Fuel Pump Motor Optimization for Noise Reduction
Multi-Physics Application

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EATC 2017

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Context

• The acoustic aspect in electrical machines is more and more taken into consideration in industry (automotive, railway,…)
• Industrials need to be able to consider the noise at the design stage (before prototyping)
• Altair HyperWorks offers an efficient solution
Introduction

• Design of a fuel pump permanent magnet motor in an airplane wing
• Reduce motor noise while maintaining the electromagnetic performances
• A multi-physics optimization application
Motivation

• Demonstrate a multi-physics design of a real-world application using Altair software:
  • **HyperStudy** for optimization
  • **Flux** for electromagnetic analysis
  • **OptiStruct** for structural analysis (HyperMesh for the preprocessing)

• Leverages
  • The automatic coupling between the Flux, OptiStruct and HyperStudy for easy set-up
  • Morphing for shape optimization
  • Global Response Surface Method for optimization
Summary

- Studied structure: Airplane wing
- Studied device: Brushless AC permanent magnet motor
- Electromagnetic analysis with Flux
- Vibro-acoustic analysis with OptiStruct
- Optimization with HyperStudy
- Results
- Conclusions
Airplane Wing

Position of Rib 3

Rib 3
Studied device
Brushless AC Permanent Magnet Motor

Fuel pump is activated by an electrical motor with the following characteristics:

- **Stator:**
  - 24 slots
  - M19 lamination
  - Stator OD = 96 mm
  - Stack length = 50 mm

- **Rotor:**
  - 4 poles
  - Surface radial NdFeB magnets
  - Rotor OD = 50 mm

Nominal speed: 3600 rpm (120 Hz)
Torque at nominal speed: 0.2Nm
Output power: 75W
Power supply: 15V / 3A
Noise Generation Process

Input currents → Electromagnetic excitation → Structure dynamic response → Noise radiation
Electromagnetic Analysis (Initial design)

- To evaluate the electromagnetic forces (loads for OS analysis)
  - Import the mechanical mesh from HyperMesh
  - Compute forces on this support
  - Export the forces for OptiStruct
Electromagnetic Analysis (Initial design)

• To evaluate the electromagnetic performances (torque, current density, saturation induction)

• Automatic post-processing using python file
Vibro-acoustic Analysis (Initial design)

• To evaluate acoustic behavior of the assembly Fuel pump / Rib03

• Only the noise emitted by the Rib03 web is considered

• FRA analysis is performed in OS using the forces extracted from Flux

• Equivalent Radiated Power (ERP) output is requested on the Rib03 web

ERP output requested on the green area
Vibro-acoustic Analysis (Initial design)

- To identify areas that generate the most noise due to vibration
- To get an idea of the main frequencies that compose the global emitted sound
Optimization Problem Definition

• The objective is to reduce ERP value by respecting 3 electromagnetic constraints
  • Mean torque $\geq 0.1888572$ N.m
  • $J_{\text{max}} \leq 2.75$ A/mm$^2$
  • $B_{\text{max}} \leq 1.6287$ T

<table>
<thead>
<tr>
<th>Definition</th>
<th>Initial</th>
<th>Min; Max</th>
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<tbody>
<tr>
<td>SD</td>
<td>Slot depth</td>
<td>6.93</td>
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<tr>
<td>SO</td>
<td>Slot opening</td>
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<tr>
<td>TGD_2</td>
<td>Slot opening angle</td>
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<tr>
<td>TGD</td>
<td>Opening depth</td>
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<td>TWS</td>
<td>Stator tooth width</td>
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<td>TORQUE_MEAN (N.m)</td>
<td>Mean torque</td>
<td>0.188857</td>
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<td>BTOOTH_MAX (T)</td>
<td>Max B on the tooth</td>
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<td>J_MAX (A/mm$^2$)</td>
<td>Max current density</td>
<td>2.75</td>
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<tr>
<td>ERP (mW)</td>
<td>Equivalent radiated power</td>
<td>61.44</td>
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</table>
Multi-physics Optimization Workflow

HyperStudy

Geometric parameters
Shape variables

Stator update in Flux

EM analysis and Forces computation

Extract EM performances

Mechanical mesh update

Stator update in HM

Frequency Response Analysis

Extract ERP
HyperStudy Optimization Setup

3 models, 5 linked variables, 6 responses
1 objective, 3 constraints, GRSM
Optimization with GRSM

- **TORQUE MEAN** \( \geq 0.1888572 \) N.m
- **BTOOTH_MAX** \( \leq 1.6287 \) T
- **\( J_{\text{max}} \)** \( \leq 2.75 \) A/mm²
- **ERP**
- **50 runs have been done in 16 hours**
Optimization converges to new values for each variable, defining new shapes for the stator geometry.

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<th>Definition</th>
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<th>Optimum</th>
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<td>TORQUE_MEAN (N.m)</td>
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<td>BTOOTH_MAX (T)</td>
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<td>J_MAX (A.mm²)</td>
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<td>ERP (mW)</td>
<td><strong>61,44</strong></td>
<td><strong>3,72</strong></td>
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</table>
ERP Comparison

• On the whole frequency range, we can observe an ERP reduction of an **average 1db**.

• And if we focus on most critical peaks, we observe a **reduction of up to 15db**!

\[ ERP(db) = 10 \cdot \log_{10}(ERP(mW)) \]
Electromagnetic Performances Comparison

- Constraints on average torque, max density and saturation induction are met
- Torque ripples are reduced
Conclusions

- A fuel pump motor design is optimized considering both electromagnetic and structural performance.
- The process is setup using Altair HyperWorks; HyperMorph, Flux, OptiStruct and HyperStudy.
- Improvements for both EM and acoustic performances by varying only stator slots dimensions.
- Potential for further improvements with additional variables such as rotor dimensions.
Thank You.