Electric Wheel-Hub-Drive for Aircraft Application

Institute of Vehicle Concepts
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Introduction

DLR – German Aerospace Center

- Research center
  - Aeronautics
  - Space
  - Energy
  - Transport

- Space agency
- Project management agency
Introduction

DLR – Sites and Employees

› 6,400 staff working in 29 research institutes and facilities at 13 sites

› Offices in Brussels, Paris and Washington

› Partner of
  ✩ European Transsonic Wind Tunnel (ETW)
  ◆ German Dutch Wind Tunnels (DNW)
Electric Wheel-Hub-Drive for Aircraft Application

Content

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- Requirements for passenger aircraft autonomous taxiing

- Interfaces to the nose landing gear

- Design of an electric wheel-hub-drive with a high degree of integration

- Test bench results
Electric Wheel-Hub-Drive for Aircraft Application
Requirements for Passenger Aircraft Autonomous Taxiing

- Task: Autonomous taxiing of a passenger aircraft A320
- Driving conditions: TOW 50 tons with 25 km/h
- Maximum power of 50 kW

To be solved by a drive within the NLG:
- Electric machine integrated in the rim of the NLG
- Three switchable gear ratios
- Fed by a fuel cell system

TOW: Take Off Weight, NLG: Nose Leg Gear
Electric Wheel-Hub-Drive for Aircraft Application, Boundary Conditions

- AMM: Towing force = 1,5% of TOW = 7,4 kN
  Break away force = 6 % of TOW = 29 kN

- Measured towing force < 7 kN
- Measured break away force = 7 kN (2,6 kNm)
Electric Wheel-Hub-Drive for Aircraft Application

Driving Conditions

Variables:
- $T$: Torque overall
- $Ta$: Torque for acceleration
- $Tr$: Torque for rolling
- $P$: Power overall
- $Pa$: Power for acceleration
- $Pr$: Power for rolling
- $v_{km}$: Velocity in km/h

Parameters:
- Mass: 50 t
- Wheel load: 5 t
- Friction coefficient rolling: 0.015
- Friction coefficient adhesion: 0.6
- Power supply: 50 kW
- Slope: 0 %

Maximum Torque = 11 kNm for break away
Torque = 2.8 kNm for rolling

Maximum Power = 50 kW

Maximum Speed = 25 km/h
Electric Wheel-Hub-Drive for Aircraft Application, Interfaces to the Nose Leg Gear

Sleeve as the mechanical interface to the axle

Torque link as the mechanical interface to the strut

Rim as the interface to the tyre

Original design of the NLG

Axle and strut imitation

NLG: Nose Leg Gear

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Design of the Electric Machine

EMF of the 48 wires in 24 nuts

The wires of two neighboured nuts are connected in series to get a single tooth coil

<table>
<thead>
<tr>
<th>m = 3 phases</th>
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</thead>
<tbody>
<tr>
<td>p = 8 pole pairs</td>
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<tr>
<td>N = 24 single teeth</td>
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→ 8 delta connected phase systems in parallel
→ wounded in one step

EMF: Electromagnetic Force
Design of the Electric Machine

- 120 ° rectangular form of EMK
- 120 ° rectangular stair form of short current
- 220 Nm, 2000 1/min at gear ratio 1:1

EMF: Electromagnetic Force

qualitative form of the electromagnetic force

qualitative form of the short current

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Design of the Gear System

220 Nm, 2000 1/min at gear ratio 1:1
- gear ratio 1:1 for landing
- gear ratio 12:1 for taxiing = 2,6 kNm
- free wheel function

Index: $n = \text{speed}, z = \text{number of teeth}, M = \text{Motor}, S = \text{Sun}, P = \text{Planetary}, R = \text{rim}, s = \text{side of the stator}, f = \text{side of the rim}$

$\frac{n_M}{n_R} = \frac{1}{1 - \frac{z_{pf} \cdot z_{Ps}}{z_{sf} \cdot z_{Ps}}}$

$\dot{n}_R = -\frac{z_{pf} \cdot z_{Ps}}{z_{sf} \cdot z_{Ps}} \cdot n_M + n_M$

$\dot{n}_R = -\frac{z_{pf}}{z_{sf}} \cdot n_P + n_M$

$\dot{n}_R = -\frac{z_{pf}}{z_{sf}} \cdot n_P + n_M$

(if rotor stands still) if rotor rotates
Design of the Gear and Clutch System

Sun wheel of the stator could be fixed to the stator for ratio 1:12

The sun wheel of the stator could be disconnect from the stator and could be fixed to the rim for ratio 1:1

If the sun wheel of the stator is disconnected from the stator and from the rim all parts can rotate freely
Verification Tests

Motor test bench

Static load test

EMC test

Complete drive on roller test bench

EMC: Electromagnetic Compatibility
Torque Measurements

Torque of one motor (at gear ratio 1:1):
- 220 Nm

Torque of one wheel (at gear ratio 1:12):
- \(220 \times 12 = 2.6 \text{kNm}\)

Motor overloaded for break away operation

Taxiing on plane surface

Taxiing with slope 1.5%

220 Nm

(1.3 kNm)
Architecture of the Drive System

2 motors are fed by 2 fuel cell systems with 2 x 25 kW each
Electric Wheel-Hub-Drive for Aircraft Application

Taxiing system shown on ILA 2010
Nose landing gear
Fuel cell system
ILA: International aerospace exhibition, Berlin, Mai 2010

Thank you for your attention