Developments in Traction Systems

Stuart Hillmansen
University of Birmingham

What is new in Traction?

- Physics of traction – no change there!
- Traction drives – lots of legacy stuff around
- Railway energy consumption – lots of concern about how to save energy
- Some new concepts for future traction
- Summary
Overview of energy and power

- Linear motion of a railway vehicle can be described using standard equations of motion derived from Newton’s Laws
- Force = Mass x Acceleration (Newton)
- Work Done = Force x distance (Joule)
- Power = Work Done / time (Watt)

What is a Newton, a Joule or a Watt?

If we lift the apple through 1 metre in 1 second then the power is:
P = \frac{WD}{time} = 1 \text{ Watt}

If we lift the apple up through 1 metre then the work done will be:
WD = F \times d = 1 \text{ Newton x 1 Metre} = 1 \text{ Joule}

F = M \times a = 0.1 \text{ kg} \times 10 \text{ m/s}^2 = 1 \text{ Newton}
So...

- A kettle boiling water is equivalent to 3,000 apples being lifted vertically at a speed of 1 m/s

- A Eurostar train at full power is equivalent to 12 million apples being lifted vertically as a speed of 1 m/s

Physics of traction

\[ M (1 + \lambda) \frac{d^2 s}{dt^2} = T - \left( c \left( \frac{ds}{dt} \right)^2 + b \left( \frac{ds}{dt} \right) + a + \frac{d}{r} \right) - (Mg\theta) \]
Tractive and resistive forces

Summary of traction

- Overall tractive effort is limited by number of driven wheels and maximum torque of the traction motors
- Once the constant power region is reached then the tractive effort drops off with 1/speed
- Possible to achieve good performance with low power and with distributed traction
- Distributed traction also improves regeneration potential
Traction energy overview

• Energy in at pantograph
  – Auxiliary
  – Traction
  • Losses in:
    – Converters
    – Motors
    – Resistance to motion – slow trains down?
    – Kinetic energy recovery (last low hanging fruit)

Options for energy storage 1

• Onboard storage
  – Diesel electric multiple units
  – Diesel multiple units
  – Locomotives
  – Shunting locomotives
  – Electric multiple units
Options for energy storage 2

• Wayside storage (fixed installations)
  – DC railways
    • Load levelling
    • Regeneration capture and reuse
  – AC railways – not such an important issue
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Sustainable traction drives

Gradient profile

Velocity profile

Running diagram

Specific traction, resistance and acceleration curve

Acceleration

Traction/Braking Power

Specific forces (m/s²)

Speed limit m/s

Distance km

Hybrid potential

Distance km

Speed limit m/s

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Important features of braking

• At high speed – it is very difficult (impossible) to capture all the braking energy.
• Constant power braking is required to get the most out of regenerating systems
• Using constant power and all electric regeneration will lead to longer journey times – unless you put big machines in the train

Energy Storage Capability (in MJ/kg)

• Compressed natural gas (CNG): 50 MJ/kg
  – But pressure vessel weighs a lot
• Petrol: 44 MJ/kg
• Diesel fuel: 39-42 MJ/kg
• Ethanol: 30 MJ/kg
• Coal: 29 MJ/kg
• Biomass: 15 MJ/kg
• Liquid petroleum gas (LPG): 45-50 MJ/kg
• Steel flywheel: 0.014 MJ/kg
• Battery: 0.01-0.56 MJ/kg
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Conventional DEMU

- Diesel engine
- G
- $V_{\text{DC}}$
- Inverter
- Brake chopper
- Brake resistor bank

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Hybrid DEMU

- Diesel engine
- G
- $V_{\text{DC}}$
- Inverter
- DC/DC converter
- Energy storage device
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Hybrid Fuel Cell EMU

Fuel cell

= =

V_{DC}

Inverter

= =

DC/DC converter

M

Sustainable traction drives

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Hayabusa

- Developed by Hitachi, Porterbrook, Brush Traction, and Network Rail.
- Class 43 fitted with 4 Hitachi 300 kW AC traction motors.
- Hitachi lithium-Ion batteries used as the ESD
  - 48 batteries, 960 kg battery weight
  - Capacity: 48 kWh
  - Maximum power output: 1 MW for 170 seconds
EMUs with energy storage

• Provides power in the event of supply failure
• Can improve energy efficiency on DC railways (with long headways and low voltage DC supplies)
• Can power train on sections of track which are not electrified
• No commercial main line trains are currently available – but there are some light rail examples
• IPEMU trial

http://www.railtechnologymagazine.com/Rail-News/prototype-battery-powered-ipemu-carries-passengers-for-first-time
Sustainable traction drives

Wayside energy storage

• Essentially same principles apply:
  – Need to consider the supply duty cycle
  – Careful positioning of equipment
  – Range of storage technologies to consider
    • Capacitor
    • Battery
    • Flywheel
  – Can lead to energy savings – but these are harder to realise in an electric railway – and the economic case is not there yet.
Verification Test of Energy Storage System for DC 750V Electrified Railway

Takeshi Konishi*, Shin-ichi Hase*, Yoshinobu Nakamura*,
Hidetsu Nara***, Tadashi Uemura***

RTS 2007 (The Third International Conference on Railway Traction Systems), Tokyo, Japan

Fig. 1. Test section.

Fig. 2. Main circuit.
Sustainable traction drives

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Beijing Yizhuang Metro Line field test
Sustainable traction drives

Power electronic substations
Sustainable traction drives

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Simulated voltage waveforms

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Practical voltage waveforms

Substation 1

Distance 1

Distance 2

Substation 1
And for where we don’t electrify we have the option of fuel cell trains

- Benefits of electrification without OLE
- Zero emissions at point of use
- Lots of ways of making the H₂

Summary

- Railway traction is fundamentally sustainable
- Kinetic energy recovery can improve overall energy efficiency
- Energy storage solutions are being trialled in many different railway applications
- The economic case is still a bit uncertain
- The performance of energy storage is likely to improve and we are likely to see wide scale implementation of these systems in the future
- Duty cycle is the most important factor to consider when thinking about energy storage devices
- Power electronic traction substations have the possibility to revolutionise the railway power system and be a key part of the smart railway power grid