A Highly Efficient Two Speed Transmission for Electric Vehicles

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Introduction

• Why a Multispeed Transmission for EV’s?
• Novel Twinspeed Transmission Layout
• Design & Development
• Optimized Control
• Performance & Efficiency Gain
• Integration with Range Extender
• Heavy Duty Application
• Summary & Outlook
Why a Two Speed Transmission for EV’s?

“Traditional thinking” on automotive transmissions:

1. **In Conventional Vehicles**
   It is clear and that there is a need for multispeed transmissions in combination with internal combustion engines:
   - No torque at 0 rpm
   - Limited speed range (e.g. up to 6000 rpm)
   - Peak power is delivered at one specific speed
   - More speeds is better (e.g. 8 speed, 9 speed, CVT,…)

2. **In Electric Vehicles**
   *Typical assumption: “Electric Vehicles do not require multispeed transmissions”*:
   - Electric motor can deliver high torque at 0 rpm (stall torque)
   - Electric motor can cover wide speed range (e.g. up to 14 000 rpm)
   - Peak power can be delivered in wide speed range

*Why multispeed transmissions are not desired for electric vehicles:*
   - “Multispeed transmissions inefficient”
   - “Multispeed transmissions are too large and too heavy”
   - “Multispeed transmissions are expensive”
   - “Multispeed transmissions are uncomfortable in an electric vehicle”
Why a Two Speed Transmission for EV’s?

Advantages offered by a two speed transmission for EV:

- Stall torque requirement can be reduced => downsize electric machine
- Efficiency can be optimized => increased driving range
- Top speed can be increased
Why a Two Speed Transmission for EV’s?

Advantages offered by a two speed transmission for EV:

- Stall torque requirement can be reduced => downsize electric machine
- Efficiency can be optimized => increased driving range
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<table>
<thead>
<tr>
<th>Wheel Torque</th>
<th>Vehicle Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single speed</td>
<td></td>
</tr>
<tr>
<td>Two speed</td>
<td>Increased torque in 1st gear</td>
</tr>
<tr>
<td></td>
<td>Area of max. power (unchanged)</td>
</tr>
</tbody>
</table>
Why a Two Speed Transmission for EV’s?

Electric Motor Characteristic vs. Passenger Car Load Spectrum

- Optimum efficiency of electric machines is typically at medium or high speed and at high load. However, in reality the most frequent use in real driving is at various speeds and at relatively low load.
- Two speeds can increase the effective area of high efficiency.
Why a Two Speed Transmission for EV’s?

However:
• Add-on cost should be limited
• Add-on mass should be limited
• Transmission efficiency should be high, comparable to a single speed transmission
• Gear shifting must be smooth, no torque interruption during shift

⇒ Traditional automotive transmissions as used for internal combustion engines do not meet these needs
⇒ Need for a dedicated solution
Novel Twinspeed Transmission Layout

1. Two integrated planetary gear sets
2. Single stage final drive
3. Controlled dry friction brake
4. Selectable dog clutch
5. Differential gear

Single Speed Transmission

Twinspeed Transmission
## Twinspeed Design & Development

### First Gen.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ratio 1&lt;sup&gt;st&lt;/sup&gt; gear</td>
<td>1:8</td>
<td>1:10 - 1:12</td>
</tr>
<tr>
<td>Ratio 2&lt;sup&gt;nd&lt;/sup&gt; gear</td>
<td>1:4.6</td>
<td>1:5 - 1:6</td>
</tr>
<tr>
<td>Maximum input speed</td>
<td>9000 rpm</td>
<td>12 000 rpm</td>
</tr>
<tr>
<td>Maximum input torque</td>
<td>250 Nm</td>
<td>up to 400 Nm</td>
</tr>
<tr>
<td>Centre distance</td>
<td>200 mm</td>
<td>180-220 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>55 kg</td>
<td>45 kg</td>
</tr>
<tr>
<td>Maximum efficiency</td>
<td>96%</td>
<td>97%</td>
</tr>
</tbody>
</table>
Shift strategy optimized for E-motor resulting in optimal combination of efficiency, vehicle performance and amount of shifts.
Optimized Control

Power upshift

- Electric Motor
- Clutch position
- Brake position
Power Upshift (1→2)

- Electric motor torque
- Electric motor speed
- Clutch position
- Brake pressure
Power Downshift (2\rightarrow 1)

- Electric motor torque
- Electric motor speed
- Clutch position
- Brake pressure

Graph showing changes in time [s] with labels for electric motor torque, electric motor speed, clutch position, and brake pressure.
Regenerative Downshift (2 ➤ 1)

- Electric motor torque
- Electric motor speed
- Clutch position
- Brake pressure

<table>
<thead>
<tr>
<th>time [s]</th>
<th>Electric motor torque</th>
<th>Electric motor speed</th>
<th>Clutch position</th>
<th>Brake pressure</th>
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</thead>
<tbody>
<tr>
<td>58</td>
<td></td>
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<td>58.5</td>
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<td>59</td>
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<tr>
<td>61.5</td>
<td></td>
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</tbody>
</table>
Twinspeed EV powershift transmission vs. single speed transmission:
- Extension of drive range up 4% up to 7% (depends on cycle and electric motor)
- Increased vehicle top speed
- Improvement of vehicle acceleration
- Improvement of gradeability
- Mechanical neutral enables fail-safe functions
- Powershift enables seamless gearshift

<table>
<thead>
<tr>
<th></th>
<th>Single speed</th>
<th>Twinspeed</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>1st</td>
<td>1:8</td>
<td>1:12</td>
</tr>
<tr>
<td>2nd</td>
<td>-</td>
<td>1:6</td>
</tr>
</tbody>
</table>
Integration with Range Extender

- Modular with Twinspeed EV transmission
- Ideal for small ICE’s
- Single electric motor configuration
- Operational modes:
  1) 2 x EV gear modes
  2) 2 x ICE gear modes
  3) 2 x Parallel Hybrid (PHEV) gear modes
Integration with Range Extender

Engineering example:
Vehicle: 1400 kg
ICE: 60 kW, 100 Nm, 6000 rpm
EM: 40 – 60 kW, 200 Nm, 11000 rpm
Integration with Range Extender

Increased top speed due to twinspeed transmission is very suitable in combination with range extender / PHEV powertrain.

Engineering example:
- Vehicle: 1400 kg
- ICE: 60 kW, 100 Nm, 6000 rpm
- EM: 40 – 60 kW, 200 Nm, 11000 rpm
Integration with Range Extender

- Velocity (km/h)
  - Combined
  - EV

- Tractive effort
  - Torque EM
  - Torque ICE

- SOC

Time (s)
Twinspeed Heavy Duty Application

- Heavy Duty series EREV
- Up to 1650 Nm input torque, 13000 Nm output
- 274 kW
- Overall length 280 mm
- Double dog clutch configuration (no powershift)
Conclusions & Outlook

Conclusions:
• Twinspeed is an effective solution to improve performance and efficiency
• System optimization: allowing downsizing of electric motor and inverter
• Novel Twinspeed layout allows powershifts up & down possible using only 1 friction clutch
• Interesting extension to EREV in series or parallel configuration possible

Outlook:
• Second Generation will allow higher torque range, while remaining a compact package
• Two speed solutions for electric vehicles are making their way into the market
Thank you for your attention

More info:
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