

Electromagnetic Simulation Tools for Electric Machinery Design and Analysis

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Outline

- Infolytica Corporation – Who are we?
- Electrical Energy and Efficiency
- What can Infolytica tools do?
- What is important in electrical machine design?
- How Infolytica tools enable the design process.
- Why Mentor?

Infolytica Corporation

1978 Infolytica Founded
McGill U & Imperial College
P.Silvester, E.Freeman, D.Lowther

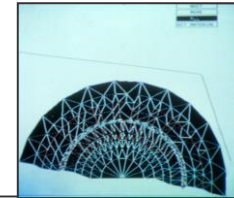
Goal:

To “democratize” access to advanced finite element based electromagnetics analysis tools.
To provide tools at the cutting edge of research and development in design and analysis systems.

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1980 MagNet eleven released



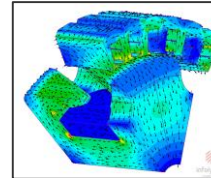
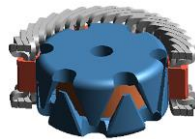
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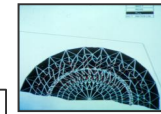
1989 World's first 3d em on a PC



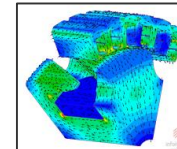
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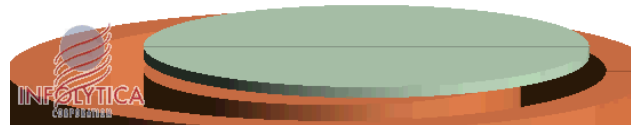
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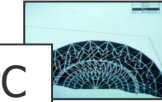
2004 Full 6 axis motion with many bodies



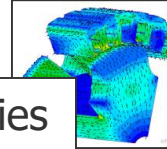
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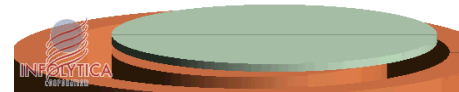
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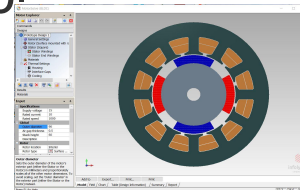
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2008 MotorSolve – an electrical
machine design tool



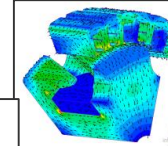
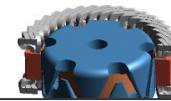
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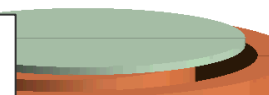
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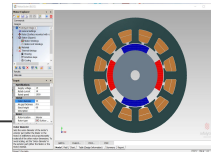
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2017 Acquired by Mentor

Electrical Energy – Global Production

- In 2016, the global amount of electrical energy used was approximately 2×10^{16} Watt-hours
 - This is the equivalent of 8×10^{15} AA batteries..
 - A volume of $6 \times 10^{10} \text{ m}^3$
 - approximately 20 million Olympic swimming pools
 - $2.6 \times 10^9 \text{ m}^3$ of gasoline
 - Approximately 1 million Olympic swimming pools



Electrical Energy – Global Production

- In 2016, the global amount of electrical energy used was approximately 2×10^{16} Watt-hours
 - A typical electric vehicle has a motor with a power rating of about 150kW
 - Driving the car one hour a day for a year uses about 5.5×10^7 Watt-hours

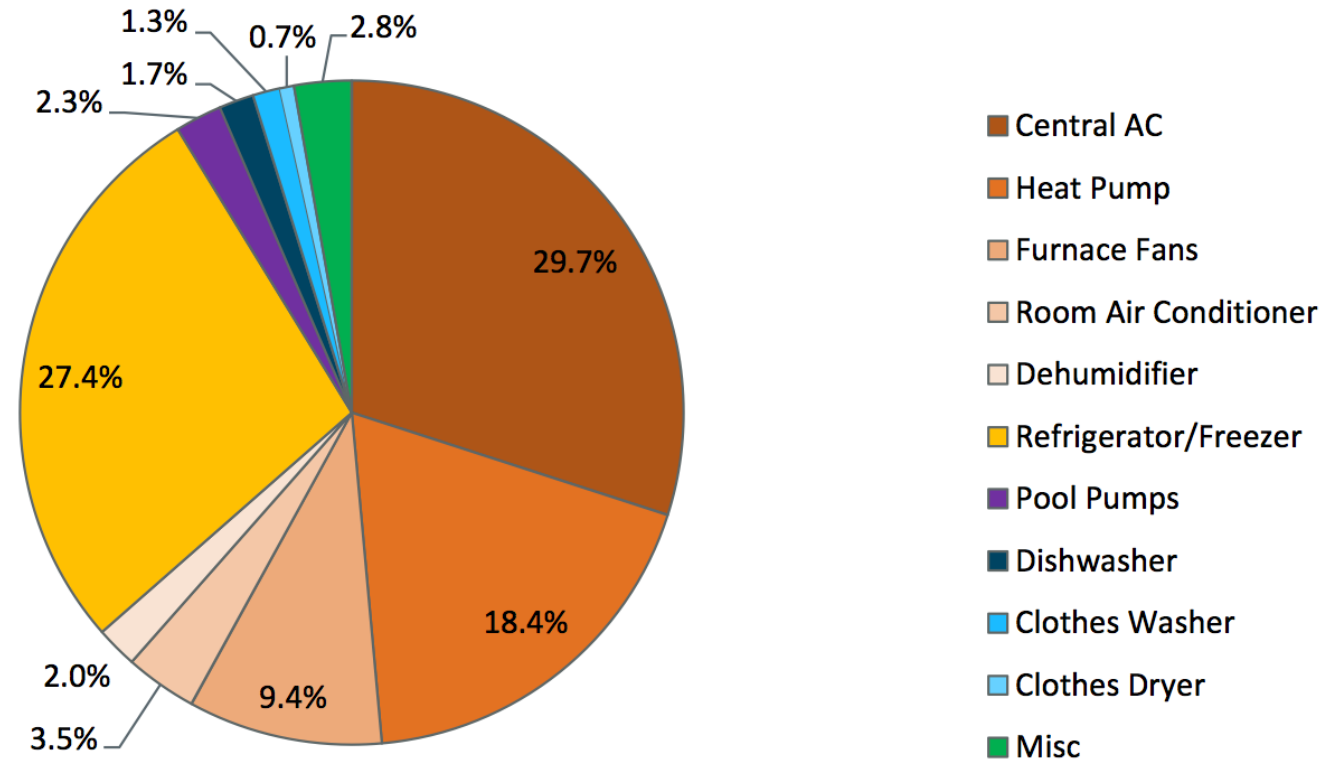
The world's electricity consumption is equivalent to about 400 million vehicles being driven for 1 hour per day...

*there are actually about 1 billion motor vehicles in the world
There are about 2 million electric vehicles world-wide...*

To go to fully electric transportation will more than tripling the world's electrical energy production.



Residential Motor-Driven energy distribution = 1.3×10^{12} KWh

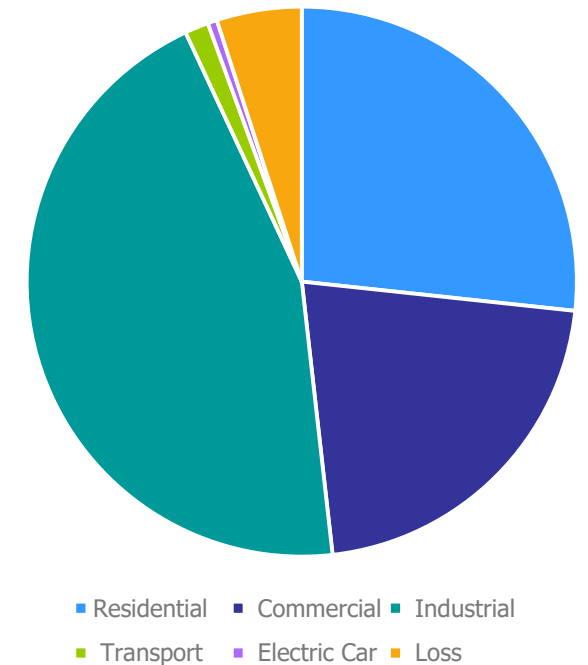


Total Residential Motor-Driven Primary Energy = 4.73 Quads

December 2013

Energy Conversion

- Transformers, motors can have efficiencies greater than 90%..
- The losses are between 2% and 10%
- With an efficiency of 95% the lost energy per year is enough to power 10 times the number of electric vehicles that currently exist!
- A gain of 1% in overall efficiency of electrical energy conversion and usage would allow doubling of the number of electric vehicles in the world without increasing energy production...

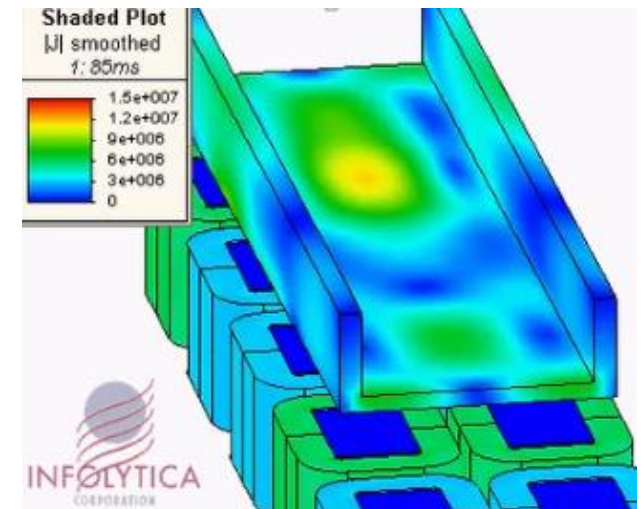
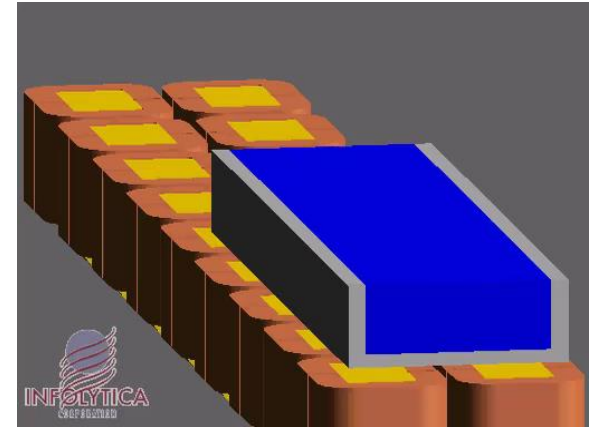


Electromagnetic Applications



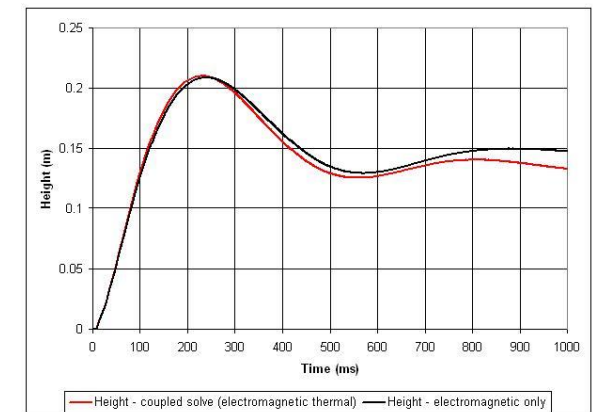
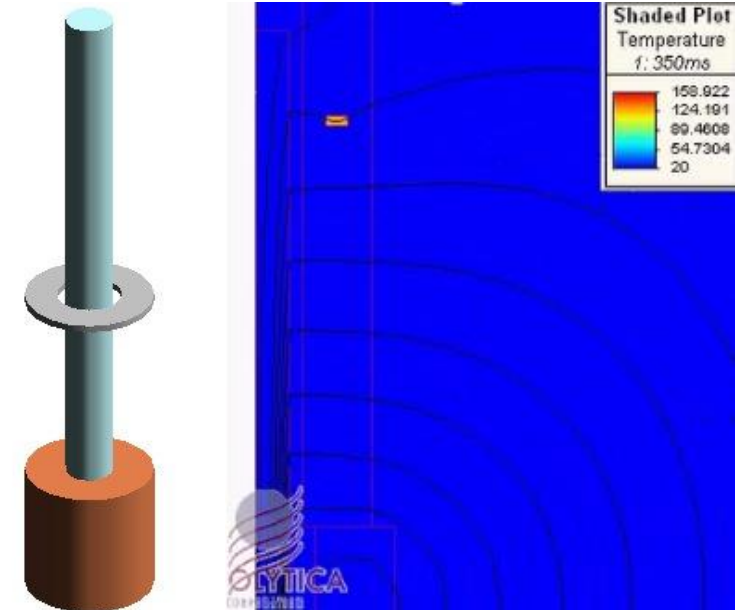
Electromagnetic Analysis Tools

- Existing electromagnetic analysis tools from Infolytica can perform extremely detailed and complex 3-d analyses
- Material properties are non-linear and temperature dependent
- Coupling to the mechanical performance is included

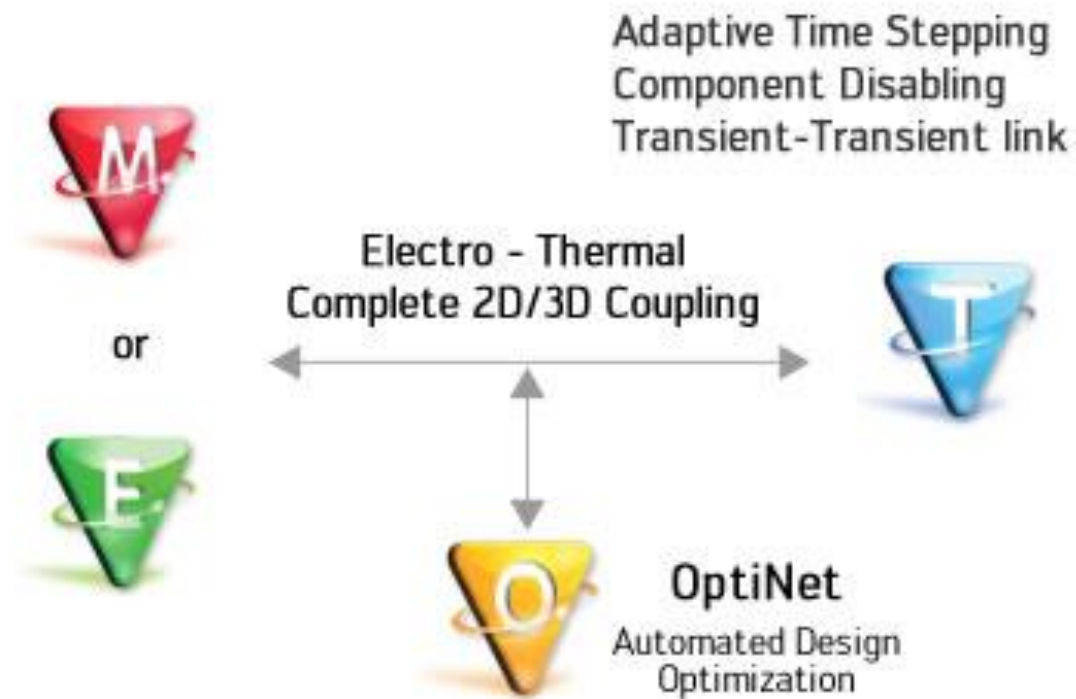


Electromagnetic Analysis Tools

- Electromagnetic devices are rarely single-physics problems
 - The devices use an electromagnetic field as an energy transfer mechanism
 - To and from mechanical, i.e. force and torque production
 - To thermal – e.g. induction heating
- Analyzing a device requires a coupled solution
 - In an electric motor, thermal performance prediction is crucial



Electromagnetic Multi-Physics



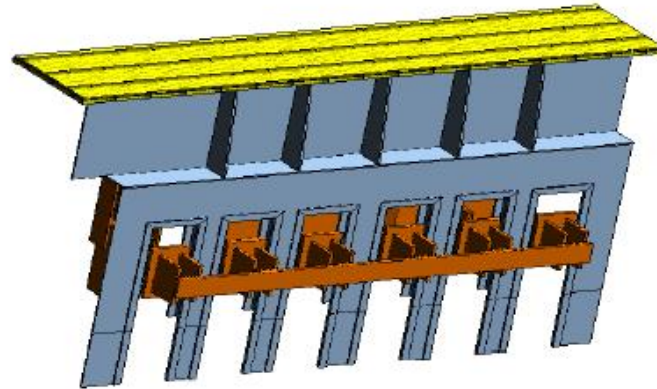
General Purpose

Electromagnetic Centric

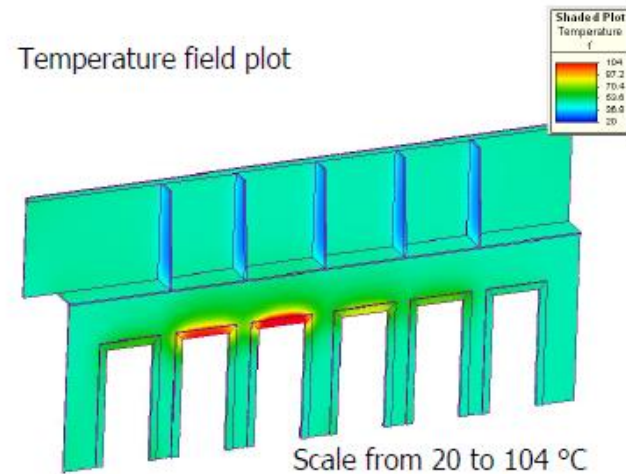
Thermal Predictions for a 50MVA Transformer

4. Results

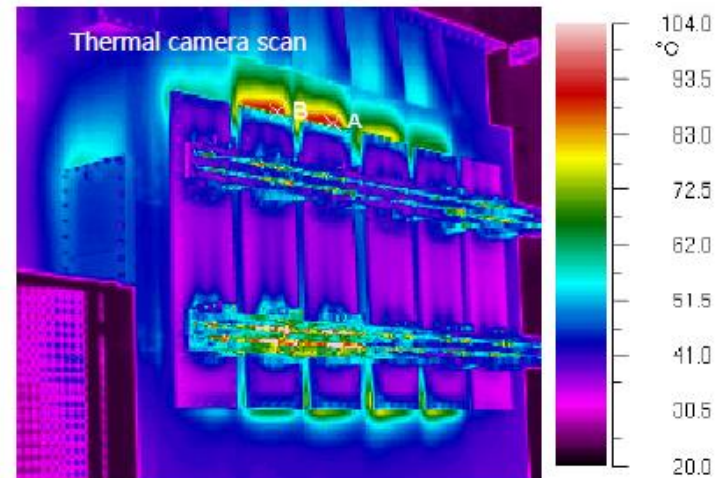
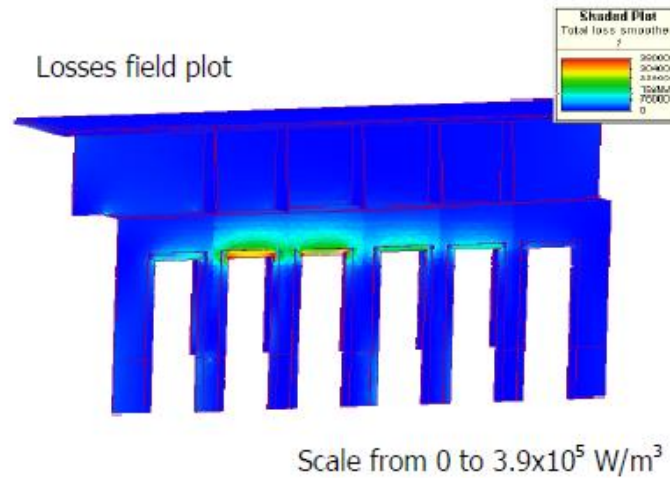
3D geometry



Temperature field plot



Losses field plot



Electric Motors and Generators

- Electric motors for an extremely large subclass of low frequency electromagnetic devices
- The majority of the world's electrical energy is produced and used in them
- A complex, multi-physics exercise
 - Electric motors use electromagnetic fields primarily to generate mechanical force
 - Effects to be minimized include
 - Heating – can cause winding and insulation failure
 - Vibration – can cause mechanical failures, insulation issues, etc.
 - Noise – an environmental problem

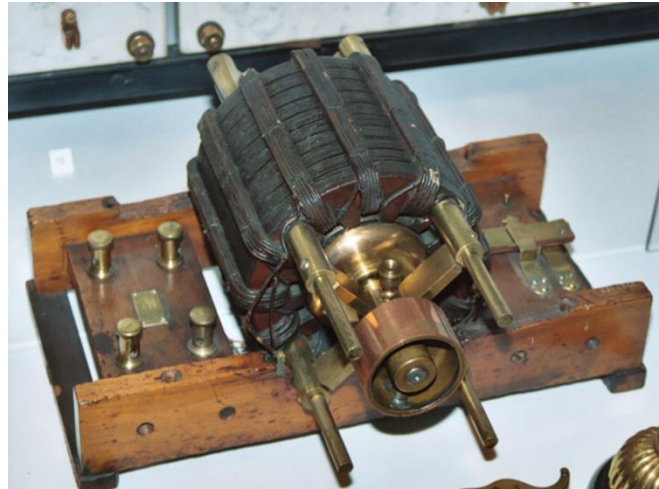
Designing Electric Motors

The objectives of design have continuously pushed towards smaller frame sizes with:

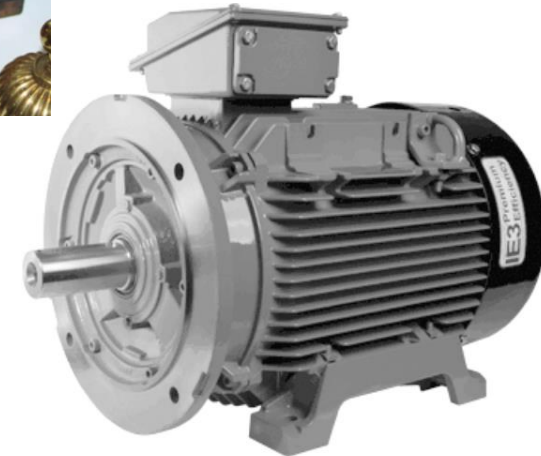
- More output power
- Longer life
- Higher efficiency
- Lower costs

This has been achieved through:

- Improved material performance
- Improved manufacturing techniques
- Continual advances in design methodologies and tools

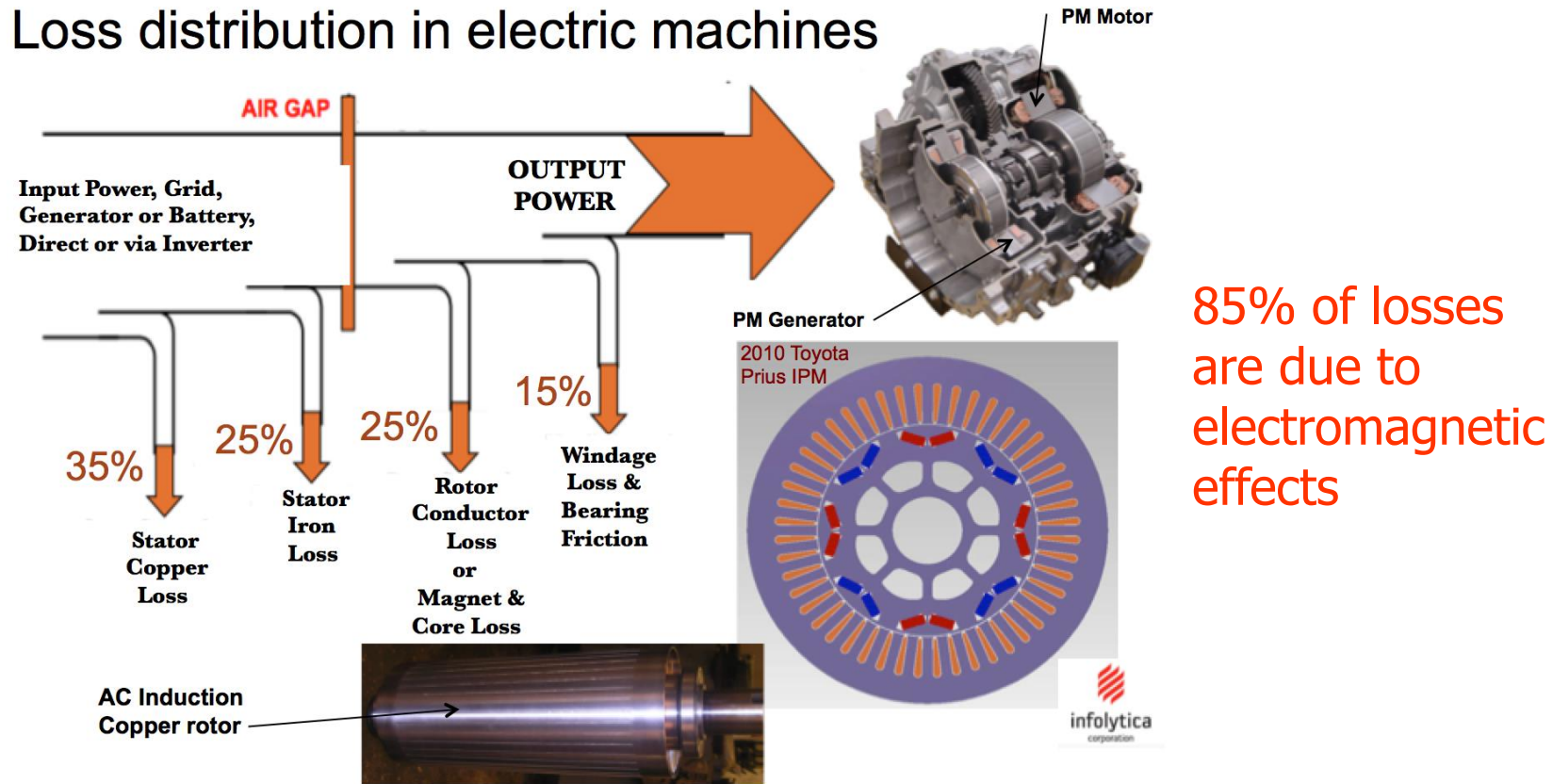


Demonstrated
at 1888 lecture



Loss Estimation is Critical

Loss distribution in electric machines



Courtesy of J. Hendershot

How can Efficiency be Improved?

- Reduce the losses in the electrical steel
- Reduce the length of the end turns on the stator
- Improve the slot fill – larger gauge wire
- Use high energy magnets in permanent magnet synchronous machines
- Improve the cooling in the motor
- Use inverter fed three-phase machines

The Infolytica Tool Set

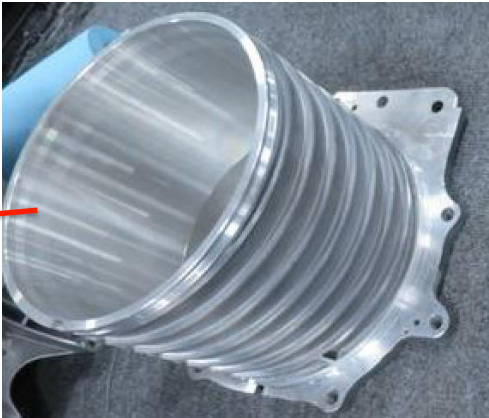
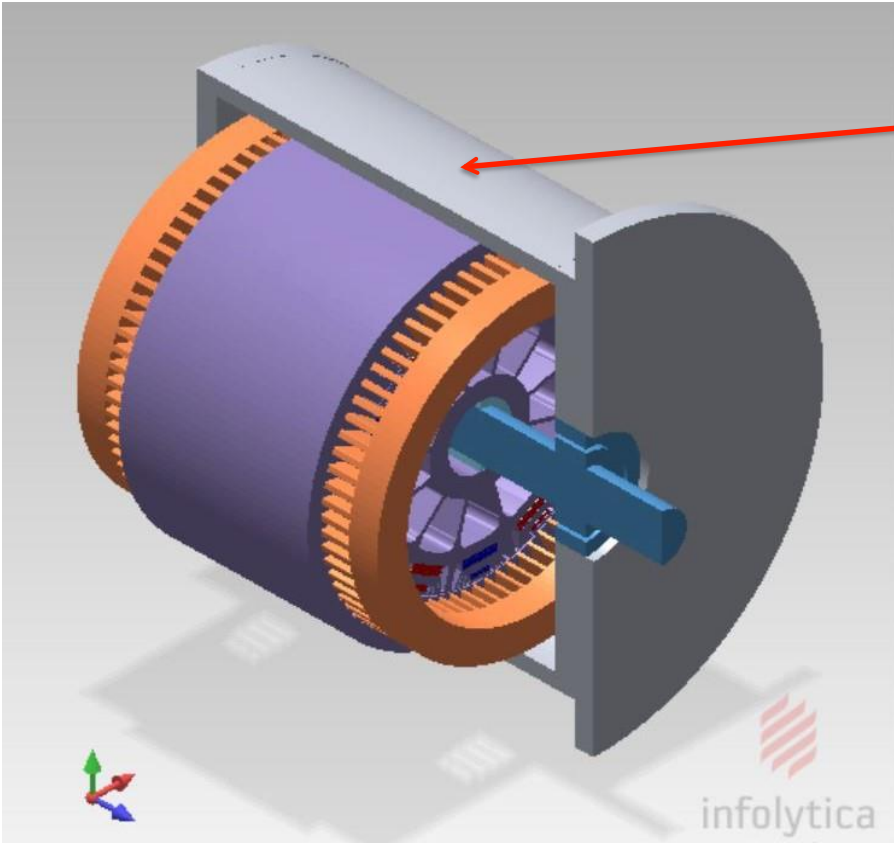
- Infolytica provides advanced tools for motor design and analysis
 - All the tools implement advanced material models for magnetic and thermal performance as well as loss estimation
 - All the tools can provide detailed electromagnetic field distributions
 - Coupled, multi-physics simulations can be implemented for thermal, structural, vibration and noise estimation
 - Optimization of a design can be achieved automatically
 - ...

Electrical Machines are a Well Defined Application

- The design of an electrical machine needs to consider a true multi-physics solution.
- This is extremely complex but, at a minimum, the drive, electromagnetic and thermal performance needs to be considered
- Machine topology is well defined and can be handled by templates
- MotorSolve implements a template based electrical machine design process.

Typical Motor – BMW i3

Active Magnetic Materials



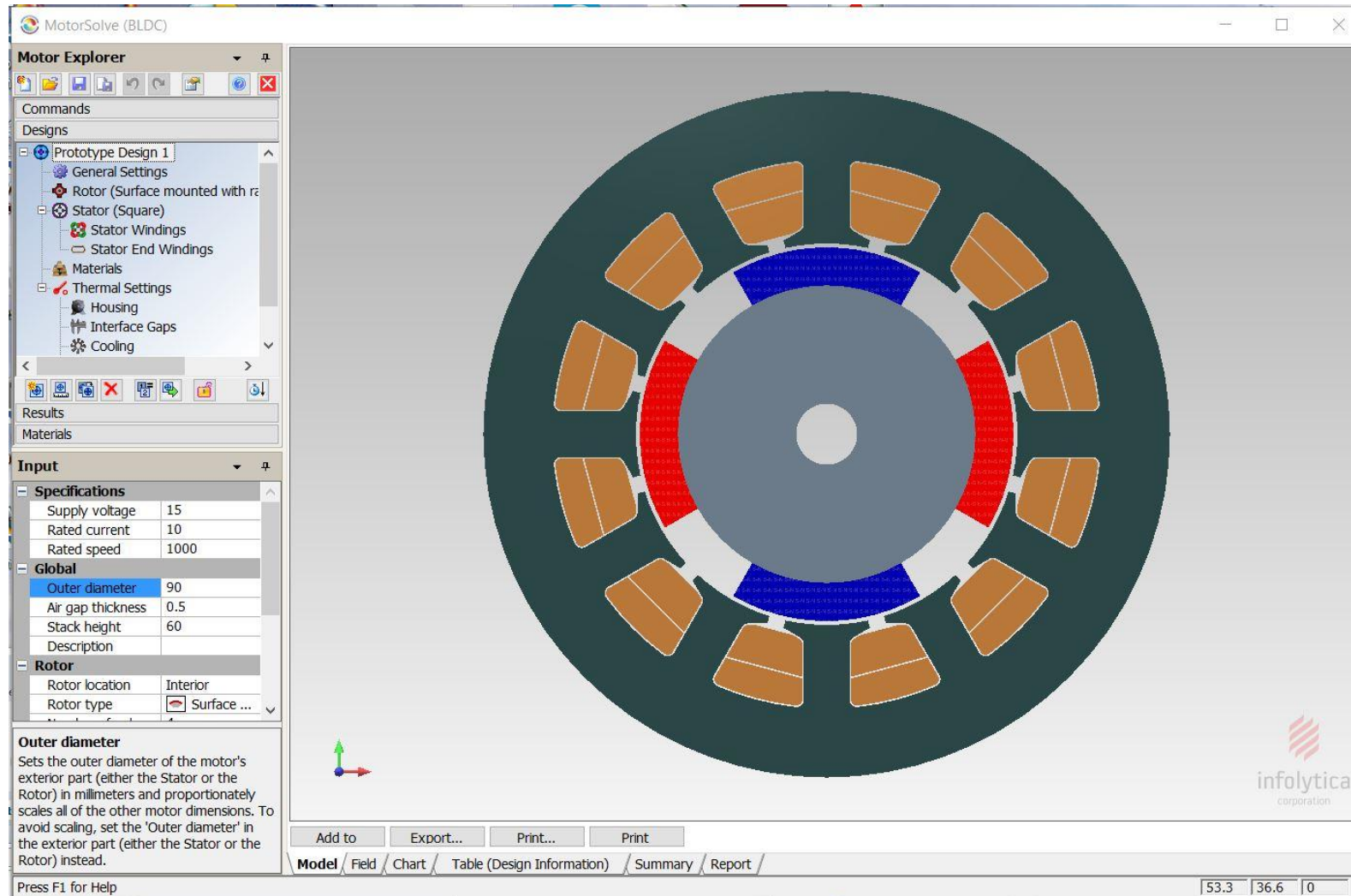
Aluminum liquid cooling housing

Rotor core material	M-19 29 Ga
Rotor magnet material	Neodymium Iron Boron: 38/23
Sleeve material	304 Stainless steel
Rotor stacking factor	1
Rotor permeability adjustment factor	1
Magnet strength adjustment factor	1
Rotor eddy current loss adjustment factor	1
Rotor iron loss adjustment factor	1
Stator Materials	
Stator back iron material	M-19 29 Ga
Stator tooth material	M-19 29 Ga
Stator coil material	Copper: 100% IACS
Stator slot liner material	Epoxy resin
Stator stacking factor	1
Stator permeability adjustment factor	1
Stator iron loss adjustment factor	1
Shaft & Hub Materials	
Shaft material	CR10: Cold rolled 1010 steel
Hub material	Non-magnetic

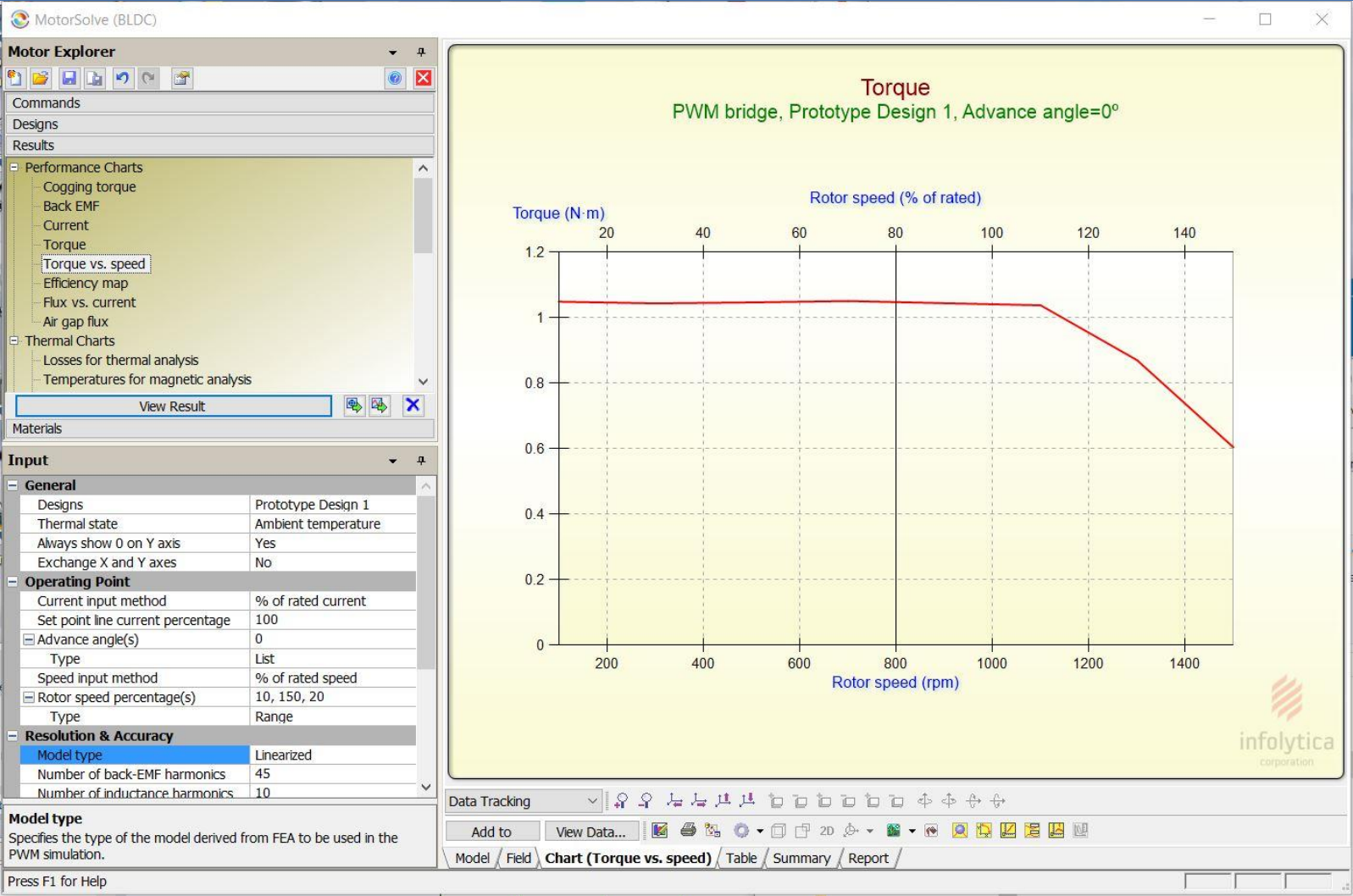
Typical Motor Design Targets

- Specified maximum volume
- Particular torque-speed curve
- Supply voltage
- Maximum current – cooling regime
- Efficiency
- L_d/L_q , L_q/L_d ratios
- Drive waveform
- ...

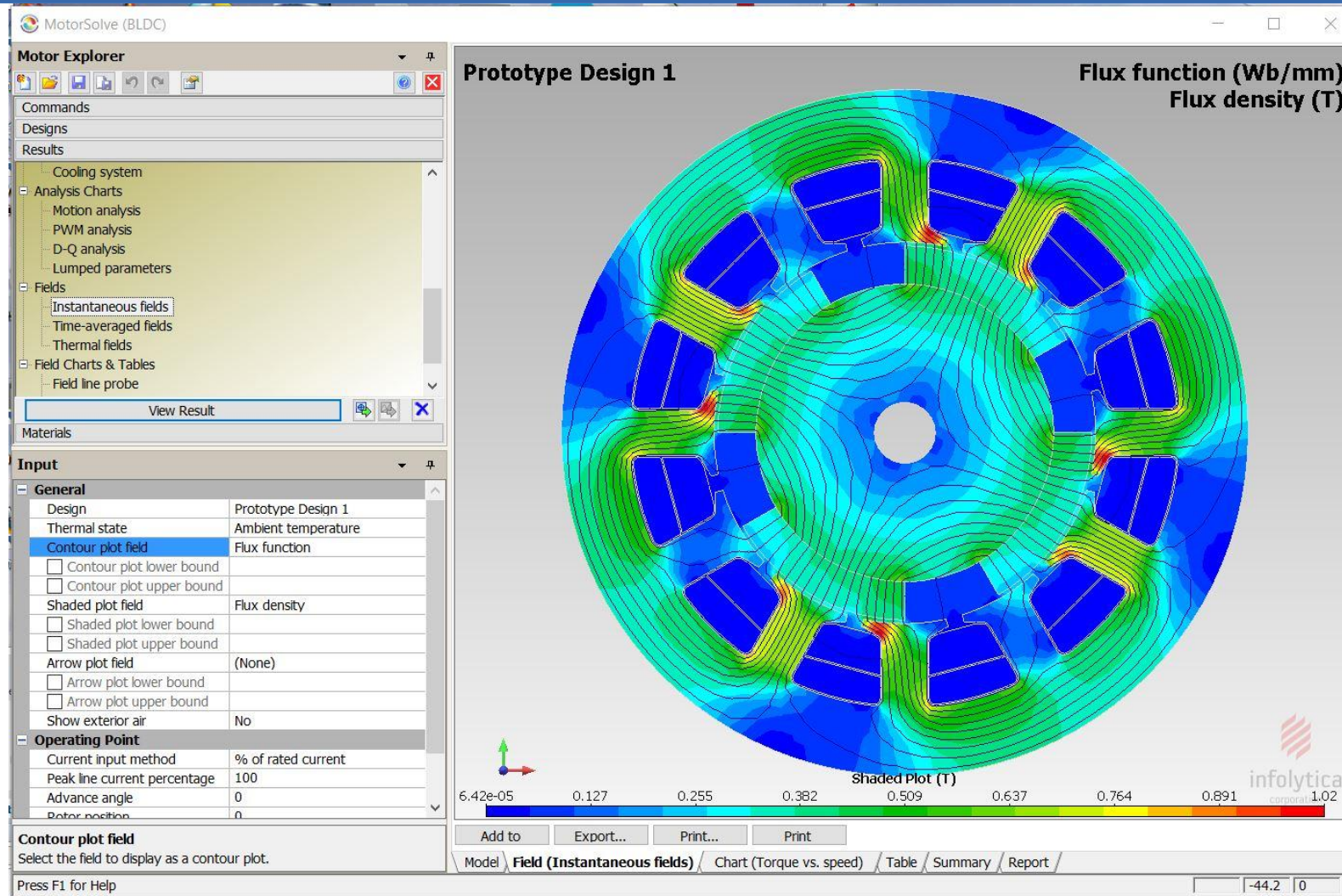
MotorSolve



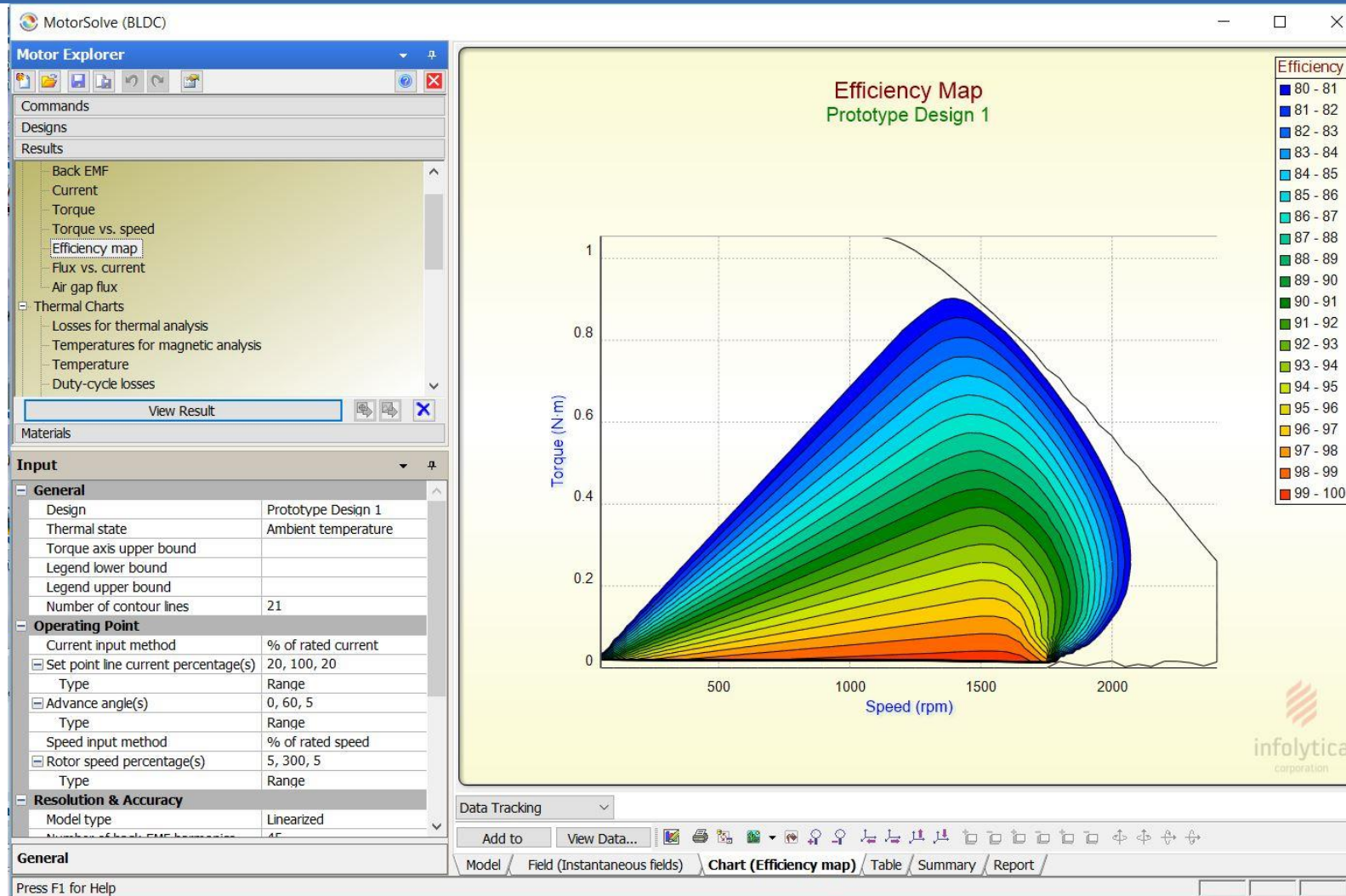
Torque-Speed Curve



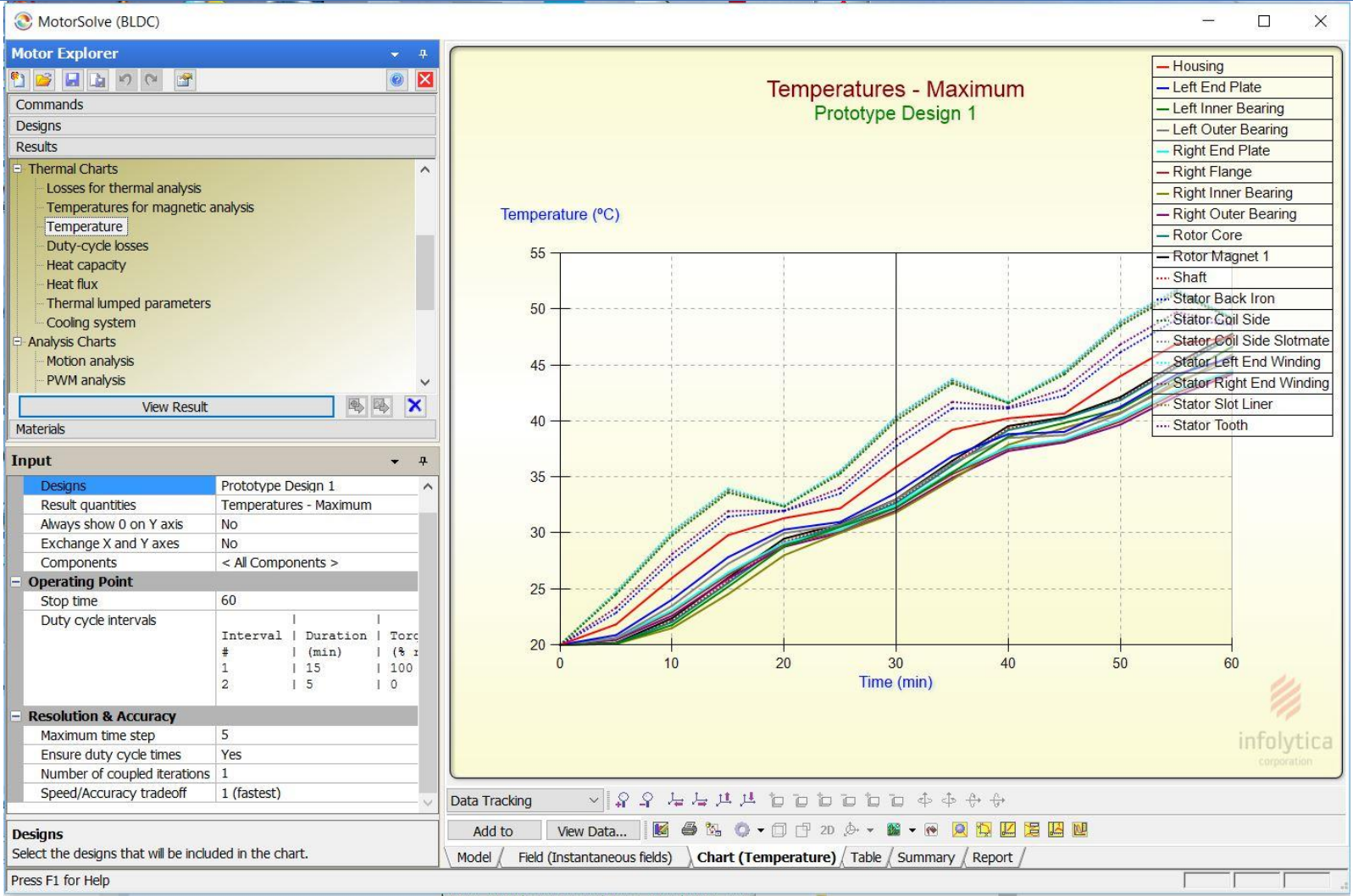
Field Distribution



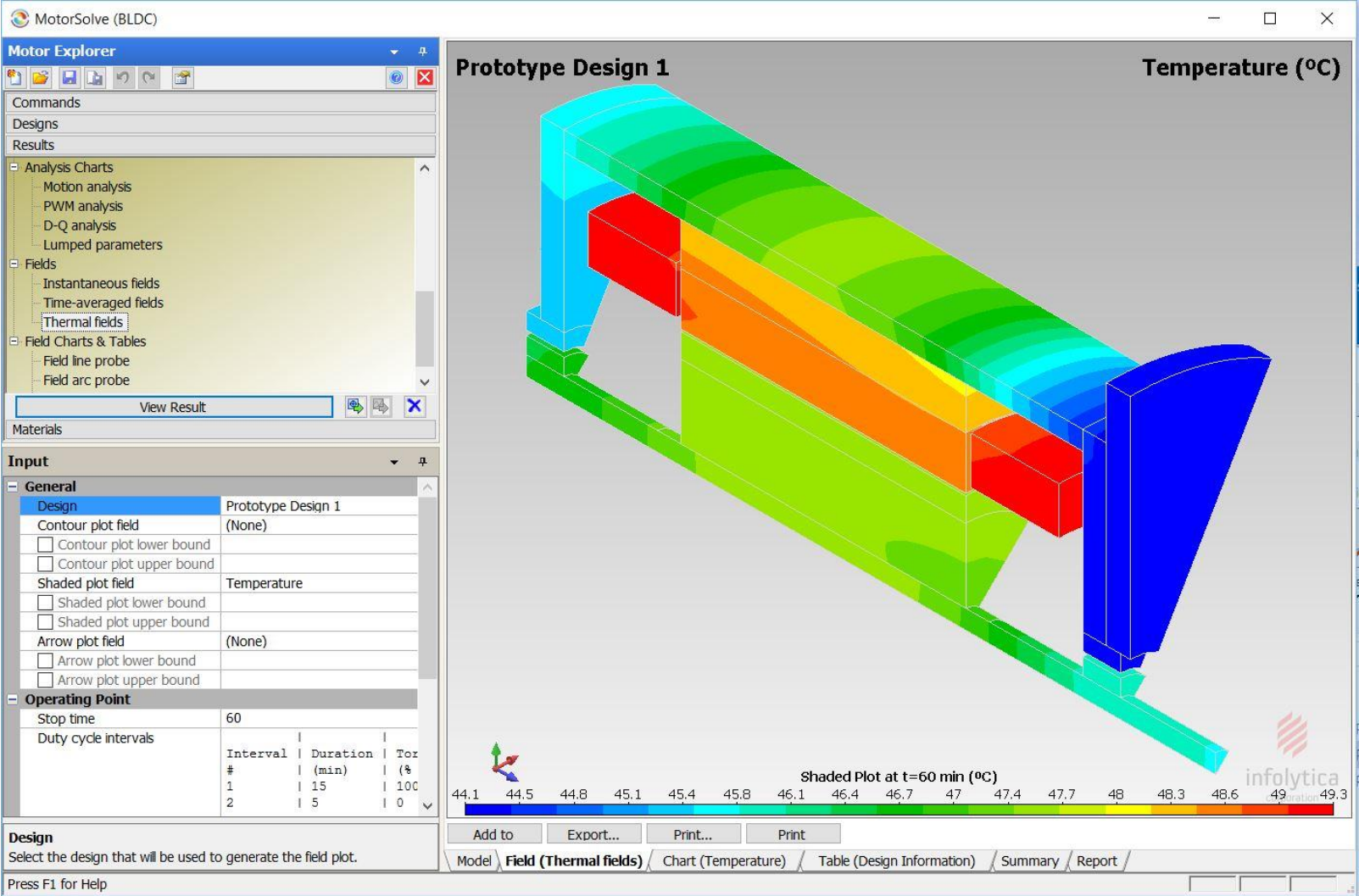
Efficiency Map



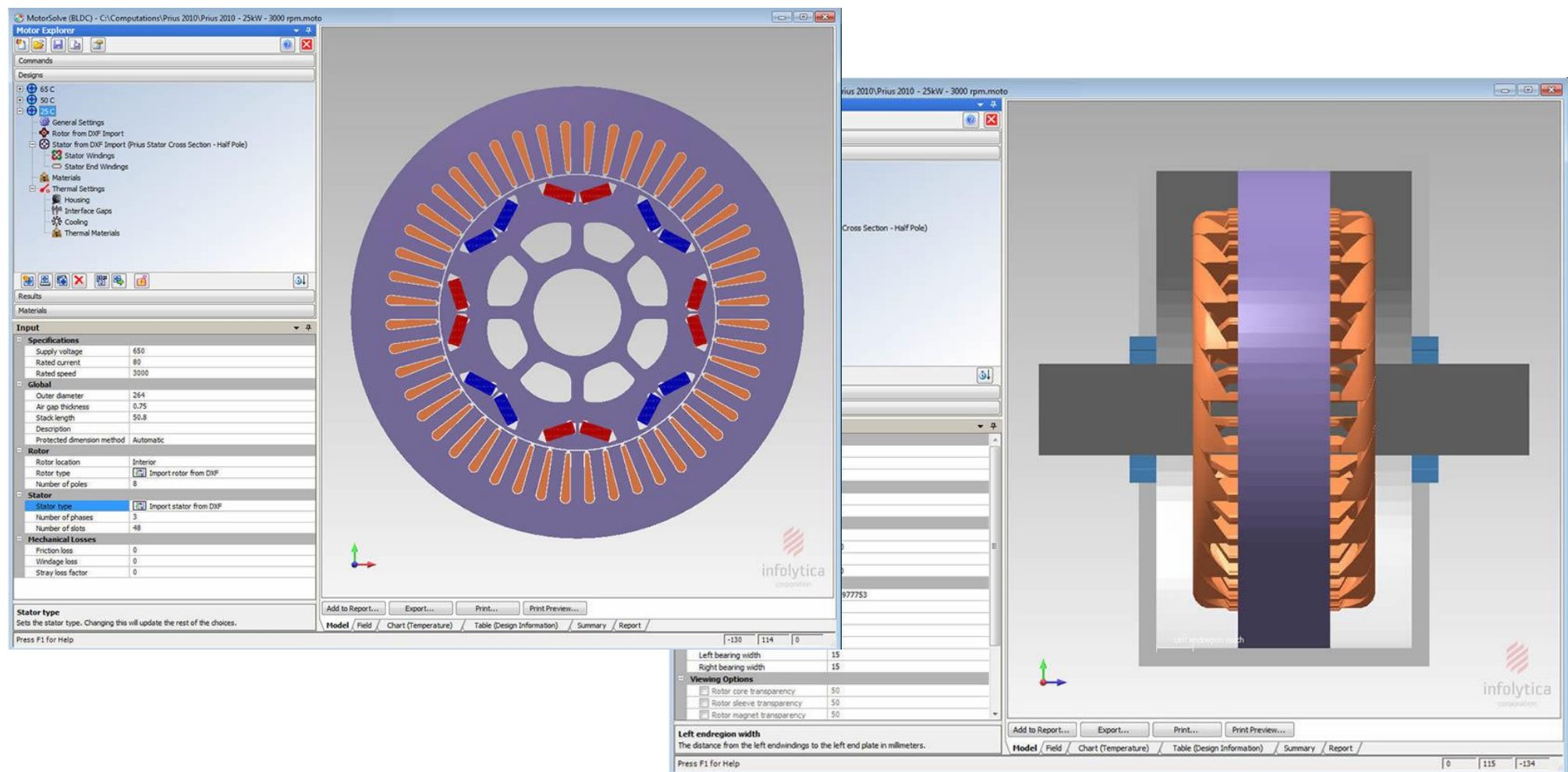
Temperature Distribution



Thermal Field

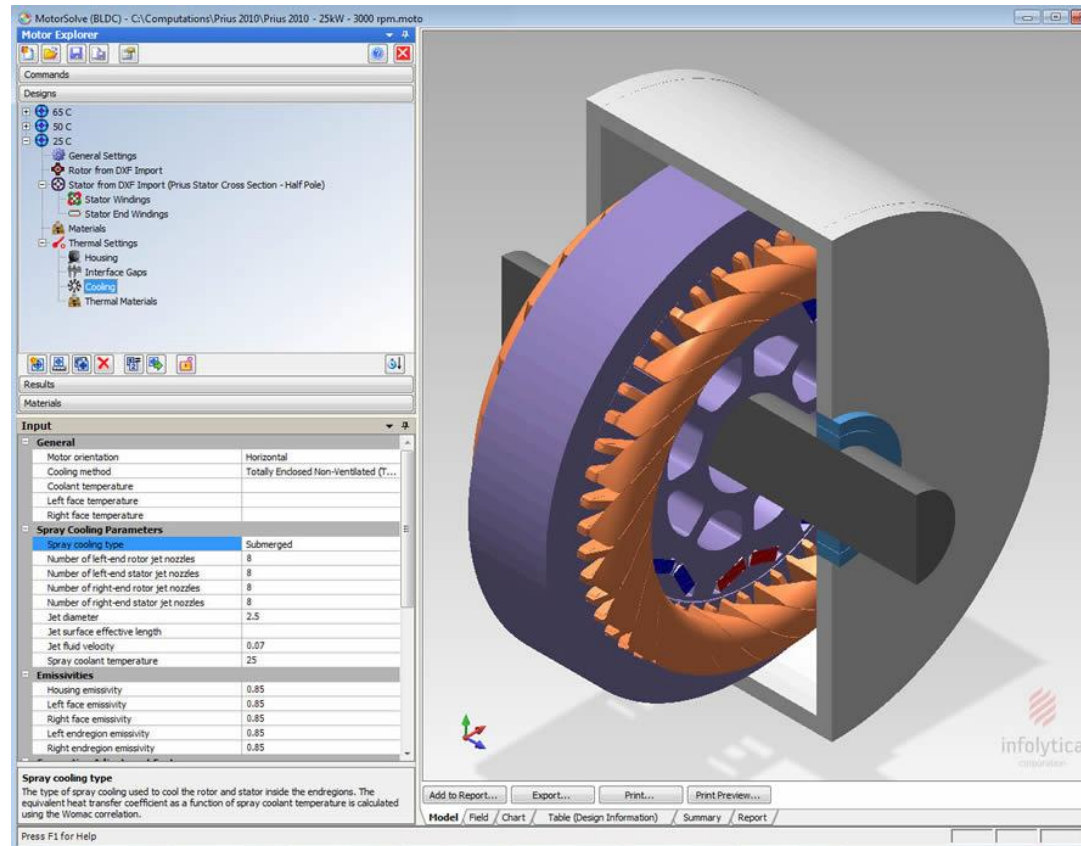


Thermal Example – Prius 2010 Motor



Example – Prius 2010 Motor

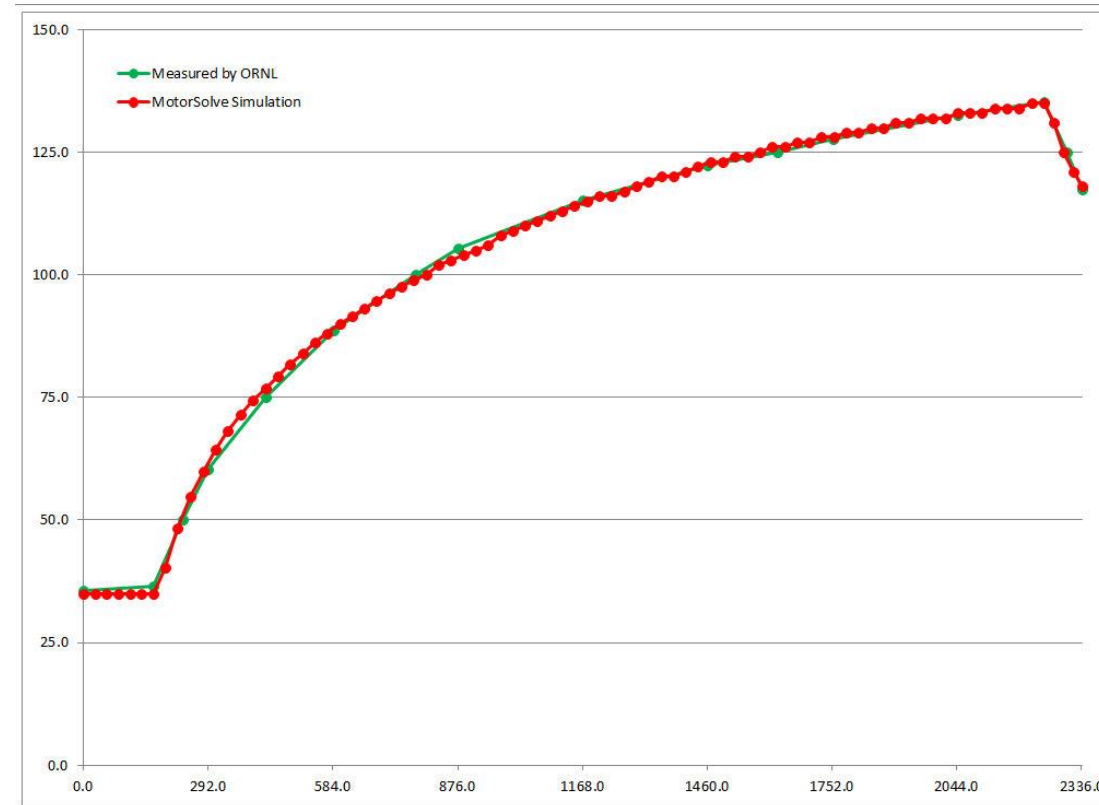
This is a spray cooled motor so add in the cooling design



Example – Prius 2010 Motor

The motor was measured by Oak Ridge National Laboratory and the details published

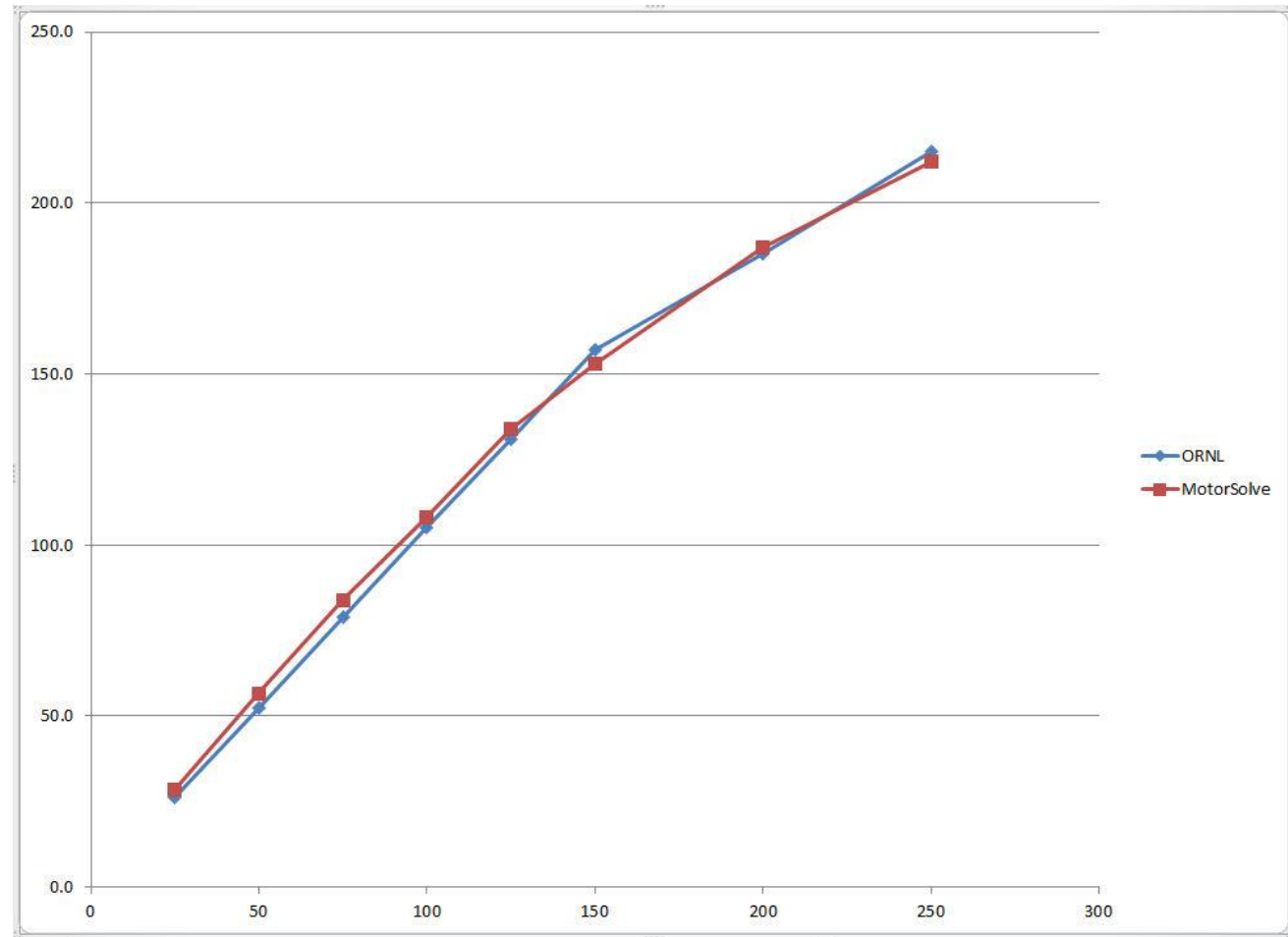
The figure shows the comparison of the measured temperatures over time and the temperatures computed from MotorSolve



Example – Prius 2010 Motor

Torque versus current.

ORNL results compared
with MotorSolve
predictions



MotorSolve

- MotorSolve provides a dedicated electrical machine environment which allows a designer to explore the solution space
- It provides fully coupled drive-electromagnetic-mechanical-thermal simulations
- It can be setup to explore the parameter space for a solution and automatically produce a report on the results
- It can reduce the time to market of a new design as well as lowering the overall costs of the design

Mentor Graphics and Siemens

■ Why Mentor?

- Over the past 10 years, Infolytica has worked with engineers at Mentor to develop links with the SystemVision product – allowing system and, in particular, drive simulation.
- More recently, we developed a link between MotorSolve and FlowMaster to demonstrate a prototype system for modeling the heat transfer issues in an electric vehicle.
- Mentor has been developing mechanical analysis capabilities (through their MAD division)
- When Infolytica was approached by Mentor it seemed a natural fit.

Mentor Graphics and Siemens

■ Why Mentor?

- Many of Infolytica's customers are also customers of Mentor
- The capabilities of the two companies is complementary
- In the process of discussions with Mentor, Siemens acquired Mentor Graphics
- Siemens added even more capability in multi-physics analysis with the NX-Nastran products and the recent acquisition of CD-Adapco provided advanced CFD capabilities.

Summary

- Infolytica provides leading edge electromagnetic design tools
- Electric machines are appearing in diverse applications from electric vehicles to robots
- Electromagnetic systems exist in devices from computer disks to medical imaging and in a vast range of sensing systems.
- Infolytica tools can be used for all of these.
- Through the acquisition by Mentor, more complete multi-physics simulations of electromagnetic devices has become possible.