Multi-physics Motor Optimization for Noise Reduction

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Abstract

The concept of More Electric Aircraft is now pushed in the aeronautic industry to optimize aircraft performance and reduce their environmental impact. In this context, more and more electric machines are introduced in planes to replace hydraulic or pneumatic systems by electric actuation. Far for being silent, electric machines associated to their drives and the mechanical systems connected to their shafts generate vibrations and noise nuisance.

In an electric machine, the torque is generated by electromagnetic forces which also create some parasitic vibrations of the stator. These vibrations excite the mechanical structure on which the motor is fixed and generate sound. When designing the electric machine, this aspect has to be taken into account from the start since it depends on the harmonic content of the currents that feed the machine, on the shapes of the rotor and stator, and on the interaction of the electric frequencies with the natural mechanical modes of the structure.

To simulate this phenomenon, a coupling between electromagnetic calculations and vibration analysis has to be set-up. Some optimization procedure can also be added in order to reduce the noise.

In what follows, it is shown how Altair HyperWorks suite; specifically Flux™, OptiStruct®, HyperMesh® and HyperStudy® products have been successfully used to perform a multi-physics optimization for noise reduction in a fuel pump permanent magnet motor.

Introduction

This study deals with the design of a brushless AC permanent magnet motor, which is implemented in the fuel pump of an airplane wing (Fig. 1).

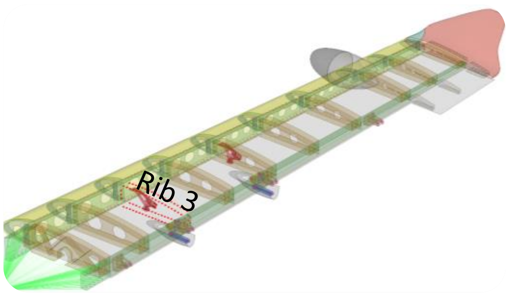


Fig. 1. Airplane wing.

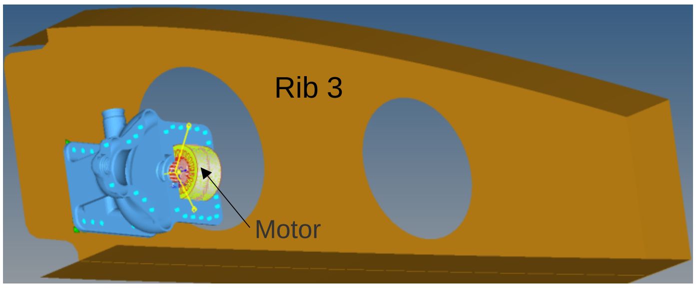
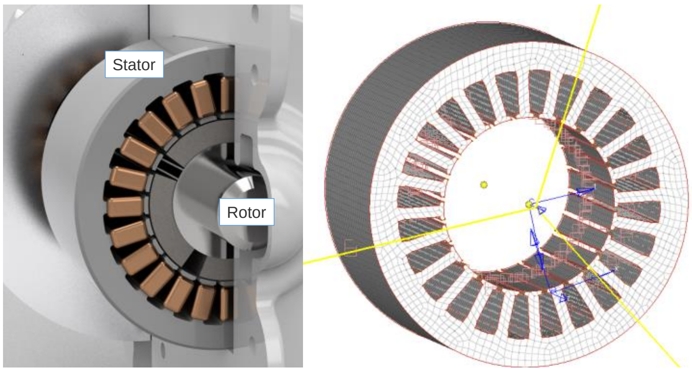


Fig. 2. Studied structure with fuel pump and Rib 3.

We consider only the Rib 3 (Fig. 2) on which the fuel pump is attached using fasteners. The motor inside the fuel pump is a brushless permanent magnet motor having the characteristics presented on Fig. 3.



<u>Stator :</u>
- 24 slots (M19 lamination)
- OD = 96 mm; Stack length = 50 mm

<u>Rotor :</u>
- 4 magnetic poles (Surface radial NdFeB)
- OD = 50 mm

Nominal speed : 3600 rpm (60 Hz)
Torque at nominal speed : 0.2Nm
Output power : 75W
Power supply : 15V / 3A

Fig. 3. Studied device: Brushless AC permanent magnet motor

The goal of the study is to reduce motor noise by working on both electromagnetic and vibration aspects. A challenge is to maintain the initial electromagnetic performances while reducing the noise.

Starting from the initial design, electromagnetic and vibro-acoustic analysis have been done. Then, both analysis have been implemented in an optimization loop that drives automatically the whole process until the optimal solution is found. For the optimization study we have considered only the stator slots variations.

Electromagnetic analysis

The motor has been modeled using Flux 2D software. A transient magnetic analysis has been used (Fig. 4). The electromagnetic performances have been evaluated: mean torque (T_{mean}=0.19 N.m); saturation induction (B_{tooth_max}=1.63 T) and current density in the coil (J_{max}=2758639 A/m²). The forces have been computed using a dedicated support (mechanical mesh) located at the interface between the rotor and the stator (Fig. 5). Then these forces have been exported in OptiStruct format in order to be used as loads in the vibration analysis.

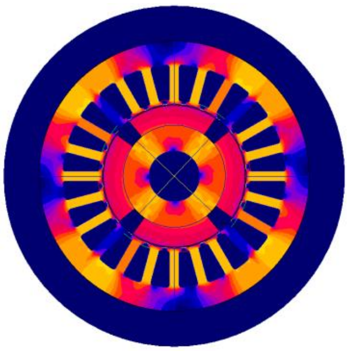


Fig. 4. Flux density.

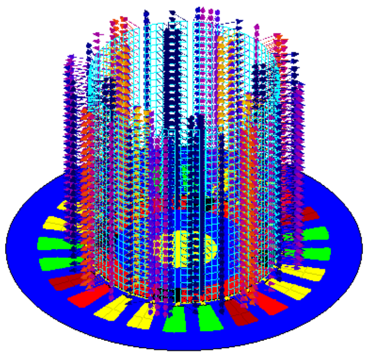


Fig. 5. Arrows of the force harmonics.

Vibro-acoustic analysis

A coupling between Flux and OptiStruct is established. For the electromagnetic part, the model is a 2D one solved in the time domain, whereas the vibration analysis is performed in 3D in the frequency domain. An automatic procedure is proposed to exchange data between these two models that are also based on two different meshes.

A vibro-acoustic analysis has been performed to evaluate the acoustic behavior of the assembly Fuel pump/Rib 3. Concretely, a frequency response analysis has been performed in OptiStruct using the forces extracted from Flux. Only the noise emitted by Rib 3 is considered by means of summed equivalent radiated power (ERP) requested on the green area shown on Fig. 6. ERP computation is a simplified method to evaluate dynamic radiation of panels and their acoustic performances. Figure 7 presents the ERP results obtained with the initial design.

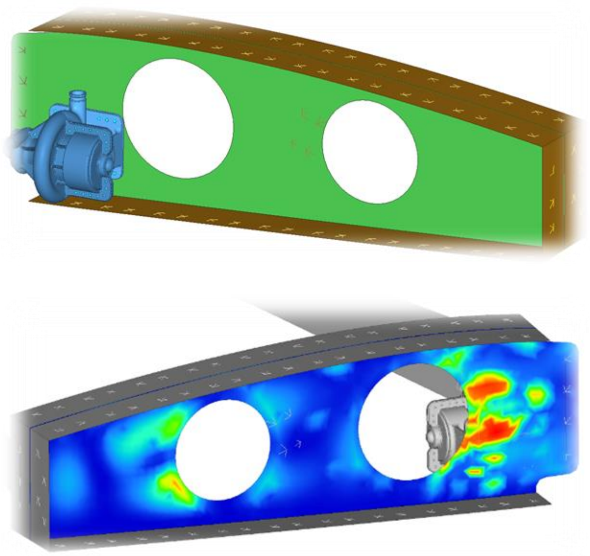


Fig. 6. Rib 3: ERP computation.

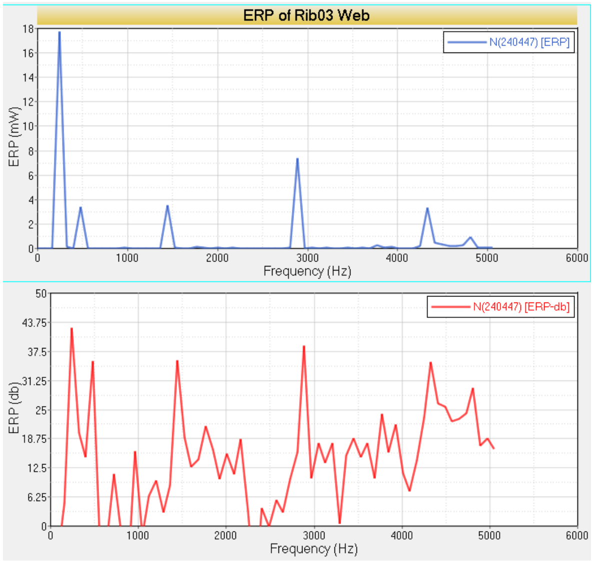


Fig. 7. ERP results (initial design).

Optimization study

The objective of the optimization is to reduce ERP value by respecting the following electromagnetic constraints: T_mean >= 0.19 N.m; J_max <= 2758639 A/m² and Btooth_max <= 1.63 T. The design variables and the initial performances are presented on Fig. 8.

	Definition	Initial	Bounds
SD	Slot depth	6.93	3.05; 9.9
SO	Slot opening	0.74	0.5; 0.8
TGD_2	Slot opening angle	0.72	0.5; 1.9
TGD	Opening depth	0.495	0.4; 1
TWS	Stator tooth width	1.683	1.16; 2.08
T_mean (N.m)	Mean torque	0.188	
Btooth_max (T)	Max B on the tooth	1.628	
J_max (A/mm²)	Max current density	2.75	
ERP (mW)	Equivalent radiated power	61.44	

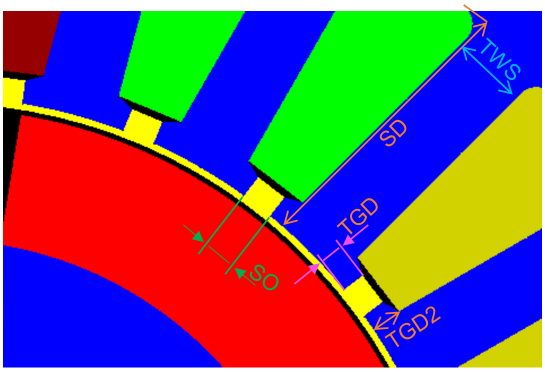


Fig. 8. Design variables and initial performances.

Altair HyperStudy, HyperWorks's multi-disciplinary design exploration tool, has been used to find the optimal design. HyperStudy is connected to Flux and OptiStruct and it enables automatic execution of intelligent design variants and guides the user in interpretation of the collected data. The HyperStudy Global response Surface Method (GRSM) has been used as the optimization method. At each evaluation the stator parameters are modified in both EM and OS models and the simulations are run. The mechanical mesh is imported to Flux in order to compute the forces which are then imported to OptiStruct to evaluate the ERP. The outputs from Flux and OptiStruct are extracted and recovered in HyperStudy. The workflow driven by HyperStudy is presented on Fig. 9.

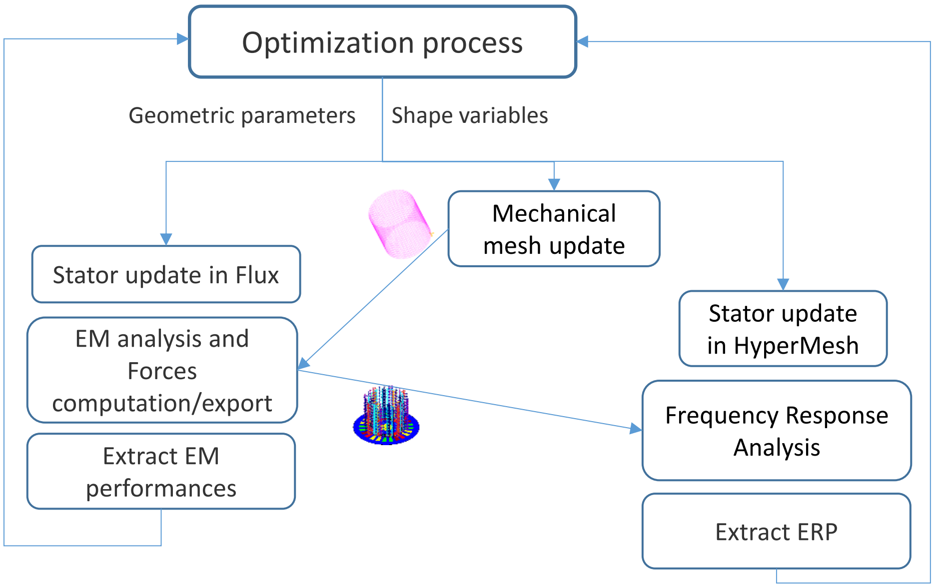


Fig. 9. Optimization process workflow.

Results overview

Coupling together EM simulations, vibro-acoustic analysis and optimization method, a noise reduction of 15 dB for critical frequency has been obtained (Fig. 10).

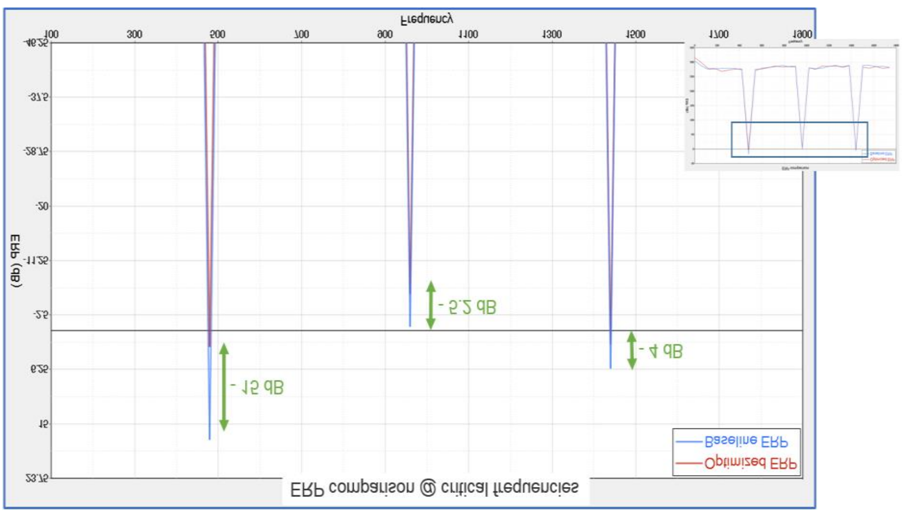
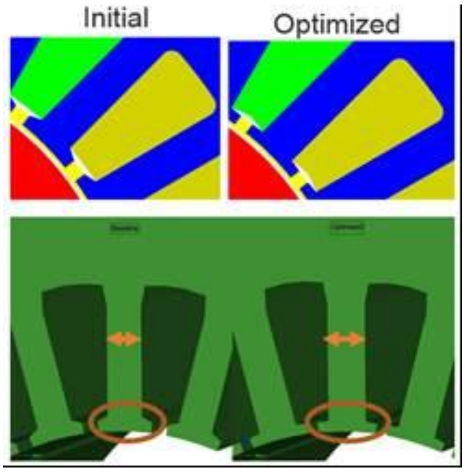


Fig. 10. ERP comparison.

As shown in the designs comparison on Fig. 11, the optimization converges to new values for each variable, defining new shapes for the stator geometry.



	Initial	Optimum
SD	6.93	7,04
SO	0.74	0,627
TGD_2	0,72	0,506
TGD	0,495	0,456
TWS	1.683	1,756
T_mean (N.m)	0.188	0,189
Btooth_max (T)	1.6287	1,576
J_max ($A.mm^2$)	2,75	2,73
ERP (mW)	**61,44**	**3,72**

Fig. 11. Initial and optimized designs comparison.

A comparison of both designs (initial/optimized) on the EM side shows that not only the constraints about average torque, max density and saturation induction are met, but as a bonus we limited the torque ripples, which means better motor behavior and reduced vibrations at the shaft level.

The optimization with GRSM (50 runs) has taken about 16 hours. The computational time could be speed-up by using multi-execution functionality allowing to run several concurrent Flux simulations.

Conclusion

This coupled HyperStudy-Flux-OptiStruct optimization has generated impressive performances gains for both EM and acoustic performances, while working only on very limited variables (stator slots dimensions). It can be imagined that gains would be even higher if more variables were used (rotor dimensions, pump housing geometry, panel stiffening…).

Being part of the same suite, integration between Flux, HyperMesh, OptiStruct and HyperStudy tools have already been established. As a result, process setup time was minimal.

References

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[2] F. Luise, *Design Optimization and Testing of High-performance Motors*, IEEE industry Applications Magazine, Vol. 22, No. 6, pp. 19-31, November/December 2016.