Development of the “New Energy Train -hybrid type-”

Takehito Fujii
R&D Center, East Japan Railway Co.
Development of the NE Train

Purpose

1. Background of the NE Train project
2. Outline of development
   2-1 Concept
   2-2 Overview of NE Train
   2-3 Energy control system
3. Evaluation test
4. Conclusion
Background of the project

DMU Problem

- A JR East’s DMU: 530 cars
- Low energy efficiency
- Pollution and Noise
- High maintenance
- Poor acceleration and deceleration

Energy consumption for train operations and transported volume

<table>
<thead>
<tr>
<th>Year</th>
<th>1st (billion MJ)</th>
<th>2nd (billion MJ)</th>
<th>1st (MJ/car-km)</th>
<th>2nd (MJ/car-km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>44.0</td>
<td>37.8</td>
<td>20.6</td>
<td>18.8</td>
</tr>
<tr>
<td>2001</td>
<td>41.0</td>
<td>30.9</td>
<td>18.8</td>
<td>23</td>
</tr>
<tr>
<td>2002</td>
<td>40.6</td>
<td></td>
<td>18.6</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td>17.5</td>
<td></td>
</tr>
</tbody>
</table>

Energy efficiency

<table>
<thead>
<tr>
<th>1st</th>
<th>253g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd</td>
<td>200g/kWh</td>
</tr>
</tbody>
</table>

Weight

- 1st: 37.8 ton
- 2nd: 30.9 ton

2nd generation diesel railcars
Concept of the NE Train project

Purpose

• Reduce environmental load of railcars through innovation of propulsion system.

1st step: Hybrid system  2nd step: Fuel cell system

Concept & Target

= Environmental friendliness =
  • Energy saving
  • Reduction of pollutants and noise

= Conversion to electric railcar technology =
  • Labor saving maintenance
  • Improvement of driving performance
### NE Train Overview

#### Body
- **Stainless steel** (Length: 20 m)

| Max. speed | 100km/h |

#### Power unit
- **Hybrid type**
- **Series type**
- **Main controller**
  - VVVF inverter (IGBT)
- **Main motor**
  - Induction motor (120 kW × 2)
- **Main battery**
  - Lithium-ion battery (10 kWh)
- **Main generator**
  - Induction motor (180 kW)
- **Engine**
  - Diesel engine (330 kW/2100 rpm)

#### Bogie
- Bolsterless Bogie

#### Brake system
- Electric command air brake system with regenerative braking
Hybrid system

2 types of hybrid system

(a) Series-hybrid system
(b) Parallel-hybrid system

Requirements demanded of NE Train
- Advance and sternway used equally.
- Adoption of fuel cell system in future.
- Effective use of latest EMU technology.
- Achieve high performance equivalent to EMU.
Hybrid system Overview

- Effective use of latest EMU technology and equipments

![Diagram of hybrid system]

- Induction motor 120kW ※E231 equipment
- Low-emission engine 330kW(450PS)
- Diesel engine
- Main controller
- Generator
- Battery unit
- Lithium ion battery 10kWh
- Engine generator
### Selection of power equipment

#### Main motor

- 60km/h on 25°/00 slope (equal to EMU) 120kW x 2

#### Engine & Generator

- 60km/h on 25°/00 slope 250kW
- Power supply for service equipment (Air conditioner etc.) 50kW

**Total** 300kW or more

#### Engine with reduced emissions

<table>
<thead>
<tr>
<th>Emission</th>
<th>Conventional type</th>
<th>NE Train engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>60%</td>
<td>30% or more</td>
</tr>
<tr>
<td>PM</td>
<td>80%</td>
<td>50% or more</td>
</tr>
</tbody>
</table>

Emission reduction 30% or more
## Selection of battery unit

### Comparison of electricity storage equipment

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Energy density (Wh/kg)</th>
<th>Power density (W/kg)</th>
<th>Life span (cycle)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ultra Capacitor</strong></td>
<td>6</td>
<td>500</td>
<td>Infinity</td>
<td>High</td>
</tr>
<tr>
<td><strong>Lead Acid Battery</strong></td>
<td>40</td>
<td>300</td>
<td>500</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Nickel-Metal Hydride Battery</strong></td>
<td>40〜70</td>
<td>200〜700</td>
<td>1000</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Lithium-Ion Battery</strong></td>
<td>30〜130</td>
<td>30〜1400</td>
<td>1000</td>
<td>High</td>
</tr>
<tr>
<td><strong>Flywheel</strong></td>
<td>〜50</td>
<td>1000〜</td>
<td>Infinity</td>
<td>Average</td>
</tr>
</tbody>
</table>

Regeneration energy per 1 stop: 1kWh
5km running by Battery only: 3kWh
Optimal operation range: 40%

- **Average**
- **High**
- **Low**
- **Infinity**
- **10kWh**
Requirements demanded of system

- **Energy saving =**
  - Effective storage of brake generation energy
  - Operation of engine at optimal rpm.

- **Reduction of pollutants and noise =**
  - Use of battery as power source at station
1. Keep the sum of kinetic energy and storage battery energy.

2. Control engine for charging a battery efficiently

**Basic principle**

- **Storage battery energy**
- **Battery energy**
- **Braking**

Energy control system diagram:
- Energy axis: E0 to E1
- Train speed: 0kmh to E1
- Storage battery energy = total energy
- Regenerative energy
- Battery energy
- Total energy
Energy control system

4 energy management zones

Engine controlled by “Train speed”, “Battery charged level SOC”

SOC* (%)

Upper limit (60%)

Zone D

Zone A
(Normal operation domain)

Zone B

Lower limit (20%)

Train speed (km/h)

Power running

Zone A: Engine highest efficiency (Engine 2N: 200kW)
Zone B: Engine idling
Zone C: Engine maximum power (Engine 3N: 300kW)
Zone D: Engine stop

Braking

Zone A-D: Engine idling

*SOC = State of charge
Management diagram of energy control system

Power running to 70km/h (Engine idling from 25km/h) → Braking
Operation state of hybrid system

- **Stop**
  - Diagram showing the hybrid system in stop mode.
  - Components: Engine (E), Generator (G), Converter (C), Inverter (I), Battery (B), Motor (M), Wheel (W), Auxiliary power supply (SIV).

- **Departure**
  - Diagram showing the hybrid system in departure mode.
  - Components: Same as in stop mode.

- **Power running**
  - Diagram showing the hybrid system in power running mode.
  - Components: Same as in stop mode.

- **Braking**
  - Diagram showing the hybrid system in braking mode.
  - Components: Same as in stop mode.

E: Engine  G: Generator  C: Converter  SIV: Auxiliary power supply  I: Inverter  B: Battery  M: Motor  W: Wheel
NE Train evaluation test

Drivers’ monitor

NE Train test run
Evaluation by test runs of the NE Train

Place: Karasuyama line, Nikko line, Tohoku line
Test program:
1. Basic performance and functionality
2. Emergency function
   (generator disconnected, battery disconnected)
3. Energy-saving effect
4. Effect of temperature (in winter and summer)

Station distances:
- Karasuyama line: 3.2km
- Nikko line: 6.7km
Test result

- **Functionality and basic performance**
  (a value equivalent to that of electric railcar)
  - Acceleration = 2.3km/h/s at 35km/h
  - Deceleration = 3.6km/h/s
  - Proper coordination of generative and mechanical brake

- **Energy-saving effects**
  (Target) saving of 20% in energy compared with diesel railcars
  (Result) regeneration ratio is 33%
  *Karasuyama line max

- **Temperature effects**
  (Condition) from -5 degree to 35 degree
  - Basic performance operated satisfactory

- **Noise reduction at stations**
  (Target) Engine stop at stations and at a low speed
  (Result) Engine stop at stations: within 5 minutes; at low speed
Simulation and evaluation test

=Karasuyama line=
Station distance: 3.2km
- 60m
Simulation: 25%
Evaluation test: 33%

=Nikko line=
Station distance: 6.7km
- 420m
Simulation: 15%
Evaluation test: 14%

=Tohoku line=
Station distance: 5.4km
- 180m
Simulation: 15%
Evaluation test: 16%
1. Engine stop  
   Train speed: 0-25km/h

2. Engine efficiency control  
   Engine 2N (about 0-80km/h)

3. Regenerative energy  
   1.5kWh (one stop, from 60 to 0km/h)
Basic performance (Speed control at a downward slope)

- Speed control at a downward slope-
  (Step 1) Regenerative brake
  (Step 2) Engine exhaust brake
JR East began the NE Train project and developed a prototype with a hybrid system.

We adopted a series hybrid system with future potential of conversion to fuel cell system.

We developed an original “Energy Control System” for the control of the hybrid system.

Results of the test runs demonstrate hybrid system achieved planned performance.

Test runs on various routes to be conducted henceforth.