Reduction of electricity consumed by rolling stock is an urgent issue for JR East. In this study, we conducted measurement and analysis of driving energy of Shinkansen trains, which run at high speed over long distances, and clarified the change in figures of electric power for all units in a train set. In the measurement, we utilized an intelligent function of the Shinkansen Train Information Management System (S-TIMS) of Series E5 rolling stock. Furthermore, we attached an integrating wattmeter to the inside of the converter inverter and a current sensor in the main transformer to precisely grasp pantograph point current.

**Keywords**: Series E5 rolling stock, S-TIMS, Electric energy of powered running, Electric energy of regeneration, Electric energy of auxiliary equipment

### 1 Introduction

Reduction of electricity consumed for railway operation is an important issue for JR East. As part of efforts aiming at reducing driving energy, we conducted measurement and analysis of electric power for conventional lines on the Sagami Line and the Yamanote Line, from which we clarified electric energy of powered running/regeneration, electric energy consumed for running, and electric energy of auxiliary equipment. This time, we conducted measurement and analysis of running energy for Shinkansen trains, which run at high speed over long distances, from which we clarified the change in figures of electric power for all units in the train set.

### 2 Overview of the Measurements

Measurement was conducted using Series E5 Shinkansen rolling stock (Fig. 1). The Series E5 is operated with a maximum speed of 320 km/h on the Tohoku Shinkansen Line while exchanging information with the Shinkansen Train Information Management System (S-TIMS).

Fig. 1 Series E5 Shinkansen Rolling Stock

Fig. 2 shows an overview of the temporary installation and system configuration of the measurement system. S-TIMS installed to Series E5 Shinkansen EMUs measures notching and integral power consumption in commercial operation. In utilizing this function, we attached a recording device in the equipment room of the driver’s cab to record measurement data for a specified period of time. We also changed S-TIMS and air conditioning software to transmit measurement data to that recording device. The major items measured include…

- Driving commands (notching, etc.)
- Speed, running location, and the like
- Electric energy of auxiliary equipment (air conditioner, compressor, total)
- Air conditioning electric power (cooling, heating)

The recording device automatically turns on and off depending on whether or not voltage is applied to individual EMUs. The data recorded in the recording device is for at least the past two weeks (360 hours) and is stored on a CF card.

In order to more accurately identify pantograph point current, we also conducted measurements with ammeters attached to primary through tertiary wiring of the main transformer and an integrating wattmeter built in to power converters. Data recorded in the integrating wattmeter for the past last two weeks is stored on a SD card. The major items measured include…

- Primary electric power
- Secondary (powered running/regeneration) electric power
- Tertiary (auxiliary device) electric power

### 3 Measurement Results

#### 3.1 Comparison of Driving Energy between Operation Types

Table 1 shows driving energy consumed between Tokyo and Sendai per operation pattern (number of stops on the line). It demonstrates that energy consumption significantly varies according to the operation pattern. Operation as the Hayabusa super-express Shinkansen, where trains run at a maximum speed of 320 km/h and stop at the least number of stations, consumes the largest amount of energy. Even when compared to operation as the Hayate with almost the same operation pattern but different maximum speed of 275 km/h, energy consumption of Hayabusa is larger.

Fig. 3 shows running charts of the Hayabusa and Yamabiko (stops at every Shinkansen station) trains as typical examples.
for the trains listed in Table 1. While the Hayabusa runs for a long distance at a constant high speed, the chart shows that it constantly consumes electric power in high speed running. As it produces a large amount of electric energy of regeneration only while stopping at Sendai station, its electric energy consumed for running (energy of powered running - energy of regeneration) also is the largest among the trains.

Since the Yamabiko stops at many stations and accelerates often to depart those stations, it shows smaller difference in energy of powered running than that of the Hayabusa; however, it also applies braking often. In total, its electric energy consumed for running is smaller than that of the Hayabusa.

These results indicate that driving energy consumption is significantly affected by speed; specifically, driving energy consumption increases as maximum speed increases. This is because running resistance increases in proportion to the square of speed; thus, the energy required to overcome running resistance increases as the speed increases. At the same time, in an AC feeding system with long feeding sections, there are many opportunities for other EMUs to use the regenerated power; moreover, the circuit design makes it easy to return electric energy of regeneration from EMUs to the system without regeneration throttling. Consequently, electric energy of regeneration increased for the Yamabiko as it stops at more stations and thus the number of times it applies brakes increases.

3.2 Comparison of Driving Energy Between Driving Operations

Fig. 4 plots electric energy consumed for running according to average speed in a section. It shows that electric energy consumed for running increases as average speed increases. However, it also shows that two trains with almost the same average speed differ from each other in terms of electric energy consumed for running. Table 2 lists a comparison of those two trains and Fig. 5 shows change in speed and power consumption of those. The

<table>
<thead>
<tr>
<th>Train name</th>
<th>Number of stop stations</th>
<th>Running time</th>
<th>Electric energy of powered running</th>
<th>Electric energy of regeneration</th>
<th>Electric energy consumed for running (Energy of powered running - Energy of regeneration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hayabusa</td>
<td>2</td>
<td>1:29</td>
<td>1.00</td>
<td>0.06</td>
<td>0.94</td>
</tr>
<tr>
<td>Hayate</td>
<td>3</td>
<td>1:44</td>
<td>0.75</td>
<td>0.06</td>
<td>0.69</td>
</tr>
<tr>
<td>Yamabiko (stops at major stations)</td>
<td>6</td>
<td>1:59</td>
<td>0.95</td>
<td>0.18</td>
<td>0.77</td>
</tr>
<tr>
<td>Yamabiko (stops at every station except Shiraishi-Zao)</td>
<td>9</td>
<td>2:17</td>
<td>0.92</td>
<td>0.27</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Running time of those two trains differs from each other by only 3%, so it is almost the same.

Train A ran completely by automatic driving at constant speed almost over all the section. On the other hand, Train B repeatedly alternated between powered running, coasting, and regeneration by intermittent manual notching. As a result, Train B showed coasting and regeneration longer than for Train A, consuming less electric energy for running.

These results suggest that carefully arranged driving operations could achieve energy-conserving driving even for the same running time.

<table>
<thead>
<tr>
<th>Average speed [km/h]</th>
<th>Electric energy of powered running</th>
<th>Electric energy of regeneration</th>
<th>Electric energy consumed for running</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train A 275</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Train B 285</td>
<td>0.83</td>
<td>0.10</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Fig. 3 Running Charts between Tokyo and Sendai

Fig. 4 Electric Energy Consumed for Running in Same Section
3.3 Comparison of Driving Energy Between Braking Operations

Fig. 6 plots electric energy of regeneration and maximum speed of trains arriving at Sendai Station. Trains that ran at higher speed produced more electric energy of regeneration, indicating that the amount of electric energy of regeneration depends on speed. At the same time, as in the preceding paragraph, there were two trains that varied in the amount of electric energy of regeneration even though they ran at almost the same maximum speed. Table 3 shows a comparison of those two trains, and Fig. 7 shows the change in speed and energy consumption. Fig. 6 shows that the amount of electric energy of regeneration produced by Train A was larger than that by Train B, while Table 3 shows that the amounts of electric power consumed for running of those trains were the same. This is because Train B coasted in some sections and driving energy was consumed by running resistance in those sections, without regeneration.

Table 3  Comparison of Electric Energy of Regeneration of Trains at Arriving at Sendai Station
(electric energy for powered running of Train A as 1)

<table>
<thead>
<tr>
<th></th>
<th>Max. speed (km/h)</th>
<th>Electric energy of powered running</th>
<th>Electric energy of regeneration</th>
<th>Electric energy consumed for running</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train A</td>
<td>300</td>
<td>1.00</td>
<td>1.11</td>
<td>-0.11</td>
</tr>
<tr>
<td>Train B</td>
<td>300</td>
<td>0.65</td>
<td>0.76</td>
<td>-0.11</td>
</tr>
</tbody>
</table>
3.4 Effect of Overhead Contact Line Voltage

We conducted analysis of the change of driving energy due to overhead contact line voltage. Fig. 8 shows the relationship between electric energy consumed for running and overhead contact line voltage of trains that ran in a section at a constant and almost the same speed. In all sections and times, the voltage at measurement was constantly higher than the rated voltage 25 kV.

Sometimes trains consumed different amounts of electric energy for running than each other under the same overhead contact line voltage, and other times they consumed almost equal amounts of electric energy for running under different overhead contact line voltages, showing no change in amount of driving energy due to overhead contact line voltage. The cause of this result could be converter control.

Concerning the change in electric energy of regeneration of trains at arriving at Sendai Station due to overhead contact line voltage, Fig. 9 shows the relationship between electric energy of regeneration and overhead contact line voltage. As shown in Fig. 8, sometimes trains produced different amounts of electric energy of regeneration under the same overhead contact line voltage, and other times they produced almost equal amounts of electric energy of regeneration under different overhead contact line voltages, showing no change in amount of electric energy of regeneration due to overhead contact line voltage. We found no tendency for rise in overhead contact line voltage due to increase in electric energy of regeneration, either.

3.5 Electric Energy of Auxiliary Equipment

Fig. 10 shows the relationship between electric energy consumed by auxiliary equipment per hour and average outdoor temperature in the section between Tokyo and Sendai. As the amount of electric energy consumed for auxiliary equipment varies greatly according to the amount of electric energy consumed for air conditioning, it thus varies according to the ambient temperature (average outdoor temperature).

The electric energy consumed for auxiliary equipment was lowest at an average outdoor temperature around 15 ºC between Tokyo and Sendai, and it increased as that temperature diverged from 15 ºC. The reason is that heating turns on at an average...
outdoor temperature less than 15 ºC, increasing the amount of electric energy consumed for heating increases as the temperature decreases, and that cooling turns on at an average outdoor temperature more than 15 ºC, increasing the amount of electric energy consumed for cooling as the temperature increases. In the measurement period, electric energy for cooling exceeded electric energy for heating. The maximum amount of electric energy of auxiliary equipment for cooling reached approx. 1.4 times of the maximum amount of that for heating.

In past measurement and analysis on the Yamanote Line, we observed a tendency for electric energy consumed by auxiliary equipment to be larger as the passenger load factor became higher. We thus carried out analysis to see whether the same result could be observed with Series E5 rolling stock. Fig. 11 shows the relationship between the amount of electric energy consumed for auxiliary equipment per hour and the average air spring (AS) pressure in the section between Tokyo and Sendai. The figures for average AS pressure are the total of 10 cars of a train set. Since passenger load factors were not recorded in the measurement, we made analysis using the average AS pressure.

Larger electric energy consumption by auxiliary equipment can be found in areas where average AS pressure is higher, but that is due to outdoor temperature. Electric energy for auxiliary equipment not always became larger, even when average AS pressure varied. We thus found no particular relationship between electric energy consumed for auxiliary equipment and average AS pressure.

Conclusion

These measurements clarified driving energy and auxiliary energy of Series E5 Shinkansen rolling stock. They also demonstrated that, with the Shinkansen rolling stock, driving energy consumption differs depending on operation types, and that is greatly affected by speed. On the other hand, driving energy consumption varies according to driving operations.

We will use those results to study further energy conservation and go forward with analysis of those results with an aim of developing more energy-conserving rolling stock and driving operations.

Reference: