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Reduction of Train Driving Energy by Energy-conserving Driving



Yuji Nomura* Takayuki Iida** Hideki Sonoda***

* Researcher, Environmental Engineering Research Laboratory, Research and Development Center of JR EAST Group
** Chief Researcher, Environmental Engineering Research Laboratory, Research and Development Center of JR EAST Group
*** Koriyama General Rolling Stock Center, Sendai Branch (previously at Environmental Engineering Research Laboratory)

Abstract

We developed a method to analyze train driving energy and driving operations in the past to create a train performance curve that is energy efficient among arbitrary stations satisfying requirements for the target running time. In order to confirm the effect, running tests were carried out by creating energy-conserving train performance curves for limited express trains of the Chuo/Shinonoi Line (Hachioji-Matsumoto) and suburban trains of the Tohoku Line (Omiya-Utsunomiya), and we confirmed that a maximum energy-conserving effect of about 20% can be expected.

●***Keywords*:** Train driving energy, Energy-conserving driving, Energy-conserving train performance curve, Driving operation

1. Introduction

JR East is aiming to reduce energy used in railway operations by 20% by fiscal 2030 (compared with fiscal 2013), and the Environmental Engineering Research Laboratory is working on energy-conserving driving to reduce energy use by modifying driving operation. In that, we measured train operating energy and the like of trains in commercial operation and studied methods of reducing energy consumption.[1)] As a result of analyzing that measurement data, we developed a method of creating train performance curves that will be energy-conserving (hereinafter, “energy-conserving train performance curve”).[2)]

In this paper, we report creation of energy-conserving train performance curves and on the effects of the energy-conserving running profiles by running tests for limited express trains of the Chuo Line and local trains of the Tohoku Line.

2. Creation of Energy-conserving Train Performance Curves

2.1 Energy-conserving Train Performance Curve

An energy-conserving train performance curve is a train performance curve where driving energy and vehicle status in commercial operation is analyzed and that which conserves energy the most while satisfying requirements for target running time between stations. The target running time is that in commercial operation, and the energy-conserving train performance curve can be applied without changing the current timetable. Past studies indicated that driving energy can be reduced by up to 20%.[2)]

2.2 Method of Creating Energy-conserving Train Performance Curve

Creation of an energy-conserving train performance curve is separated into three steps.

Step 1: Superimpose measurement data at interval between stations for which energy-conserving train performance curve created, determine separation point (point with small speed difference), and separate interval between stations into sections with the separation point as the boundary (see Fig. 1).

Step 2: Join measurement data separated at the separation point in all possible combinations to create joined profiles (see Fig. 2).

Step 3: From driving energy and driving time of all joined profiles, select the most energy-conserving joined curve out of those that conform to the set running time.

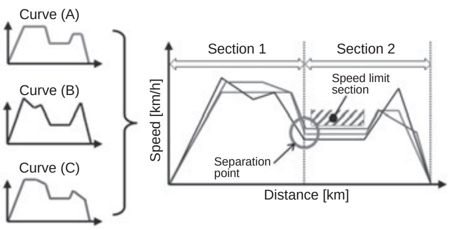

Fig. 1 Data Superimposition and Separation of Sections

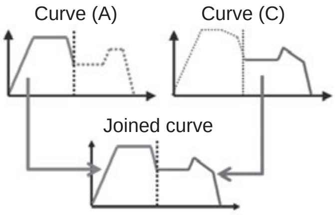

Fig. 2 Creating Joined Curves

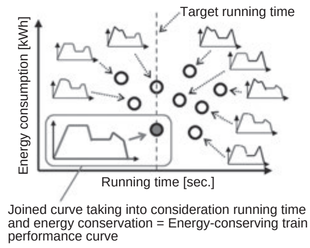

Fig. 3 Selection of Energy-conserving Train Performance Curve

3. Confirmation of Effect of Energy-conserving Train Performance Curve

3.1 Running Tests

Running tests were performed at night after commercial operation using rolling stock with measuring instruments temporarily attached. Driving was done by drivers being instructed of the energy-conserving train performance curve created and them driving as instructed (hereinafter, "energy-conserving driving"). Data measured in order to confirm the effect was speed, overhead contact line voltage, overhead contact line current, driving operations, and amount of various types of electric power (powered running, regenerative, rheostatic braking). Ordinary driving was also done and measured as comparison for confirming effects.

3.2 Test Results (Comparison of Energy-conserving Driving and Ordinary Driving)

(1) Energy consumption reduction effect

The energy consumption reduction effect compared with energy consumption at ordinary driving (hereinafter, "energy-conserving effect") was confirmed. Note that intervals between stations where running could not be done according to the target curve are omitted.

a) An energy-conserving effect of 8.5% to 25% overall and 1.4% to 54.3% in intervals between stations was seen on Chuo Line "Azusa" and "Kaiji" limited express trains, with energy-conserving effect of 5% or more confirmed in 26 of 28 intervals between stations (see Fig. 4 and Table 1).

b) An energy-conserving effect of 4.3% to 12.0% overall and -10.6% to 39.4% in intervals between stations was seen on Tohoku Line local trains, with energy-conserving effect of 5% or more confirmed in 17 of 25 intervals between stations (see Fig. 5 and Table 2).

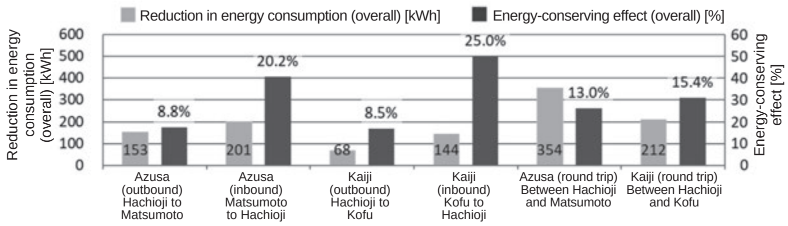

Fig. 4 Overall Reduction in Energy Consumption and Energy-conserving Effect on Chuo Line Limited Express Trains

Table 1 Reduction in Energy Consumption and Energy-conserving Effect in Intervals Between Stations on Chuo Line Limited Express Trains

	Departure station	Arrival station	Reduction in energy consumption (between stations) [kWh]	Energy-conserving effect (between stations) [%]
Azusa (outbound)	Hachioji	Kofu	73.4	9.9%
	Kofu	Nirasaki	13.1	8.4%
	Nirasaki	Kobuchizawa	8.4	1.4%
	Kobuchizawa	Chino	9.6	16.8%
	Chino	Kami-Suwa	13.5	36.9%
	Kami-Suwa	Shimo-Suwa	6.5	15.3%
	Shimo-Suwa	Okaya	5.8	13.9%
	Okaya	Shiojiri	14.1	23.7%
	Shiojiri	Matsumoto	8.3	45.2%
Kaiji (outbound)	Hachioji	Otsuki	24.8	5.0%
	Otsuki	Enzan	24.3	8.8%
	Enzan	Yamanashi	7.9	44.0%
	Yamanashi	Isawa-Onsen	0.5	7.0%
	Isawa-Onsen	Kofu	10.6	18.7%

	Departure station	Departure station	Reduction in energy consumption (between stations) [kWh]	Energy-conserving effect (between stations) [%]
Azusa (inbound)	Matsumoto	Enzan	6.3	3.0%
	Enzan	Okaya	7.9	5.5%
	Okaya	Shimo-Suwa	14.0	33.5%
	Shimo-Suwa	Kami-Suwa	3.6	13.4%
	Kami-Suwa	Chino	11.0	12.6%
	Chino	Kobuchizawa	17.1	7.7%
	Kobuchizawa	Nirasaki	23.7	9.2%
	Nirasaki	Kofu	9.8	54.3%
	Kofu	Hachioji	107.6	21.5%
Kaiji (inbound)	Kofu	Isawa-Onsen	20.4	43.3%
	Isawa-Onsen	Yamanashi	14.9	14.1%
	Yamanashi	Enzan	18.2	15.0%
	Enzan	Otsuki	44.0	21.0%
	Otsuki	Hachioji	46.4	50.4%

Energy-conserving effect ≥ 5% | Interval between stations where energy conservation effects could not be confirmed

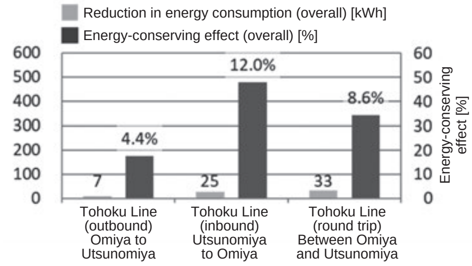

Fig. 5 Overall Reduction in Energy Consumption and Energy-conserving Effect on Tohoku Line Local Trains

Table 2 Reduction in Energy Consumption and Energy-conserving Effect in Intervals Between Stations on Tohoku Line Local Trains

	Departure station	Arrival station	Reduction in energy consumption (between stations) [kWh]	Energy-conserving effect (between stations) [%]
Tohoku Line (outbound)	Toro	Higashi-Omiya	2.0	31.0%
	Higashi-Omiya	Hasuda	2.2	15.1%
	Hasuda	Shiraoka	-1.6	-10.6%
	Shiraoka	Shin-Shiraoka	0.7	7.3%
	Shin-Shiraoka	Kuki	0.3	2.7%
	Kuki	Higashi-Washinomiya	0.8	7.5%
	Higashi-Washinomiya	Kurihashi	2.8	14.1%
	Kurihashi	Koga	0.7	2.0%
	Nogi	Mamada	-0.2	-1.6%
	Koganei	Jichi Medical University	-0.2	-2.2%
	Jichi Medical University	Ishibashi	0.0	-0.1%

	Departure station	Arrival station	Reduction in energy consumption (between stations) [kWh]	Energy-conserving effect (between stations) [%]
Tohoku Line (inbound)	Ishibashi	Jichi Medical University	3.4	21.0%
	Jichi Medical University	Koganei	1.1	13.1%
	Oyama	Mamada	4.2	17.7%
	Mamada	Nogi	2.9	19.1%
	Nogi	Koga	0.5	2.7%
	Koga	Kurihashi	-0.1	-0.3%
	Kurihashi	Higashi-Washinomiya	0.7	3.1%
	Higashi-Washinomiya	Kuki	3.1	34.4%
	Kuki	Shin-Shiraoka	1.3	10.2%
	Shin-Shiraoka	Shiraoka	1.7	14.3%
	Shiraoka	Hasuda	1.0	5.9%
	Hasuda	Higashi-Omiya	0.8	5.7%
	Higashi-Omiya	Toro	3.7	39.4%
	Toro	Omiya	1.0	9.3%

Energy-conserving effect ≥ 5%

Intervals between stations where energy conservation effects could not be confirmed

(2) Intervals between stations with large energy-conserving effect

Intervals between stations where large energy-conserving effect was seen have a common tendency in that maximum speed is reduced and braking is done to restore delayed running time to that scheduled, and this is assumed to be one form of driving operation that conserves energy. A Chuo Line limited express train from Chino to Kami-Suwa is used as an example (see Fig. 6).

In ordinary driving from Chino to Kami-Suwa, the train accelerates to around 120 km/h at 4 km from departure, but that is around 90 km/h in energy-conserving driving. The difference comes to 20 kWh, leading to a large energy-conserving effect of 39.6% in the interval between stations. One would assume the speed difference of 30 km/h would lead to a large difference in running time, but arrival time was 10 seconds earlier than with ordinary driving. The main reasons for that are that speed just after braking is higher in a speed limit section and that stop braking is applied with more force, therefore restoring running time to schedule.

The energy-conserving effect also tended to be large in intervals between stations where driving operations differed greatly. Driving operations tended to differ greatly on lines such as the Chuo Line with more gradients and speed limit sections than the Tohoku Line, resulting in the energy-conserving effect being high.

(3) Intervals between stations where energy-conserving effects could not be confirmed

A trend common to intervals between stations where energy-conserving effects could not be confirmed is that that driving ends up being the same. This is explained using intervals from Nogi to Mamada and from Hasuda to Shiraoka as examples (see Fig. 7 and 8).

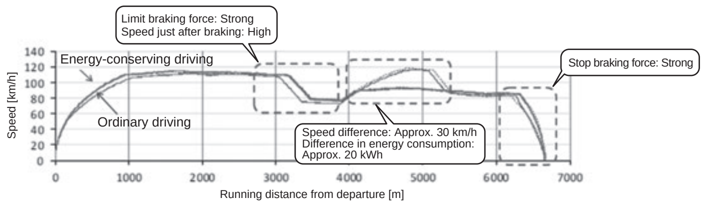

Fig. 6 Comparison of Energy-conserving Driving and Ordinary Driving Operations (Chuo Line, Chino to Kami-Suwa)

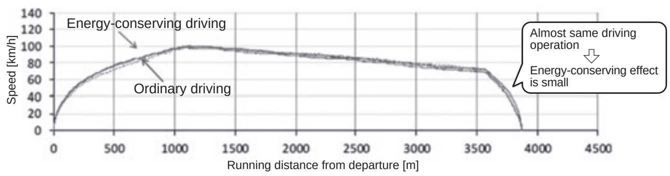

Fig. 7 Comparison of Energy-conserving Driving and Ordinary Driving Operations (Tohoku Line, Nogi to Mamada)

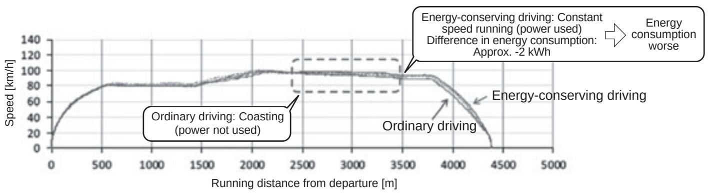

Fig. 8 Comparison of Energy-conserving Driving and Ordinary Driving Operations (Tohoku Line, Hasuda to Shiraoka)

From Nogi to Mamada, we found that the same driving was done with both energy-conserving driving and ordinary driving, accelerating to around 100 km/h after departure, then coasting and braking to stop. The reason for that is assumed to be that the interval between stations is short at approx. 4 km and there are no speed limit sections, meaning there is little leeway to change driving operations. In such intervals between stations where no difference in driving comes about, energy-conserving effects are small.

In the interval from Hasuda to Shiraoka was the interval between stations where energy conservation effects could not be confirmed at which power consumption increased the most. Confirming energy-conserving driving and ordinary driving there, we found that there was no difference due to driving operations, at that it was an interval between stations where it is difficult to achieve energy-conserving effects. With energy-conserving driving, constant speed driving was performed at around 2 km, but coasting would be done there with ordinary driving. Constant speed driving consumes power, although slight, and that resulted in a difference of approx. 2 kWh, and this is assumed to be the reason energy-conserving driving consumed more power than ordinary driving.

We believe that, in order to improve energy conservation effects, we will need to study in the future methods such as accumulating more data and constantly creating the optimum energy-conserving train performance curve.

4. Evaluation of Effects of Energy-conserving Train Performance Curve

From the results of running tests, we found the following regarding the energy-conserving train performance curve.

- An energy-conserving effect of 5% or more was confirmed in 26 of 28 intervals between stations for limited express trains of the Chuo Line and 17 of 25 intervals between stations for local trains of the Tohoku Line.
- In order to minimize energy consumption, maximum speed is lower and acceleration time is otherwise short.
- In order to secure running time, more braking force is applied for a shorter time in speed limit sections and when stopping.
- The curve is effective in sections with much gradients and speed limit sections and where differences easily come about from driving operations.

Meanwhile, the following are issues to overcome.

- The energy-conserving effect is small in intervals between stations where there are no differences in driving operations, and energy consumption may worsen in some cases.

From the above, we believe that the energy-conserving train performance curve is effective in actual driving, although there are issues to overcome.

5. Conclusion

In order to confirm the effects of the energy-conserving train performance curve developed, we created an actual energy-conserving train performance curve and performed running tests on limited express trains of the Chuo Line and local trains of the Tohoku Line. From the results of that, we confirmed energy conservation effects of 8.5% to 25% overall on limited express trains of the Chuo Line and 4.3% to 12.0% overall on local trains of the Tohoku Line. We also evaluated the effects of the energy-conserving train performance curve and extracted issues with it.

Into the future, we would like to go forward with studies in order to apply the energy-conserving train performance curve to other lines and overcome issues to obtain solid energy-conserving effects.

Reference:

1) Mitsuo Shinbo, Hiroshi Abiko, Hideki Fujita, Yoshiki Mizuguchi, "The Measurement and Analysis of the Driving Energy in Yamanote Line" [title in English], *Proceedings of the 20th Jointed Railway Technology Symposium (J-Rail 2013)* (2013).

2) Masataka Yokota, Tsutomu Miyauchi, Yoshiki Mizuguchi, and Hideki Sonoda, "A Study of Energy Saving Running Profile Based on Actual Driving Energy Data" [Abstract in English], *Proceedings of the 22nd Jointed Railway Technology Symposium (J-Rail 2015)* (2015).