Design, Dimensioning and Analysis of a novel, locally emission-free Propulsion Concept for Regional Trains on non-electrified Railway Lines

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DLR
DLR Overview

- Exploration of the Earth and the solar system
- Research aimed at protecting the environment
- Development of environmentally-friendly technologies to promote mobility, communication and security

8,000 employees, 33 research institutes and facilities, 16 locations
Branch offices in Brussels, Paris, Tokyo and Washington
Next Generation Train (NGT)

Project Overview

Main Results

• Increasing the certified speed to 400 km/h
• 50% less energy consumption (compared to ICE 3)
• Car body with 30% less weight (compared to ICE 3)
• Increase of comfort
  • 30% more passengers
  • 25% reduction of vibrations
• Improvement of wear behavior and life cycle costs

NGT HST
→ ultra-high-speed train, traction power 16 MW, operational speed 400 km/h

NGT Link
→ feeder train set, traction power 2.5 MW, operational speed 230 km/h

NGT Cargo
→ ultra-high-speed freight train set (e.g. for parcel services)
Motivation

EU28: Line electrification and CO\textsubscript{2}-emissions from railways

• 46% of railway lines were non electrified in 2012 \cite{1}

• Service on these lines typically provided by diesel traction with significant CO\textsubscript{2}-, NOx and PM emissions

• Example SBB in 2015 \cite{2} \cite{3}:
  • Line electrification > 95%
  • Diesel energy consumption < 4%
  • 31% of total CO\textsubscript{2}-emissions

• Internal CO\textsubscript{2} - reduction target of UIC (baseline 1990) \cite{4}:
  • by 2030: -50%
  • by 2050: -75%

\cite{1} International Union of Railways - UIC, “Rail Transport and Environment, Facts & Figures”, 2015
\cite{2} http://www.sbb.ch/sbb-konzern/ueber-die-sbb/zahlen-und-fakten/umwelt/energieverbrauch.html
\cite{3} http://www.sbb.ch/sbb-konzern/ueber-die-sbb/zahlen-und-fakten/umwelt/co2-emissionen.html
## Motivation

What could be the future solution?

<table>
<thead>
<tr>
<th>Possible Solution</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full electrification</td>
<td>No local emissions</td>
<td>High investment cost, low utilisation</td>
</tr>
<tr>
<td>Natural gas fuel</td>
<td>Reduction of emissions</td>
<td>Fuel stations, local emissions</td>
</tr>
<tr>
<td>Pure battery multiple unit</td>
<td>No local emissions, regeneration</td>
<td>Operation range, packaging, costs</td>
</tr>
<tr>
<td>Fuel cell hybrid propulsion</td>
<td>No local emissions, regeneration, range</td>
<td>Fuel stations</td>
</tr>
</tbody>
</table>

→ No simple solution, novel concepts required
Approach for future propulsion system

Conceptual requirements

• Propulsion system with emission-free train operation on non-electrified lines
• Boost energy efficiency by recuperation of brake energy
• One concept with different configurations to provide modularity, scalability and flexibility in different scenarios
• Smooth transition from current non-electrified lines to future system

DLR approach

• Combination of partial electrification and on-board energy storage
Implementation strategy

Static charging

Static charging

Dynamic charging and driving

(optional)
External Energy Supply

Comparison of options for partial electrification

AC-systems:
- Long distances, high power
- High investment cost
- Typically fed by high voltage grid (110 kV)
- Max. power during standstill: 1200 kW

DC-systems:
- Shorter distances, lower power
- Fed by medium voltage grid (10-30 kV)
- Max. power during standstill: 600 kW

→ Pantograph limits fast charging – other options?

External Energy Supply

Excursus: Inductive Energy Transfer System (IETS)

Concept of a catenary-free energy supply system using inductive power transmission

No limitation from pantograph during standstill
External Energy Supply

Excursus: Inductive Energy Transfer System (IETS)

For further details on IETS see WCRR-Paper No. 740:

Inductive Power Supply for Main-line Railways

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External Energy Supply

IETS satisfies conceptual requirements

Inductive energy transfer system (IETS):

• Flexible in power dimensioning
• Scalable length of electrified track
• Static and dynamic power transmission possible
• Fed by medium voltage grid (10-30 kV)
Propulsion concept – main current circuit

Modular approach – base module
Propulsion concept – main current circuit

Modular approach – base module with IETS
Propulsion concept – main current circuit

Modular approach – base module with hybrid / range extender
Propulsion concept – main current circuit

Modular approach – base module with catenary module
Use case NGT LINK

- Innovative train concept with all-wheel drive
- Double-decker regional and intercity train
- Serves as basis for requirements and packaging concept

Relevant specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum tractive power at wheel</td>
<td>2500 kW</td>
</tr>
<tr>
<td>Starting tractive force at wheel</td>
<td>412 kN</td>
</tr>
<tr>
<td>Design mass (fully loaded)</td>
<td>272 t</td>
</tr>
<tr>
<td>Number of wheelsets and traction drives</td>
<td>32</td>
</tr>
</tbody>
</table>
Use case NGT LINK: Main current circuit
Use case NGT LINK: Reference scenario

- Round-trip on non electrified line Ulm - Oberstdorf (Germany)
- Intermediate stations Memmingen and Kempten
- Overall distance of roundtrip 254 km
- Stoppage time at turning station Oberstdorf: 20 minutes
- Aux power at intermediate circuit: 303 kW continuous (worst case)
Use case NGT LINK: Battery energy trend

Concept1

Concept2

Concept3

- Battery energy [kWh]
- Time [min]

Concept1
1848 kWh

Concept2
1097 kWh

Concept3
627 kWh
### Use case NGT LINK: Battery characteristics

<table>
<thead>
<tr>
<th></th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used battery capacity kWh</td>
<td>1848</td>
<td>1097</td>
<td>627</td>
</tr>
<tr>
<td>DoD assumption %</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Installed battery capacity kWh</td>
<td>3080</td>
<td>1828</td>
<td>1045</td>
</tr>
<tr>
<td>Discharge power kW</td>
<td>3290</td>
<td>3290</td>
<td>1882</td>
</tr>
<tr>
<td>Charge power kW</td>
<td>1797*</td>
<td>3290</td>
<td>1350</td>
</tr>
<tr>
<td>C-rate discharge 1/h</td>
<td>1.1</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>C-rate charge 1/h</td>
<td>0.6*</td>
<td>1.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

* No external charging during roundtrip, C-rate calculated from recuperation power
Propulsion concept dimensioning

- Concept 1 not viable due to mass and volume restrictions
- Other concepts are in accordance with the conceptual design
Conclusion & Outlook

• Pure battery propulsion (charging only at terminal station):
  • not viable for NGT LINK due to mass and volume restrictions
  • useful for tracks with shorter non-electrified sections

• Dynamic charging concept reduces battery capacity and power
  • IETS power is used instantaneously for acceleration

• DLR propulsion concept offers opportunity to achieve UIC goal for 2050 (-75% CO$_2$-emission)

• Outlook:
  Evaluate the concept for other use cases (tracks and vehicles)
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