E-Motor Modeling: from pre-design to Fine Design including NVH Analysis, Thermal Analysis, System Analysis and with Optimisation

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HyperWorks Core Development
Outline

• Introduction
• System Analysis
• Pre-design
• Fine tune Design
• NVH Analysis
• CFD Analysis
• Optimization
• Conclusion
Introduction

• Electric motors are everywhere:
  • Cell phone vibrating
  • Hard disk drives
  • Mixers
  • Electric cars
  • Robots

• More and more constraints
  • Cost
  • Efficiency (new rules imposed by regulator : IE3, NEMA Premium…)
  • Low weight for transportation (bikes, automobile, train, aerospace)
  • New needs for new applications (drone, robots, cobots, IoT…)

• Change is dramatically fast
• Need of new tools and new methods
Introduction

• How to improve motors?
  • Magnet with higher energy, and better withstanding temperature
  • Decrease iron losses (new material, new topology, less flux density, …)
  • New insulation material
  • New components for electronic (SIC and Gan technology)
  • High speed
  • Fractionnal slot concentrated winding
  • Better interaction with system
  • …

• Reducing lead times with tools and processes
Typical Electric Motor Design Workflow

Complexity
Cost
Know-how

SIMULATION-DRIVEN DESIGN

Compose – Scientific computations
Activate – System simulation
FluxMotor
Flux 2D
Flux 3D
Magneto-thermal in Flux

CAE

HyperStudy
OptiStruct
AcuSolve

Accurarcy

Analytical Computation
Pre-design software
2D FEA
3D FEA
Multi-Physics

CAD

Drawings

Project documentation
System Modeling

• The motor is embedded in a device, it has to communicate with it!
  • To get instructions of command
  • To have feedback from the motor
  • For health monitoring of the motor
System Modeling

- **SolidThinking/Compose**
  - System level

- **SolidThinking/Activate**
  - Allow including equivalent circuit motors)
  - Allow the use of tables
  - Or cosimulate with Flux 2D/SKEW/3D

- **SolidThinking/ Embed**
  - Real-time simulation directly accessible

- **Test nominal scenario including all components**
  - Battery
  - Mechanical constraints
  - Motor consumption,
Typical Electric Motor Design Workflow

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- Cost
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**SIMULATION-DRIVEN DESIGN**

- Flux 2D
- FluxMotor
- Activate – System simulation
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**CAD**

- CAD Drawings
- Analytical Computation
- Pre-design software
- 2D FEA
- 3D FEA
- Multi-Physics
- Project documentation

Accuracy
Analytical Computation

• For each type of motor dedicated formula
• Often available in Excel format, Matlab, Compose or proprietary code

• Advantage
  • Very good correlation (due to X factor coming from experience)
  • All input data are well known

• Disadvantage
  • Limited to one type of motor
  • Experts are retiring
FluxMotor : A New Tool for Electric Machine Design

For machine designers and integrators

A dedicated tool
  - **Customizable templates**
  - Winding tool
  - **Easy to use**

Fast and accurate
  - Mixed analytical/FE based calculations
  - Embedded modeling knowledge

High productivity
FluxMotor: Checking with Prius 2004

- Old design, and easy to compare to measurement
- All results in less than half an hour

Efficiency with torque/speed curve
Typical Electric Motor Design Workflow

- **Complexity**
  - Cost
  - Know-how

- **Accuracy**
  - Analytical Computation
  - Pre-design software
  - 2D FEA
  - 3D FEA
  - Multi-Physics

- **Simulations**
  - FluxMotor
  - Activate – System simulation
  - Compose – Scientific computations

- **CAE**
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- **CAD**
  - Drawings
  - Project documentation
FEA Analysis

Accurate
- Fast and **accurate** solver
- Best-in-class modeling methods
- Efficient modeling of complex situations

Flexible
- Adjusted to the user needs
- Wide application coverage
- Customization & Automation

Connected
- CAD connection
- Coupled to system simulation
- Coupled to the best tools for multiphysics analysis

Parametric
- **Fully parameterized** models
- Embedded and easy to use
- Distribution of computation
Flux: Prius Example

- Simulate default conditions
  - Short-circuit test
  - Winding short-circuit strand
  - Excentricicites

- Compute accurately efficiency or characteristics of the motor
  - Compute losses in the motor due to supply (PWM)
  - Check demagnetization in the magnet

- Improve the motor
  - Reduce losses in the magnet
  - Reduce torque ripples of the motor
  - Reduce space and time harmonics of the torque to reduce noise and vibration
  - Optimize the magnet weight
Typical Electric Motor Design Workflow

Complexity
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Know-how

Accuracy

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SIMULATION-DRIVEN DESIGN

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NVH Analysis: Extracting Forces from Flux to OptiStruct

- **Goal**
  - Compute displacement and vibration generated from forces applied on stator
  - Avoid resonance issue due to the structure

- **Principle**
  - Extract magnetic forces applied on stator
  - Compute harmonics
  - Use harmonics as load of the mechanical computation

- **Note:** Flux 2D, or Flux 3D can be used
NVH Analysis on Prius Model

Mode 1: 710 Hz

Mode 4: 1495 Hz
Typical Electric Motor Design Workflow

- Complexity
- Cost
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SIMULATION-DRIVEN DESIGN

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Analytical Computation
Pre-design software
2D FEA
3D FEA
Multi-Physics

Accuracy
CFD Analysis

• Goal
  • Check different cooling methods
  • Find out hot spot

• Principle
  • Flux is used to model electromagnetic components to determine static thermal loading
  • Results are provided to AcuSolve and are used to define the elements based volumetric heat load

• Today : available in one way coupling
• Soon : available in 2 ways coupling
CFD Analysis: Prius Example

- Extract losses
  - Coil
  - Magnet
  - Iron losses

Water Jacket
Typical Electric Motor Design Workflow

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**Analytical Computation**

**Pre-design software**

**2D FEA**

**3D FEA**

**Multi-Physics**

**Project documentation**
Optimization with HyperStudy

• Multi-disciplinary design exploration, study and optimization software
• Possibility to connect with other softwares
• Different types of use
  • DoE: Screening or Space filling
  • Fit: Response Surface (RS) building
  • Optimization: optimization with or without RS
  • Stochastic: Robustness analysis, Optimization taking into account uncertainties
Optimization with Flux: Prius Example

- Optimize the magnet size to reduce the magnet volume by keeping the initial performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial Design</th>
<th>Prius Design</th>
<th>HyperStudy optimum</th>
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</thead>
<tbody>
<tr>
<td>BETAM (mm)</td>
<td>120</td>
<td>140</td>
<td>120</td>
</tr>
<tr>
<td>IPMHQ (mm)</td>
<td>15</td>
<td>10</td>
<td>8</td>
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<tr>
<td>BRIDGE (mm)</td>
<td>2</td>
<td>-</td>
<td>0,5</td>
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<tr>
<td>LM (mm)</td>
<td>12</td>
<td>5</td>
<td>5,98</td>
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<tr>
<td>MAGWID (mm)</td>
<td>30</td>
<td>54</td>
<td>39,99</td>
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<tr>
<td>LWEB (mm)</td>
<td>2,75</td>
<td>2,75</td>
<td>0,5</td>
</tr>
<tr>
<td>WEB (mm)</td>
<td>10</td>
<td>10</td>
<td>10,96</td>
</tr>
<tr>
<td>TORQUE_MEAN (N.m)</td>
<td>364,98</td>
<td>390</td>
<td>390,2</td>
</tr>
<tr>
<td>Magnet surface (mm²)</td>
<td>360</td>
<td>270</td>
<td>239,14</td>
</tr>
</tbody>
</table>
Conclusion

- Altair is the right suite to model E motor
  - Use the right tool at each design stage
  - Connexion between tools allow to save time and energy
  - Get accurate results with the right tool
  - Use optimization on the whole process
Building Complete Design Workflows

**INPUTS**
- CAD Imports
  - CATIA
  - Pro / Engineer
  - IGES, IGES advanced
  - STEP, STEP advanced
  - Parasolid
  - NX
  - Solidworks
- Mesh Imports
  - NASTRAN
  - PATRAN
  - UNIV Ideas
  - MED
- HyperMesh

**SYSTEMS**
- Activate, Compose
- MATLAB Simulink™
- LMS Amesim®
- Portunus

**NVH**
- OptiStruct
- LMS Virtual.Lab
- MSC Nastran
- ANSYS Mechanical

**THERMAL**
- AcuSolve
- STAR-CCM+
- ANSYS Fluent

**MECHANICAL**
- OptiStruct

**TEMPLATES FOR MOTORS**
- FluxMotor
- Motor-CAD & SPEED import

**DRIVING FLUX**
- Python
- With API
  - C/C++ language
  - Excel / VB script

**OPTIMIZATION**
- HyperStudy
- GOT-It

**DISTRIBUTED COMPUTATION**
- CDE

**OUTPUTS**
- CAD exports
  - SAT
  - CATIA V4, V5
  - IGES
  - STEP
  - MED
- Results export
  - Excel®
  - Test
  - XML

PBS Works
Thank you for your Attention!
Thanks to Other Altairians!

- Activate: Andrew Dyer, Abdessamed Soualmi
- OptiStruct: Christophe Bailly, Girish Mudigonda, Gildas Guilly
- AcuSolve: Michael Barton
- HyperStudy: Diana Mavrudieva