Multi-physics electric motor simulation workflow

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CADFEM Ireland 13th October 2017
Overview

- Introduction to Motor Design Ltd
- Motor-CAD software
  - Electromagnetic, Thermal, efficiency mapping & drive cycle analysis
  - Application examples
- Links to Ansys
- Link to OptiSlang
- E-motor analysis using Ansys – Jens Otto
Motor Design Ltd (MDL)

Motor-CAD Software
- Develop Motor-CAD software for electric motor design
- High level of customer support and engineering know-how
- Motor design software is developed by motor engineers

Consultancy
- Design, analysis & training.

Research
- Involved in collaborative government/EU funded research projects:
  - **Concept_e** – Prototype Electric vehicle development with Jaguar Land Rover (JLR)
  - **HVEMS** – High Volume E-Machines Manufacturing Supply. Make-Like-Production prototyping facility in the UK with JLR
  - **Tevva** – Design of SRM motors for Trucks
  - **ReFreeDrive** – Rare Earth Traction motors with improved performance and lower cost (Induction and Reluctance Motors)
  - **ELETAD** – Helicopter electric tail rotor
- Collaborate with Universities worldwide to develop electric machine modelling techniques and create validation data.
Motor Design Ltd (MDL) – Strategic Partnerships

- ANSYS
  - Motor-CAD links to ANSYS software (Maxwell, Mechanical, Fluent)

- Dynardo
  - Couples with OptiSlang to provide cutting-edge optimisation workflow

- Romax
  - Motor-CAD links to Romax designer software (Transmission Integration & NVH)
Motor-CAD Software

- Motor-CAD EMag, Therm and Lab modules are developed to enable fast and accurate analysis in one integrated software.

  - **EMag**: A fast 2D finite element module for accurate electromagnetic and electrical performance predictions.

  - **Therm**: Combines a lumped circuit and finite element thermal calculation for optimising the cooling system of a machine.

  - **Lab**: Provides efficiency mapping and duty cycle / drive cycle transient outputs within minutes.

- Written by motor design experts in the language of the motor designers so very easy to use.

www.motor-design.com
Motor-CAD EMag

- Extensive range of parametrised templates geometries with additional flexible DXF or script based geometry definition
- Fast 2D FEA transient electromagnetic solver combined with analytical models
- Analysis of losses inc. AC winding losses & magnet eddy currents
- Standard or custom winding designs
Motor-CAD Therm

- Thermal and flow network analysis of electric motors & generators
- Network set up automatically using proven mathematics for heat transfer and air/fluid flow
- Extensive range of cooling types
- Nearly 20 years of practical manufacturing experience built in to assist quantify manufacturing issues
- Provides detailed understanding of main heat transfer paths and cooling restrictions
Cooling Types Investigated

Motor-CAD includes models for an extensive range of cooling types:

- **TENV**: Totally enclosed non-ventilated
  - natural convection from housing
- **TEFC**: Totally enclosed fan cooled
  - forced convection from housing
- **Through Ventilation**
- **TE with Internal Circulating Air**
  - Internal air circulating path
  - water jacket as heat exchanger
- **Open end-shield cooling**
- **Water Jackets**
  - axial or circumferential
- **Submersible cooling**
- **Wet Rotor & Wet Stator cooling**
- **Spray Cooling**
  - e.g. oil spray cooling of end windings
- **Direct conductor cooling**
  - e.g. Slot ducts with oil
We can calculate the steady-state or transient thermal performance.

Even long and complex transients only take a few seconds to calculate – very useful for traction motor drive cycle analysis.
Motor-CAD Integrated Thermal FEA Solver

- Motor-CAD’s integrated FEA thermal solver allows fast calibration of the winding thermal resistance network and improved visualization of the winding hotspot location.
Heat Transfer and Flow Network Analysis

- Both heat transfer and flow networks are automatically set up
- The two networks are linked
- MDL have improved correlations for such things as developing flow in the airgap and rotating duct pressure drop, etc. via a sponsored PhD

Temperature rise of fluid as it passes through the cooling system
Manufacturing Data Built into Models

- Many manufacturing uncertainties that affect temperature rise:
  - Goodness of effective interface between stator and housing
  - How well the winding is impregnated or potted
  - Leakage of air from open fin channel blown over machines
  - Cooling of the internal parts in a TENV and TEFC machine
  - Heat transfer through the bearings ... etc.

- Test program over last 20 years developing data to quantify such issues:
  - Set default parameters in Motor-CAD giving good level of accuracy without the user having done extensive calibration using testing of their own machines
  - Also automated choice of model type to give high accuracy

Equivalent interface gap that is useful to non-heat transfer specialist as easy to visualise

Interface resistance and conductance data that is suitable for thermal experts

Example of assistance given to set stator lamination to housing interface thermal resistance
Motor-CAD Lab: Virtual Testing Laboratory

Virtual testing including fast calculation of Efficiency Maps/Losses and Duty Cycle Analysis

- Facilitates very fast and accurate calculation of the motor electromagnetic and thermal performance over the full torque/speed envelope by use of intelligent loss algorithms
- Suited to applications such as traction applications that have complex duty cycle loads
- Automated calculation of optimum phase advance angle for maximum torque/amp or maximum efficiency control

Efficiency map with drive cycle overlaid

Loss v Time calculated from efficiency map to be input into thermal model

Temperature v Time for a particular drive cycle

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Motor-CAD Lab: FEA Mapping Model

- Flux linkage and losses calculated using FEA method at limited number of current and phase advance values with interpolation to give fast efficiency and loss map calculation.
- Gives an accurate calculation of the iron and magnet losses over the full torque/speed graph.
Co-simulation between electromagnetic model (via efficiency and loss maps) with thermal model gives a quick and accurate prediction of the continuous torque envelope.

- Maximum torque at different speeds for a limited winding and rotor temperature.
- We can also calculate the peak torque envelope.
- Thermal transient for a set amount of time that gives a certain maximum winding temperature.
- Useful to compare one motor design against another or to show the benefits of design changes like improved slot insulation material.
Many Possible Motor Design Configurations

- Many motor types and topologies have been developed recently:
  - As seen by the wide range of EV traction motor designs on the market
- Motor-CAD easy to use interface and fast calculation times are very useful for designers to evaluate different motor design concepts
Performance Prediction for Tesla Model S Motor

- Data from teardown analysis of the Tesla Model S electric motor
- Copper rotor induction motor with potted end windings and water cooled stator and rotor

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Performance Prediction for Nissan LEAF Motor

- Using published teardown data for Nissan LEAF motor
- Developed models to validate & demonstrate software tools for modelling traction applications

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Performance Prediction for Nissan LEAF Motor

- Predicted efficiency map validated by test data
- Thermal model validated by 50kW, 60kW, 70kW, 80kW thermal transient test data

Fig. 15. Nissan LEAF continuous test at 7,000 rpm.
Drive Cycle Prediction (Nissan LEAF)

- Prediction of efficiency map and 10 repetitive US06 Drive Cycle thermal transient in a few minutes

![Graphs showing temperature, torque, speed, and losses over time](https://www.motor-design.com)
High Performance Motorsport Motor

- High torque density motor for Motorsport

Open Circuit

On-Load

Iron Loss (On-Load)

Magnet Loss (Over One Cycle)
High Performance Motorsport Motor

- Complex cooling system with multiple cooling circuits
- Calculated efficiency map and drive cycle analysis for LeMans circuit in few mins

Fast duty cycle analysis ideal for sizing of motor for race circuit and/or size the required cooling system

Motor Speed & Torque (LeMans)

Motor Speed

Motor Torque

20 Laps of LeMans Circuit
High Performance Motorsport Motor

- High torque density motor for Motorsport
- Used in Ariel Hipercar

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Product Development Workflow

- Workflow much larger topic area than detailed motor design
- Motor-CAD useful for all areas of the workflow and not just detailed design
- Motor-CAD used by both motor designers and application/system/test engineers
- Automated links to other software (ANSYS Mechanical, Matlab Simulink, Optimisation) useful to speed up the workflow
Motor-CAD Links to ANSYS & Dynardo Software
Example customer workflow

- Marc Brück
- EM-motive a Bosch + Daimler Company
Motor-CAD EMag – Maxwell Links

- All the information required to make a calculation in Maxwell is passed from Motor-CAD.
- Geometry, material properties, excitations and boundary conditions are automatically set-up.

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Motor-CAD Lab: Links to Maxwell

- Electromagnetic data can be imported from Maxwell to create efficiency maps and calculate performance over duty cycles.
Motor-CAD 3D Links to ANSYS Tools

- Motor-CAD 3D Geometry exported into ANSYS workbench through Design Modeler
Motor-CAD and Fluent

• Motor-CAD and Fluent CFD complement each other
• In Motor-CAD it is fast to create models and solve
• CFD is more time consuming to construct models and make calculations
• Useful to filter designs using Motor-CAD and do CFD on final candidate
• Then use results to calibrate Motor-CAD convection & flow formulations
• Assistance in CFD model setup using links to Motor-CAD being developed
  • Speed up the creation of CFD models
Detailed flow modelling using Fluent CFD can be used to validate/calibrate the convective cooling around the end-windings due to air movement induced by rotation.
Motor-CAD/Fluent Calibration Example

- Fluent CFD can be used to study the water jacket heat transfer & pressure drop in great detail and used to validate/calibrate the correlation models used in Motor-CAD.
Motor-CAD – Icepak Links

- Automatically pass the thermal resistance network from Motor-CAD to Icepak for the main body of the machine
- Solve the main body of the motor in Icepak as a thermal resistance network and the housing cooling system as a CFD problem
- Allows extremely fast combined lumped circuit/CFD simulations times
Integration with ANSYS Software for Magnetic and Thermal Sizing

Automated links to ANSYS multi-physics environment being developed to simplify and speed up sophisticated design calculations

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Motor-CAD – OptiSlang Coupling

- OptiSlang is a robust design optimisation platform that offers sensitivity analysis, optimization, and robustness evaluation.

- Previous state-of-the-art electric motor design optimisation techniques focus on only analysis of machines at single operating points and usually only account for electromagnetic operation.

- This coupling will allow the full power of Motor-CAD to be used in an optimisation procedure.

- This will include peak performance, continuous performance, and drive cycle analysis to be included in the cost or constraint functions.

http://www.proteanelectric.com/specifications/
Motor-CAD – OptiSLang Coupling
Motor Design Software by Motor Design Engineers

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