Special edition paper

Approach to Train Driving Energy Reduction

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JR East has been conducting research and development on reducing train driving energy, which accounts for more than 70% of our energy consumption. The challenges to overcome in that include reducing equipment loss, increasing regenerative energy, and achieving energy-conserving train driving. As the first step to tackle those issues, we conducted a survey on the actual energy consumption in commercial operation, gaining basic data to work out energy conservation measures. In this paper, we will give an overview of energy consumption measurement in commercial operation and analysis of the results and also introduce our efforts to reduce energy consumption in train operation.

●Keywords: Driving energy, Regenerative braking, TIMS, Simulation

1 Introduction

Energy for train operation accounts for more than 70% of the total energy consumption by JR East. The Environmental Engineering Research Laboratory is thus carrying out research and development with an aim of reducing the amount of energy needed for train operation. To achieve that aim, different types of technological advances with considerable energy conservation effects have been achieved; those include returning the energy regenerated at braking to the overhead contact lines and putting VVVF inverters into practical use. JR East is gradually employing those technologies to new rolling stock; however, such significant innovation is not likely to be seen within a couple of years.

Under these circumstances, three major issues have to be overcome in order to reduce the amount of energy needed for train operation: reducing the energy loss at equipment, increasing regenerative energy, and energy-conserving driving of trains. The Environmental Engineering Research Laboratory conducted a survey on actual energy consumption in commercial train operation (measurement of driving energy) and is using the results of that as basic data in examination and development of specific energy conservation measures. This paper will give an overview of driving energy measurement and analysis of the results, and it will also introduce our efforts to reduce energy consumption in train operation.

2 Measurement and Analysis of Driving Energy

2.1 Overview of the Measurement

2.1.1 Lines and Rolling Stock Measured

Starting with measurement using a Series 205 train on the Sagami Line in 2011, we have completed measurement of driving energy on four lines and are continuing to measure on one line as of the end of 2015 (Table 1). In order to understand actual energy consumption on lines with diverse characteristics, measurement is conducted on lines such as a commuter line (Yamanote Line), a suburban line (Shonan-Shinjuku Line), a limited express line, and a Shinkansen line. Items to be measured on the individual lines are as follows.

(1) Commuter line (Yamanote Line): On one of the lines with the densest operation in the JR East area, we conducted analysis of regeneration throttling and impact of passenger load factor. We simultaneously conducted measurement at substations to analyze the energy flow between the train and wayside equipment.

(2) Suburban line (Shonan-Shinjuku Line, etc.): On suburban lines with relatively long intervals between stations, we are planning to analyze driving energy and look into issues such as fluctuation of overhead contact line voltage and regeneration throttling.

(3) Limited express line (Chuo Line): We are planning look into the situation with energy of electric brakes equipped to Series E257 express rolling stock (the brakes consume regenerative energy with the resistors built in to the vehicle), as well as analyze the driving energy consumption when limited express trains are operated on the line.

(4) Shinkansen line: We analyze the impact on driving energy of the maximum speed and the operation method and also the energy-conserving effect of driving operations.

Table 1 Lines and Rolling Stock for Driving Energy Measurement

Period	Operation type	Line	Rolling stock
2011	Commuter	Sagami Line	Series 205
2012 - 2013	Commuter	Yamanote Line	Series E231
2013 - 2014	Shinkansen	Tohoku Shinkansen, etc.	Series E5
2014 -	Limited express	Chuo Line	Series E257
2015 -	Suburban	Shonan-Shinjuku Line, etc.	Series E231

2.1.2 Measurement Method and Measured Items

Driving energy is measured and recorded using the Train Information Management System (TIMS) implemented to Series 231 and other rolling stock. As TIMS constantly collects information of the whole train set, simple and synchronous measurement can be conducted (except in measurement using Sagami Line Series 205 rolling stock having no TIMS and measurement of the traction circuit power of Shinkansen rolling stock). Fig. 1 shows an overview of the measurement system of a Series E231 train on the Yamanote Line as an example. We modified the software of TIMS, VVVF, and air conditioners and connected a recorder to TIMS. In addition to recording existing data, we modified the program to, for example, calculate the

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status of regeneration throttling using VVVF and transmit the calculation results to TIMS.

On the Yamanote Line, we conducted measurement using 10 train sets in order to analyze how the cars in a train set affect each other. We also measured using multiple train sets of Series E257 and E231 trains for suburban lines that are coupled/uncoupled as needed in operation.

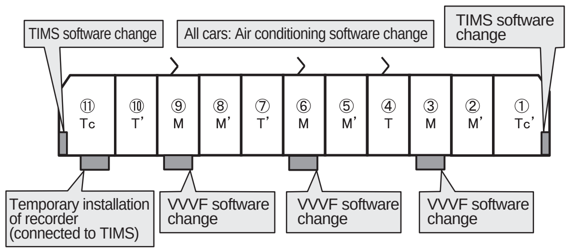


Fig. 1 Measurement System Configuration on the Yamanote Line

The items measured were mainly energy data such as overhead contact line voltage and current, amount of regeneration throttling, and energy consumption by air conditioners and auxiliary equipment along with operation data such as dates/times, locations, types of driving operations actually taken, outdoor temperature, and passenger load factors. Those allowed us to analyze driving energy according to the driving operations, locations, and passenger load factors. The recording interval is 200 msec., taking into account the data volume and analysis accuracy.

Due to the huge data volume, we developed a special analysis tool for efficient analysis (see 2.3).

2.2 Examples of the Measurement Results

2.2.1 Yamanote Line Series E231 Rolling Stock[1)]

As an example of measurement results, we show the occurrence of regeneration throttling. Fig. 2 shows the occurrence of regeneration throttling for a train set from start to end of operation on a day. Regeneration throttling occurred only with the last train set of the operation of the day, with the amount of regeneration throttling for one loop traveled on the Yamanote Line being approx. 11 kWh. That was merely 0.15% of the approx. 7,300 kWh of total regenerative energy of a day. As the almost same tendency was seen on the other days too, we could conclude that regenerative energy is effectively used on the Yamanote Line with almost no occurrence of regeneration throttling.

Fig. 3 shows the fluctuation of overhead contact line voltage while regenerative brakes activated (data for four days). Overhead contact line voltage was almost constant at regeneration in any section of the line. This also indicates that regenerative energy is effectively used in balance with the load on the Yamanote Line.

Those results showed the possibility that regenerative braking could be more widely used on the Yamanote Line with its dense train operation, and this information was incorporated to the design of the traction circuit of the latest, Series E235, rolling stock.

2.2.2 Shinkansen Series E5 Rolling Stock

As an example of measurement results, Fig. 4 shows the energy consumption measurement results for the *Hayabusa*, the fastest

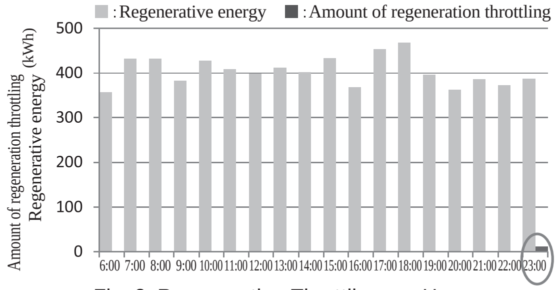


Fig. 2 Regeneration Throttling per Hour

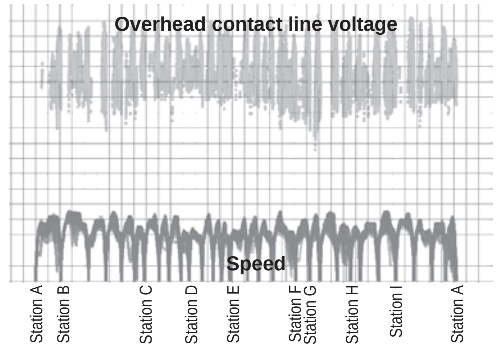


Fig. 3 Overhead Contact Line Voltage Fluctuation (at regeneration)

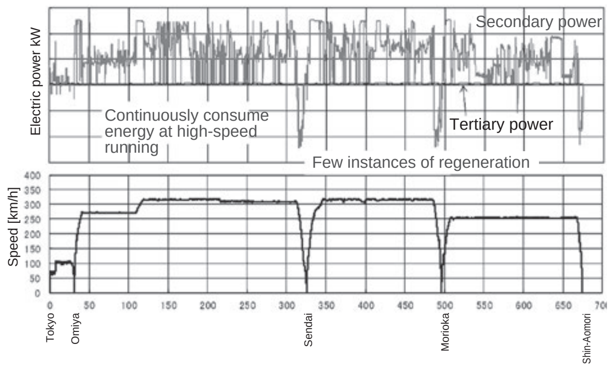


Fig. 4 Comparison of Energy Consumption in Constant Speed Control

Shinkansen service (between Tokyo and Shin-Aomori). As energy consumption to maintain high speed operation is overwhelmingly large and the number of times the brakes are applied is small, regenerative energy is understandably small too. As an energy conservation measure with the Shinkansen, improvement of constant speed control at high speed would be the most effective.

2.3 Development of an Analysis Tool

As driving energy is measured over a period of about a year, data volume is so large that organization and analysis of the data requires much time. It is also difficult to find the data necessary for effective analysis. In light of that, we developed an analysis tool for effective and efficient analysis of driving energy. Fig. 5 shows an example of the screen of the tool. Using the tool, we could extract the required data in a short time by specifying time, section, passenger load factor, and the like. Also, graphs could be displayed easily, enabling visual examination. The tool is applicable to many lines, and we will make full use of it in future analysis.

For the tool, we used the Python programing language to enable data extraction and allow statistic methodologies to be used.

Python has modules for data analysis and scientific calculation, and its specifications take into account future expandability.

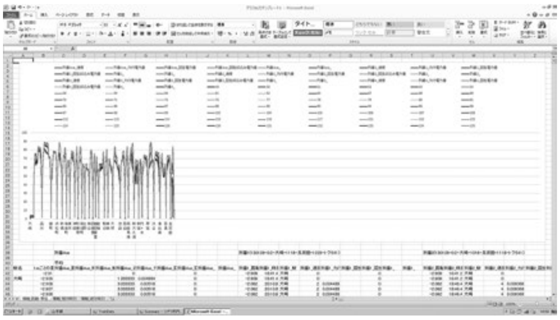


Fig. 5 Screen Example of the Driving Energy Analysis Tool

3 Work to Determine Energy-conserving Driving Operations

3.1 Study based on Yamanote Line Measurement Results

There is much past research and development on the effect driving operations have on driving energy (shown in train performance curves); however, no research based on data from actual running is found. We thus conducted analysis of driving energy differences between driving patterns based on the data of measurement for the Yamanote Line with an aim of establishing environmental friendly driving operations.

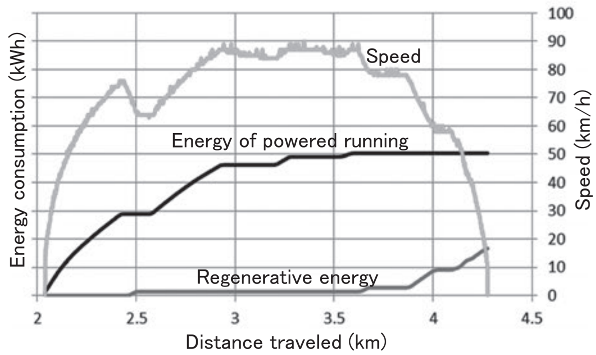
The Yamanote Line is a loop line in central Tokyo with a length of 34.5 km and 29 stations. To examine energy-conserving driving patterns, we chose sections of long (2.2 km) and short (1.3 km) intervals between stations and compared driving energy consumed in those sections. Fig. 6 and 7 show the examples of the electric energy consumed for running (energy of powered running - regenerative energy) and the driving patterns for the same driving time. In the section with a long interval between stations, the maximum driving energy consumed for running (a) increased by 60% over the minimum driving energy consumed for running (b). And in the section with a short interval between stations, (a) likewise increased by 13% over (b).

Fig. 8 shows the difference in the electric energy consumed for running per 10 seconds of driving in the section with a long interval between stations. This indicates that the longer the driving time, the smaller the electric energy consumed for running is. This means that energy-conserving driving operations in the margin time in the timetable between stations can be used create effective energy-conserving driving patterns.

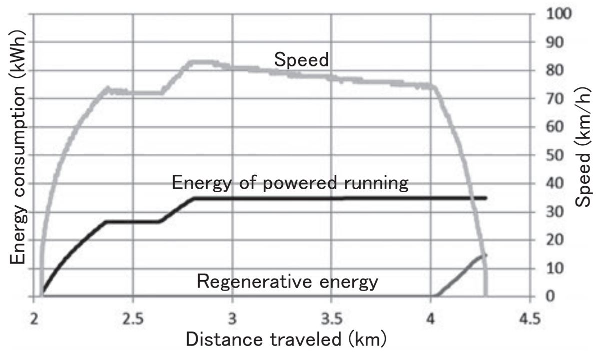
Those analyses clarified that the difference in driving patterns result in a difference in electric energy consumed for running, and that optimizing driving patterns produces major energy-conserving effects. As greater energy-conserving effects can be particularly expected in sections with long intervals between stations, we will give priority to establishing energy-conserving driving patterns for suburban and limited express lines, which have long intervals between stations.

3.2 Study Using a Simulator

As one of method of R&D for reducing driving energy, we developed an energy simulator that calculates driving energy of trains. In addition to the approach based on the measurement data described in 3.1, we are proceeding with study of energy-

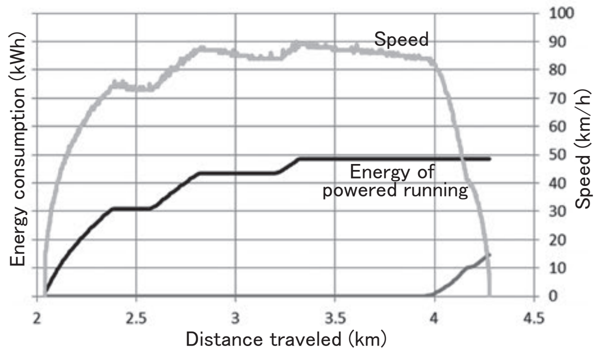


(a) Max. electric energy consumed for running (33.7 kWh)

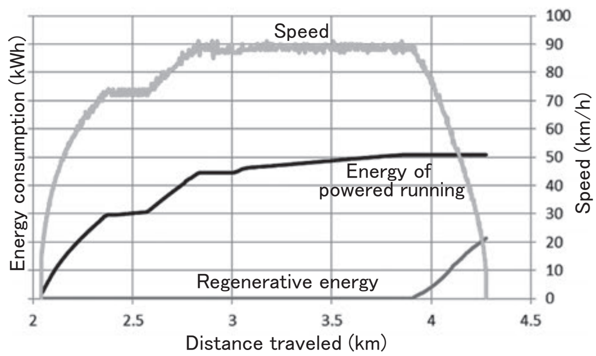


(b) Min. electric energy consumed for running (20.2 kWh)

Fig. 6 Train Performance Curves and Driving Energy (in long station interval)



(a) Max. electric energy consumed for running (20.7 kWh)



(b) Min. electric energy consumed for running (18.3 kWh)

Fig. 7 Train Performance Curves and Driving Energy (in short station interval)

conserving driving operations from the perspectives of both data and theory using the simulator.

Table 2 shows the examples of calculation results on the Ban-etsu West Line, and Fig. 9 shows train performance curves of that operation. Our examination of energy-conserving operations with varied parameters such as notching and handling timing produced a calculation result that driving energy could be reduced by 48%. This examination confirmed for us that detailed consideration of characteristics of individual lines is needed to tailor special driving operations for individual inter-station sections as gradient and station intervals are different from section to section. We are planning to utilize the developed simulator for purposes such as studying energy conservation in constant speed control, as is described in Chapter 4, in addition to for energy-conserving driving operations.

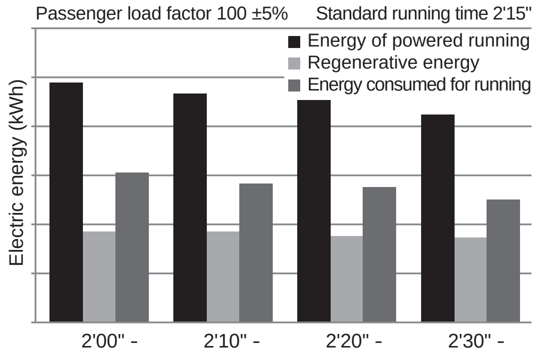


Fig. 8 Driving Energy per 10 Sec.

Table 2 Effects of Energy-conserving Driving Operations (on Ban-etsu West Line)

	Running time	Driving energy (kWh)	Regenerative factor
Current driving	3:28	7.5	75.8
Energy-conserving driving	3:29	3.9	87.0

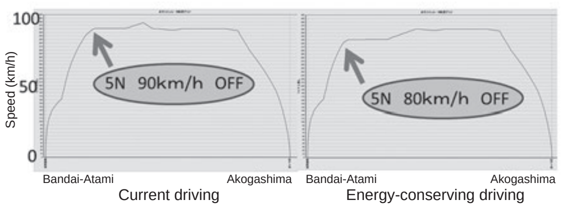


Fig. 9 Comparison of Driving Patterns

4 Aiming for Development of Energy Conservation Measures in Constant Speed Control

4.1 Energy Conservation in Constant Speed Control on Conventional Lines

Much development has been conducted in the areas of mechanical solutions and control methods with an aim of achieving energy conservation in traction circuit units. As one case of research including development of mechanical units, the Environmental Engineering Research Laboratory worked on the development of a traction circuit using SiC power devices and evaluated that on a test vehicle.2) As SiC devices have lower resistance and can be used at higher temperatures than with traditional Si devices, application of SiC devices is expected to broaden in the future.

One energy-conserving measure by improving the control method could be use of control system components at the most efficient performance points of the individual components. The efficiency of the traction motor in particular is not constant; it varies by running situation such as required torque. However, the torque pattern is determined according to the notch, speed, and load weight, without taking into account energy efficiency. Improvement of energy conservation can be thus achieved by using the traction motor intentionally at the point where it shows the most efficient performance. It goes without saying that we must maintain the torque required for the whole train set, so we will work on establishing a control method where the required torque is secured while efficiency is improved at the same time. As the first step of that, we plan to start with detailed analysis of efficiency of the traction circuit system components (traction motor, inverter, filter reactor, etc.).

4.2 Energy Conservation in Constant Speed Control on Shinkansen Lines

Measurement of energy conservation using Shinkansen rolling stock in commercial operation showed us that energy needed to maintain speed is tremendous on Shinkansen lines. As intervals between stations are longer and trains run at a constant speed for a longer time on Shinkansen lines compared to on conventional lines, constant speed control is often applied. Fig. 10 shows an example of power generation in constant speed control. This is just an example, but the train ran in the less efficient area (small electric power for powered running) for a long time in constant speed control, suggesting the possibility that loss of driving energy occurred. Focusing on that, we will proceed with future development of energy-conserving driving control methods.

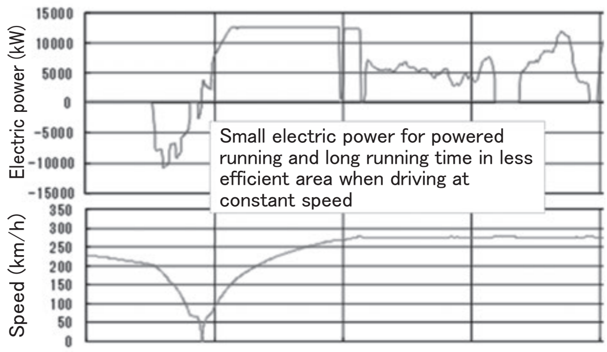


Fig. 10 Electric Power Generation at Constant Speed Driving

5 Conclusion

This paper has summarized different efforts of the Environmental Engineering Research Laboratory to reduce driving energy. As described, we are taking diverse approaches from analysis of data obtained in commercial operation to analysis by simulation. Using the data obtained and methods developed, we will further carry out development of a new traction circuit control method and consider methods for energy-conserving driving operations.

Reference:

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