High Efficiency Electric Vehicle Powertrain

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Drive System Design

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Main issues with current single speed EV powertrain systems:

- High motor speeds required with single speed systems to get vehicle speed range (Vmax)
- High motor speed effects of speed related loss: bearings, gears, windage, seals
- Reliance on field weakening to get high speeds
- High losses in power electronics
- Difficult balance between vehicle launch and Vmax requirements

Solution?

MULTI-SPEED TRANSMISSION
System Efficiency
Powertrain Efficiency Map

>91% Efficiency

1st Gear
2nd Gear
3rd Gear

Peak torque < 120s

Continuous region

>92%

First gear
Second gear
Third gear
Background

Why the novel shift system?

- The challenge introduced by a multispeed system…

  … IT NEEDS TO SHIFT!! – “POWERSHIFT”
• DSD considerations for EV shift system:
DSD considerations for EV shift system:

- Shift Quality
- SEAMLESS
- Cost
- Drag
- In Gear Energy
- DSD considerations for EV shift system:
  
  - Shift Quality
  - Cost
  - Drag
  - In Gear Energy

CLOSE TO MANUAL
DSD considerations for EV shift system:
• DSD considerations for EV shift system:

- ESTABLISHED TECHNOLOGY
- Cost
- Shift Quality
- Drag
- In Gear Energy

Concept Definition
Shift system consideration
• Review of available technologies
  • Friction: smooth torque control
  • Mechanical lock: reduced energy requirements

<table>
<thead>
<tr>
<th></th>
<th>Power Shift</th>
<th>Drag</th>
<th>In Gear Energy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clutches/brakes</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Synchronisers</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dog Clutches</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>One way clutches</td>
<td>?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Const. Load Synch.*</td>
<td>?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MSYS</td>
<td>✓</td>
<td>✓</td>
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"Separation of synchroniser functions"
• MSYS input shaft
• **STEP1**: 1st Gear DOG Engaged
• STEP2: Apply CLT
• **STEP3**: Release 1\textsuperscript{st} Gear DOG – Drive on CLT
• STEP4: Perform CLT2CLT torque transfer
• **STEP5**: Adjust input speed to new gear & Release 1\textsuperscript{st} Gear CLT
• STEP 6: Engage 2\textsuperscript{nd} Gear DOG
• **STEP7**: Release 2\(^{nd}\) Gear CLT
Shift Control
MSYS optimised power shift

- **TORQUE**
- **SPEED**

**Graph:**
- Input Shaft Speed
- Low Gear
- High Gear
- Time

**Table:**

<table>
<thead>
<tr>
<th>ACT 1</th>
<th>ACT 2</th>
<th>ACT 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare + Torque Phase</td>
<td>1st CONE</td>
<td>1st DOG</td>
</tr>
<tr>
<td>Speed Phase</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Eng.</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Off</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>
Cooling and Lubrication

Integrated Fluid System

- Motor and transmission will share fluid for cooling, lubrication and hydraulics
  - Lubrizol developed fluid
- A single motor drives a two stage pump providing a twin path for oil flow
  - High Pressure - Hydraulic
  - Low Pressure – Cooling / Lubrication
- The transmission sump is used to cool the powertrain using cooling fins
- Large sump volume allows gears to be out of oil reducing churning losses
- Low pressure / high flow circuit flows through the motor then the transmission
<table>
<thead>
<tr>
<th><strong>E-Machine Type</strong></th>
<th>Axial Flux YASA motor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E-Machine Power</strong></td>
<td>55kW continuous (100kW+ for 60s peak)</td>
</tr>
<tr>
<td><strong>E-Machine Max Torque</strong></td>
<td>200Nm @ 4000 rpm (limited by power electronic)</td>
</tr>
</tbody>
</table>
| **Transmission Ratios** | 1<sup>st</sup> - 9.93:1  
2<sup>nd</sup> - 7.11:1  
3<sup>rd</sup> - 5.08:1 |
| **Gear Shift** | Hydraulically Actuated Powershift Technology |
| **Driveline Efficiency** | 98% Transmission, 95% Motor, 97% Power electronics, 91% Overall |
| **Lubrication System** | Dry Sump (Light Oil Spray) |
| **Park Lock** | Integrated Plunger Type with Electrical Actuation |
| **Powertrain Weight** | 55kg Prototype Unit (wet)  
45kg Production Intent (wet) |
| **Installation Length** | 366mm Prototype Unit  
320mm Production Intent |
| **Cooling System** | Pump and In-built Sump Radiator |
| **Options** | Output disconnect for e-AWD application |
Demonstrator Vehicle

Performance Calculation

0-100kph in 8.3s

Max Speed on Flat:
160kph
(continuous torque)

Max Speed 33% Grade:
20kph (continuous torque)
55kph (peak torque)

Max Speed 17% Grade:
83kph (continuous torque)
107kph (peak torque)

A 33% grade can be driven in 1st & 2nd (Laden or Unladen)

1st Gear will break traction in unladen “kerb+100kg” condition
• Currently in prototype testing and development phase

• Vehicle build on going at MIRA

• Concept demonstrator vehicle available to drive Q2 2014.
• Torque to Pressure Curve:

![Graph showing Pressure (bar) vs Torque (Nm) with two lines: one for Active Cooling and one for Restricted Cooling. The x-axis represents Pressure (bar) ranging from 0 to 22, and the y-axis represents Torque (Nm) ranging from 0 to 100.](image)
• Test facilities:

- TRANSMISSION SPIN RIG
- HYDRAULIC RIG
- DEMO VEHICLE
- COMPONENT RIG
• DSD has created a high efficiency and controllable power shift transmission for EV based on established technology
Acknowledgement

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Technology Strategy Board
Driving Innovation

YASA MOTORS

JAGUAR

LAND ROVER

MIRA