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Sponsors
Rapid identification of transmission layouts for lowest vehicle energy consumption

6 September 2017
Rob Parkinson
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SELECT-R
Rapid identification of transmission layouts for lowest vehicle energy consumption

- Motivation for transmission synthesis
- What is the SELECT-R process and how does it help?
- Benefits of dedicated hybrid transmissions & SELECT-R case study
- Benefits of multi-speed transmissions for EV’s & SELECT-R case study
- Conclusions
Motivation for transmission synthesis is the need to improve overall powertrain system efficiency without increasing cost and complexity

SELECT-R process benefits

- Rapid and robust generation and selection of efficient transmission architectures using algebraic algorithms
- Minimises transmission complexity leading to lower development costs, lower BoM costs and lower warranty costs
- Transmission architecture ranking by vehicle level energy consumption
- Process applicable to conventional, hybrid and electric vehicle applications in all market sectors


Vehicle CO2 emissions targets is key driver for reduced energy consumption

Human inspiration can no longer be relied upon to identify the most efficient transmission candidate

SELECT-R process provides rapid identification of transmission layouts for lowest vehicle energy consumption
• Motivation for transmission synthesis

• **What is the SELECT-R process and how does it help?**

• Benefits of dedicated hybrid transmissions & SELECT-R case study

• Benefits of multi-speed transmissions for EV’s & SELECT-R case study

• Conclusions
### SELECT-R process overview – unique algebraic method and weighted attribute function to quickly identify most efficient transmission layouts

<table>
<thead>
<tr>
<th>Step</th>
<th>SELECT-R Process</th>
<th>Conventional Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>User requirements</td>
<td>Concept and detailed design</td>
</tr>
<tr>
<td>2</td>
<td>Synthesis &amp; elimination process</td>
<td>Unique, semi-automated process</td>
</tr>
<tr>
<td>3</td>
<td>Ranks most efficient layouts</td>
<td>Unique weighted attribute function</td>
</tr>
<tr>
<td>4</td>
<td>Ranking and selection of efficient layouts</td>
<td>Stick diagram and concept layout</td>
</tr>
<tr>
<td>5</td>
<td>Best option taken forward with confidence</td>
<td>Saves time and cost</td>
</tr>
</tbody>
</table>

1. **SELECT-R process**
   - **1. User requirements**
   - **2. Synthesis & elimination process**
     - Unique, fast, algebraic method
   - **3. Ranks most efficient layouts**
     - Unique weighted attribute function
   - **4. Ranking and selection of efficient layouts**
   - **5. Best option taken forward with confidence**
     - Stick diagram and concept layout

2. **Select-R process starts by understanding the user requirements for the transmission.**

3. **Using a unique algebraic method** developed by Ricardo, SELECT-R **synthesises all possible architectures** leaving only physically feasible solutions that could achieve the required number of forward and reverse gears.

4. **Candidates are ranked using a unique weighted attribute function** to identify those with highest efficiency and proximity to ratio targets.

5. **SELECT-R de-risks product development** by ensuring that only the highest efficiency layout that satisfies user requirements progresses to the concept and detailed design stage.

6. **Ricardo – Rapid identification of transmission layouts for lowest vehicle energy consumption**

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SELECT-R process rapidly identifies transmission layouts from clean sheet to concept layout. All solutions explored and compared giving confidence to designer.

- User requirements
  - Unique, fast, algebraic method
- Identify area for investigation
  - e.g. Number of gearsets (planetary or parallel axis), brakes, clutches, active shift elements and motors
  - Eliminate non-shiftable structures
  - Eliminate structures far from target ratios
- Generate structures within chosen class
  - e.g. 3 planetary gearsets, 3 brakes, 3 clutches, 3 active shift elements
- Expand all possible epicyclic options
- Find planar layouts
- Size friction elements and estimate losses
- Rank efficiency & drag
  - Automatic sizing to check design feasibility
  - Vehicle level simulation and ranking
- Designer uses automatically generated building blocks to generate stick diagram
- Update loss estimates
- Concept layout developed with SABR
  - Best option taken forward with confidence

Ricardo database of pre-processed solutions accelerates process.
SELECT-R, robust synthesis and selection process for rapid identification of transmission layouts for lowest vehicle energy consumption

1. Conventional planetary automatic transmissions
2. Mixed planetary and transfer gear transmissions
3. Dedicated hybrid transmissions
4. Multi-speed transmissions for EV’s
5. Solutions for tight package spaces
6. Independent verification of layouts

“Rapid identification of transmission layouts for lowest vehicle energy consumption”
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- What is the SELECT-R process and how does it help?
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What is a Dedicated Hybrid Transmission (DHT)?
- “A transmission requiring an electric machine/s in the drivetrain to undertake its desired functions”

Why develop a DHT?
- Use electrification to simplify the conventional base transmission architecture whilst improving energy efficiency
- A P2 hybrid adds parts, cost and complexity; a DHT simplifies the system and reduces BoM cost overall

Rapid identification of transmission layouts for lowest vehicle energy consumption

Dedicated hybrid transmissions use electrification to simplify the conventional base transmission architecture whilst improving energy efficiency and BoM cost

![Diagram of 6 speed DCT with P2 Hybrid Architecture](image1)

### Parts Added
- Electric Motor
- EM Clutch
- Clutch Actuation System
- Battery and Power Electronics

### Parts Removed
- No parts removed from conventional (non-hybrid) base transmission

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Dedicated Hybrid Transmission example (Toyota Prius) (additional functionality over P2 Hybrid)

![Diagram of Dedicated Hybrid Transmission](image2)

### Parts Added
- Electric Motor x2
- Battery and Power Electronics
- Planetary Gear Set

### Parts Removed
- Dual Clutch Unit
- Dual Clutch Actuation System
- 3.5 Synchronisers and Actuation
- Many gears, shafts and bearings

Growing interest in DHT’s is demonstrated by the increase in patent applications. Ricardo has a growing database of coded patents to identify freedom to operate.

DHT patent applications are increasing

- In the late 1990’s and 2000’s, DHT patent applications were dominated by Toyota
- More recently, DHT patent applications have been growing with ZF being most active
- A wide variety of transmission architectures utilising **one and two electric motors** are being patented
- **SELECT-R process** can be used to help secure your own unique design including Ricardo’s growing database of coded transmission patents

* Hybrid vehicles with orbital gear motion (planetary gear sets) and parallel arrangement of EM and engine.  **Sources:** Patsnap; Ricardo analysis
Case study: Six-speed Dedicated Hybrid Transmission with one electric motor
Enhanced functionality over a P2 hybrid with fewer parts and lower BoM cost

1) Define SELECT-R search for layouts with 3PGs, 0 parallel gears, 2 active shift elements, 0 brakes, 4 clutches & 1 motor

12,515 results

2) SELECT-R scores each candidate for suitability for the desired ratios and geometrical factors

100 results

3) Layouts ranked by drive cycle energy consumption (including friction element slip speed and torque losses)

3 results

4) Highest ranking layout developed in Ricardo SABR

Highest ranked candidate of the initial 12,515 options is taken forward with confidence

Case study: Six-speed Dedicated Hybrid Transmission

- **Aim:**
  - To identify a DHT layout with one motor to give enhanced functionality over a P2 hybrid with fewer parts and lower BoM cost

- **Conclusion:**
  - A six-speed DHT layout offering 10 modes of operation with fewer parts and lower BoM cost

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<thead>
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<th>C2</th>
<th>C3</th>
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DHT offers enhanced functionality over a P2 hybrid including 10 modes of operation.
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  - Benefits of multi-speed transmissions for EV’s & SELECT-R case study
- Conclusions
Multi-speed electric drive unit for electric vehicles saves cost, improves EV range and is more compact than a single-speed system

Key benefits of a multi-speed electric drive unit

- **Cost saving**
  - Integrating motor with a multi-speed transmission reduces motor torque requirement reducing motor and system cost for same EV range with same or better vehicle performance as a single-speed system
  - **Savings in excess of £300 (2-spd) & £400 (3-spd)** using an internal permanent magnet (IPM) motor

- **EV range increase**
  - Improvement from operating in larger efficiency “eye” of smaller motor for same battery size
    - 4.8% energy reduction over WLTC (2-speed)
    - 5.7% energy reduction over WLTC (3-speed)
    - 7.9% at 70mph steady state (2-speed)
    - 9.0% at 70mph steady state (3-speed)

- **Compact system**
  - Greater dimensional positioning flexibility within vehicle platforms enabled by motor volume reduction exceeding 45% (4 litres)

Multi-speed transmissions enable higher efficiency motors

* Assumes C-segment EV simulation for same WLTC EV range with system comprising: multi-speed transmission with actuation and control unit, power electronics, Li-ion battery and 85kW continuous IPM motor using EU-sourced magnetic material.
Case study: Generation and selection of two-speed transmission layout for EV
SELECT-R rapidly identified and ranked candidate layouts for best efficiency

1) Define SELECT-R search for layouts with 3PGs, 0 parallel gears, 1 active shift element, 2 brakes & 0 clutches

4,100 results

2) SELECT-R scores each candidate for suitability for the desired ratios and geometrical factors

55 results

3) Layouts ranked by drive cycle energy consumption (including friction element slip speed and torque losses)

8 results

4) Highest ranking layout developed in Ricardo SABR and concept design

SELECT-R process ensures the best of 4100 options is taken forward with confidence

Case study: Two-speed transmission for electric vehicle

- **Aim:**
  - To identify a two-speed planetary gearbox for an electric vehicle actuated by two brakes using SELECT-R process

- **Conclusion:**
  - SELECT-R process rapidly identified the highest ranking powershift transmission layout out of 4,100 options which was taken into the concept design phase with confidence

Two-speed transmission for electric vehicle developed in Ricardo SABR

Integrated two-speed electric drive unit for electric vehicle
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• Benefits of multi-speed transmissions for EV’s & SELECT-R case study

● Conclusions
SELECT-R process offers rapid identification of transmission layouts for lowest energy consumption for conventional, hybrid and electric vehicle applications

- **SELECT-R process**
  1. Conventional planetary automatic transmissions
  2. Mixed planetary and transfer gear transmissions
  3. Dedicated hybrid transmissions
  4. Multi-speed transmissions for EV’s
  5. Solutions for tight package spaces
  6. Independent verification of layouts

- **DHT case study**
  - Growing number of DHT patent applications indicate that there is no “one size fits all” solution and an intelligent transmission layout selection process that assesses all possible layouts is required
  - SELECT-R rapidly identified a six-speed DHT layout offering 10 modes of operation with fewer parts and lower BoM cost than P2 hybrid

- **Multi-speed transmission for EV’s case study**
  - SELECT-R identified a compact powershift drive unit that can be tailored for different applications
  - 2-speed offers over £300 saving for same EV range; 4.8% WLTC energy reduction
  - 3-speed offers over £400 saving for same EV range; 5.7% WLTC energy reduction
If you would like to discuss this further, please **come and speak to me on stand C3-601** or contact me using the following contact information:

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**Integrated two-speed electric drive unit for electric vehicle**

- **Two Speed Transmission**
- **Integrated Power Electronics**
- **Down-sized Electric Motor**