,
15 mins open discussion

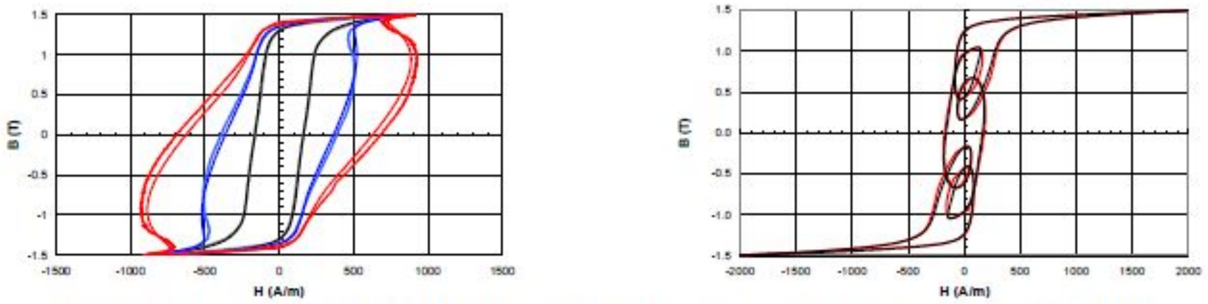
It should be about 9.30am now - complete chaos yet?

WHAT IS THE NEXT BIG COMPUTATIONAL ADVANCEMENT?

Philippe Wendling

What is next

- Better materials models:
  - Equivalent B(H) curves
  - Loss computations
  - Hysteresis
  - Models for which coefficient can be measured
- New materials adapted models:
  - SMC
- Windings – effect of higher frequencies:
  - Loss computations
  - Effective resistance
  - Better models of superconductors

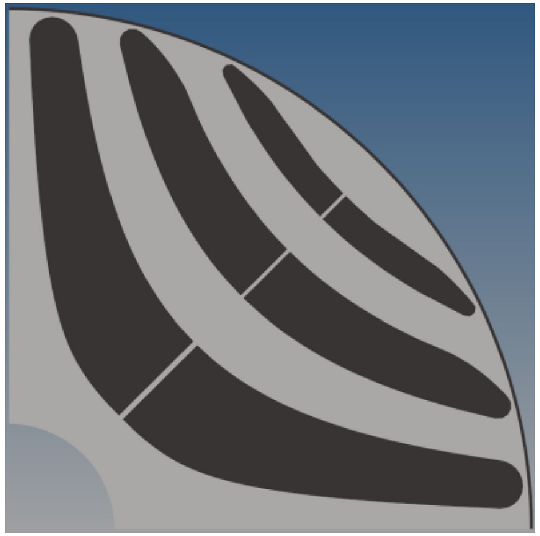


B(t) sine at 50,200 and 400 Hz, M800-65A B(t) sine + 50% Harm. 5, 60%, 100 Hz, M400-50A

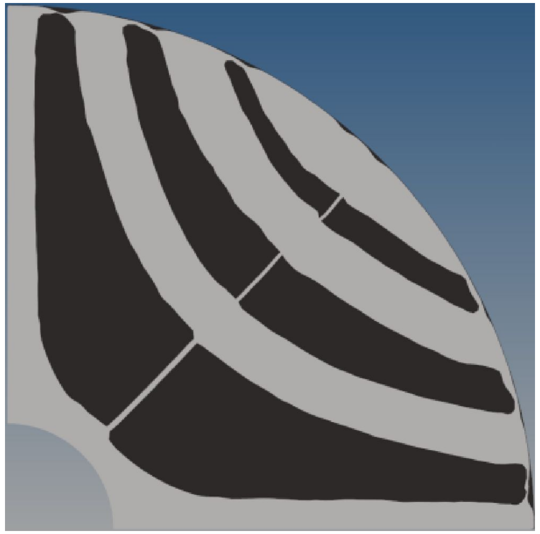
Figure 6: LS Model Hysteresis loops compared to experiment

Shape Optimization

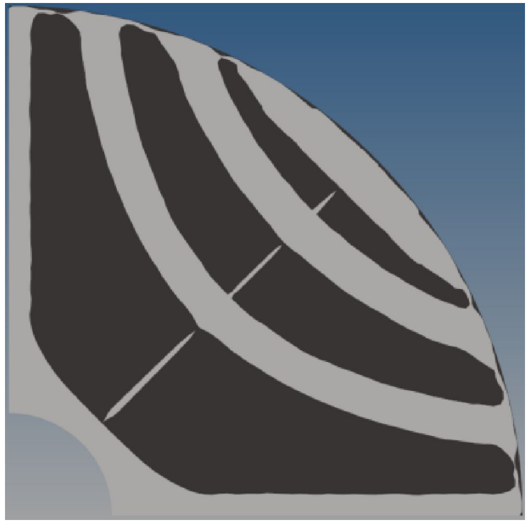
- Initial design



- No constraint



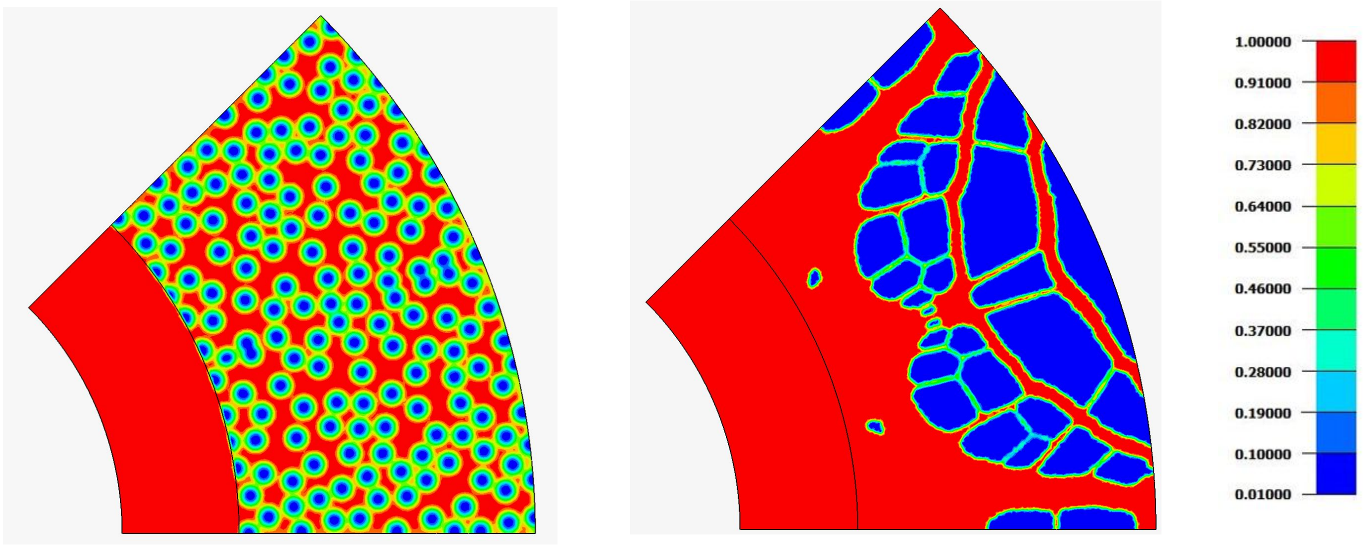
- Rotor mass constraint and symmetry imposed



- In a Multiphysics environment

Topologic Optimization

- Multiphysics
  - Electromagnetic
  - Mechanical



Faster Solving

- Take advantage of GPU
- Mixing methods to reduce sizes – eg: IM/FEM
- Minimize mesh density
- Solving algorithms
- Cloud

What is the next big Computational Advancement?

Ian Brown

What is the next big Computational Advancement?

- Integrated, fully coupled, high fidelity, multiphysics modeling and optimization with full design space exploration

Fully integrated

- –Electromagnetics
- – Nonlinear large deformation stress analysis with representative boundary conditions (contact boundaries, etc.)
- – CFD
- – Vibra-acoustics (NVH)
- – Rotor dynamics
- – Drive cycle analysis

What is the next big Computational Advancement?

- Detailed geometric templates for full design space exploration
  - –Deformable boundaries for shape optimization with robust mesh deformation (maybe radial basis functions), perhaps combined with topology optimization
  - –Direct extraction of gradient information for boundary deformation for fast optimization
  - –Computational geometry checks on feasibility of the design and deformation of the boundaries to avoid unphysical geometries
- Can we leverage computational resources that are being built up for AI training or repurpose them once the replacement cycle has started
- Some of this already seems to be happening

What is the next big Computational Advancement?

Alireza Fatemi

What is the next big Computational Advancement?

Better Electromagnetic Simulations:

Continued advances in electromagnetic simulation tools for accurate modeling.

More Realistic Simulations And Robust Design:

Enhanced multiphysics simulation to account for coupled effects.

AI-Powered Design:

AI-assisted design for automation and optimization.

Supercomputers for Precision:

Utilizing HPC for complex simulations and improved designs.

Materials of the Future - Modeling and Development:

Development of advanced materials for improved performance.

Cooler Machines:

Better heat management through computational tools.

Size and Integration:

Co-design of component for smaller, lighter, and more integrated designs, sensors, electronics, EMI.

Cloud-Powered Simulations:

Scalable and accessible simulation in the cloud.

Your Machine, Your Way:

Tailoring designs to specific applications or needs.

APPENDIX

TIMING REALITY CHECK

1 min intro each (10 mins)

80 mins in total left - 11.4 mins each panellist

would like to have an interactive discussion with the audience so presented material should be only just over half of this

My suggestion is to ask each panellist to prepare a two 3 min presentations that address two of the 9 suggested topics (we can adjust topics at the request of the panellists)

With a bit of preparation, we will hopefully have a good coverage of the topics. At the end of each section there will be an opportunity for the audience to ask questions and any panel member to contribute a response.

Not part of final presentation (preparation only)

PROPOSED PREPARATION PROCESS

1. Mircea and Greg agree on structure and the topics
2. Email panellists with a link to this shared presentation and ask them to select in the table (slide 6) which two topics they would like to prepare a 3 min presentation on
3. Mircea and Greg review the proposed presentations and adjust if required
4. Mircea and Greg will create “placeholder” slides for the presenters to add in their content
5. Email panellists to confirm their topics and ask them to add 1 - 3 slides on that topic directly into this presentation
6. Once finalised, Mircea or Greg upload the presentation prior to the session

Not part of final presentation (preparation only)

Panellist Preparation

Not part of final presentation (preparation only)

IEEE ENERGY CONVERSION CONGRESS & EXPO Nashville, TN | OCT.29-Nov.2

Choose two topics to prepare a 3 min presentation (with an optional backup if possible) - label 1,2,3

Section	Topic	Gianmario Pellegrino	Ian Brown	Keld Rasmussen	Alireza Fatemi	Joel Van Sickel	Philippe Wendling	Takashi Yamada
Model type (15 mins presentation + 10 mins discussion)	Completely trusted results vs experimental validation?		3	1				
	Accuracy vs Time (inc 2D vs 3D)	1					2	1
	Subsystem Focus vs Multiphysics		1					
	Empirical vs Physics based			2		3		2
Model implementation (15 mins presentation + 10 mins discussion)	Open Source vs Commercial (inc customer/ developer relationship)	2		3				
	Local vs Cloud Computing							
	AI vs Human					2	3	3
	Traditional Simulation vs Digital twin (inc real time modelling)					1		
Open discussion (15 mins presentation + 10 mins discussion)	What is the next big Computational Advancement?		2		1		1	

Open panel discussion focussed on:

* Solutions that are commercialized and available now.
* Possible computational solutions that will bridge the present with the future of electric machines design.
* Accuracy vs time: dilemma of the computing solutions
* Physics vs Engineering computing solutions

Questions to be Answered

* Can we narrow the gap between computing usage and development (customer/developer)?
* How much 3D and cloud computing vs analytical and 2D, empirical computing? Can both approaches coexist in the future?
* Is AI part of the solution?

SCOPE CLARIFICATION (NOT SURE IF REQUIRED)

In Scope

Electromagnetic modelling -
- torque / force production
- Loss modelling

Thermal analysis

Mechanical
- strength/deflection
- vibration

Condition monitoring