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Induction Rim Drive for Boundary Layer Ingestion

Introduction. Concerns about air pollution along with the rapid growth in air traffic have set challenging targets for the next generations of aircraft to reduce emissions, fuel consumption and noise. Boundary layer ingestion implemented through an array of electrically-driven fans has been identified as potentially beneficial towards achieving these targets, without requiring disruptive changes in the aircraft architecture.

This study focusses on the high-level design of an electrical rim drive to power fans for boundary layer injection. The induction motor technology is adopted because of some key features suited to a high-speed drive around the outer rim of each boundary layer fan:

- no induced electromotive forces when spinning without stator excitation
- potential no need of power electronics if the fan has to spin at roughly constant speed
- robust rotor for high-speed and possibility to reduce weight using aluminium cage
- easy to assemble and repair
- no cogging torque

Figure 1: BLI system [copyright: NASA]

Electromagnetic design summary

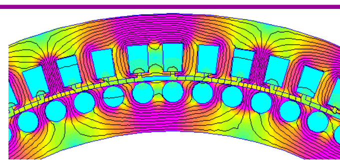
BLI fan motor specifications:

- Rated power 250 kW at 14000 rpm
- Max frequency 2 kHz
- duct diameter 300 mm

Electromagnetic Design Summary

- Cobalt lamination steel (Vacodur),
- Aluminium rotor bars
- Slot fill factor 0.5 (stator)
- Airgap length 2 mm
- end winding / active length 41%
- Operating stator current density <15 A/mm2

Leading Dimensions	
Airgap diameter	354 mm
O/D	410 mm
Axial length	33 mm
Rotor I/D	305 mm
Frequency	1400 Hz
Current	317 A
Power Factor	0.67
Pole number	12



Weights	**kg**
Stator core	6.3
Rotor core	5.0
Stator Cu	6.5
Rotor Al	1.4
Total	**19.2**

Losses	**kW**
Stator Cu	2.65
Rotor Al	2.13
Iron losses	1.30
Total	6.03
Efficiency	**97.6 %**

Stress analysis

Analysis assumptions:

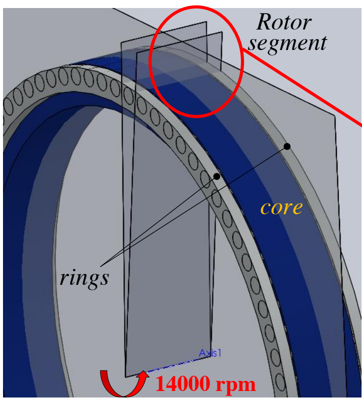
- Linear elastic isotropic materials
- Free-rotor, contact constraints between core and bars
- Centrifugal forces only, 14000 rpm (tip speed ≈310 m/s)
- Only a sector of the rotor is analysed (symmetries)

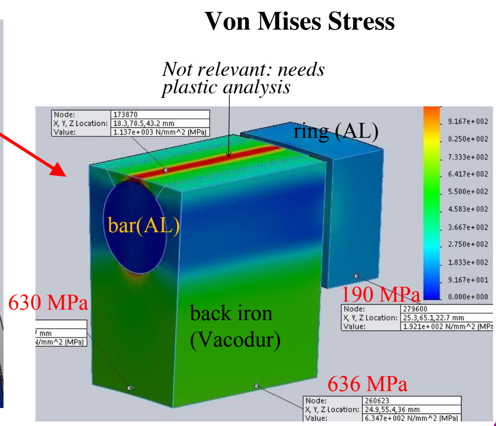
Results

- Peak Von Mises stress: core back 636 MPa, AL 190 MPa
- Vacodur might cope with stress level: σ_y up to 800 MPa

Recommendations

- Rings need pre-stressed bandage: σ_y = 30-60 Mpa
- Bandage can be fit on the top of the rings
- Stress on the slot bridge can be relieved by indenting bars
- Fatigue analysis needed (pulsating fatigue in on/off cycles)
- Fan blades might provide additional support to the shroud





Conclusion. This study has investigated the feasibility of a fan rim drive for boundary layer ingestion in aircraft applications. The preliminary electromagnetic design showed that the induction motor solution can achieve weight and efficiency figures comparable to those of other electrical machine technologies. The mechanical stress analysis undertaken in the worst scenario of unsupported rotor back-iron showed that the stress levels produced by centrifugal forces in the rotor core are compatible with available high-performance cobalt iron alloys, though the short-circuit rotor rings need pre-stressed carbon-fibre bandage support. Based on these outcomes, further work will be undertaken to finalise the design in all the aspects including 3D modelling, cooling system, full mechanical design.

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