Improvement of diesel electric locomotive traction system

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1. Abstract

In 1992, Japan Freight Railway Company (JR Freight) developed a diesel electric locomotive of AC traction motor driving system, type DF200 (6 axle drive, the output at wheel rim is about 1,900 kW), to enable high speed operation of freight trains in non-electrified section on main line in Hokkaido. We have replaced a diesel hydraulic locomotive, type DD51 (4 axle drive, the output at wheel rim is about 1,200kW) that had been used with type DF200, in order. We introduced 26 units of type DF200 locomotive.
The traction system of type DF200 is divided into two groups, each of group consists of a diesel engine, a synchronous generator coupled to the diesel engine, a 3-phase rectifier, 3 units of PWM control inverter equipments and 3-phase squirrel-cage induction motors. In total six traction motors are controlled individually by inverter equipments.
In the conventional system, we had been applied GTO for switching device and used slip frequency control. This time, we changed GTO to IGBT which having a high speed switching specific in 2005. And, control system was adopted 32 bit microprocessor system exclusively developed for locomotive. The vector control which was established by changing GTO to IGBT enabled locomotive running performance to keep it stable.
In addition, we developed synchronous generator to improve generating performance in the low revolution. In this system, engine revolution could be slow down at idling and low-notch operation, so the surroundings noise was decreased.
We would like to introduce the summary of this locomotive and this new traction system with the result of running test.

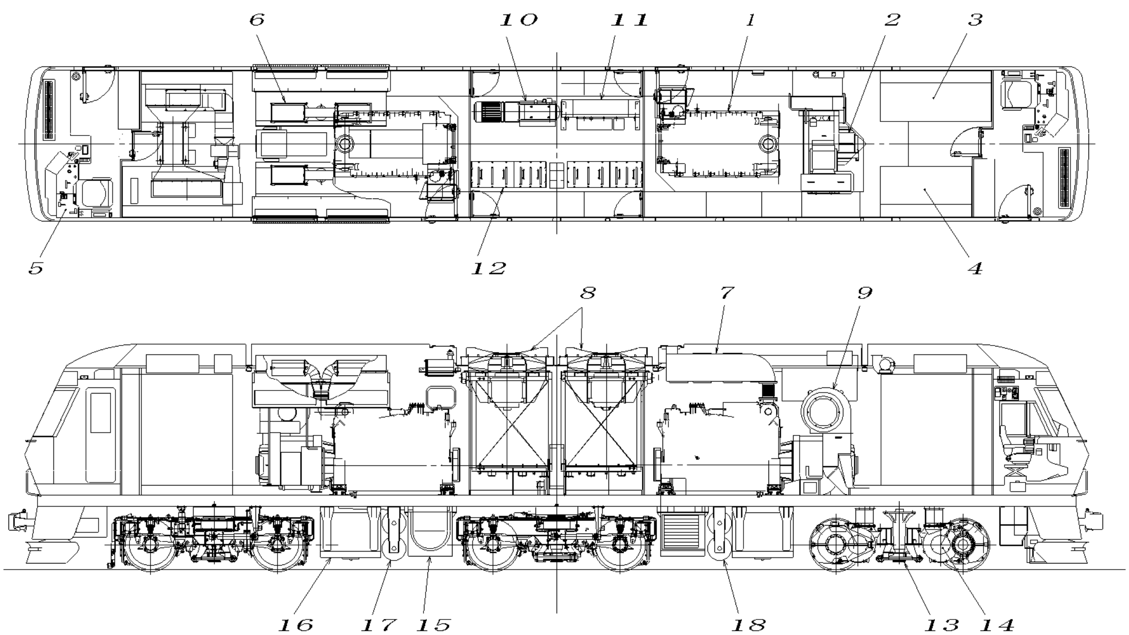
2. Introduction

The external appearance of type DF200 is shown in Fig. 1; the equipment layout in Fig. 2; the traction system in Fig. 3 and main specifications in Table 1.
Type DF200 is mainly designed to reduce the locomotive weight to enable to use on low class of tracks and to insure high-acceleration and high-speed performance. We understand that type DF200 is one of the best locomotives at worldwide, in point of engine output and mass of locomotive.
Main characteristics are as follows:

(1) The locomotive has six drive axles, each of them are controlled individually in order to provide increased starting tractive effort and starting acceleration with an optimum control of slip re-adhesion control.
(2) The locomotive has been installed two engines, and even if one engine fails, the locomotive can be operated with normal starting tractive effort.
(3) The axle arrangement is adapted B-B-B. Advantage of its axle arrangement reduces impact on track and bridge and improves high-speed running performance and curving performance.

Since the development of the first unit in 1992, we continued carrying out improvement of its performance, such as better stability of main alternator output control and enhanced engine output. However, the manufacture of the locomotive has been continued with the original designed traction system. In the meantime, technology related to the traction system, such as switching device and traction motor control system has made a great stride. Therefore, beginning with the locomotive made in 2005, we have incorporated the progress of switching device, and made improvement of the traction system design to improve performance and stability of control and to reduce impact on environment (reduction of noise).

Fig. 1: External appearance of type DF200



No.	Equipment	No.	Equipment	No.	Equipment
1	Diesel engine	7	Muffler	13	Bogie (bolsterless)
2	Main alternator	8	Cooling unit (with Radiator fan)	14	Traction motor
3	Main converter unit	9	Main blower	15	Brake resister
4	Auxiliary power supply unit	10	Electric air compressor	16	Fuel tank
5	Master controller	11	Brake control unit	17	Main air reservoir
6	Suction filter	12	Storage battery	18	Supply air reservoir

Fig. 2: Equipment location

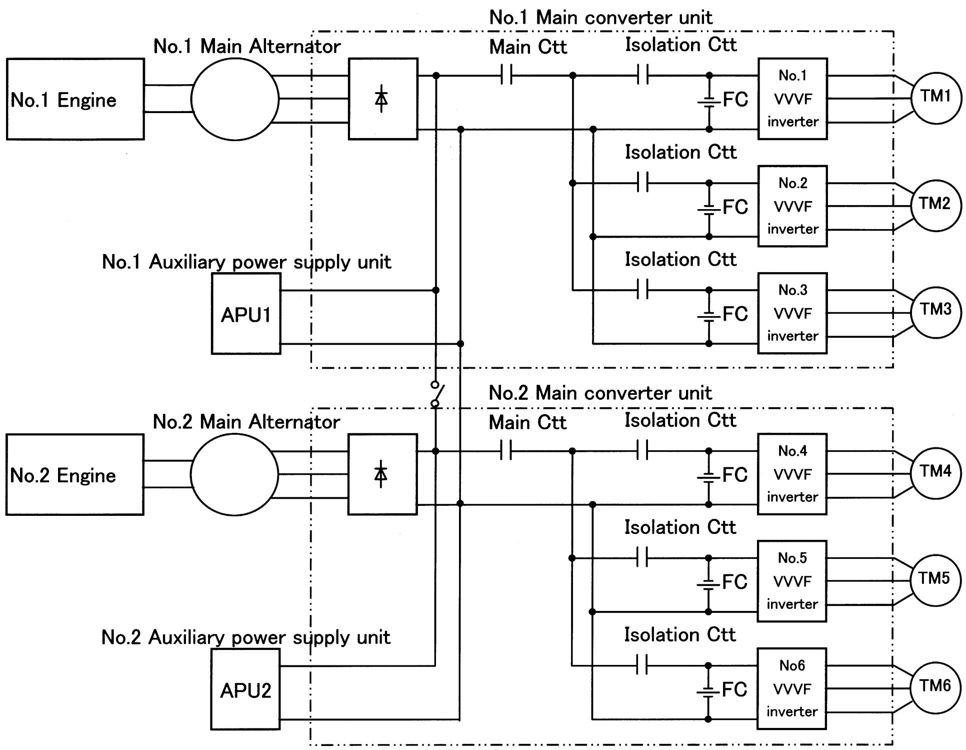


Fig. 3: Traction system

Axle arrangement	B-B-B
Size (length×width×height)	19,600mm × 2,800mm × 4,078mm
Mass in working order / Axle load	96.0 t / 16.0 t
Maximum running speed	110 km/h
Output at wheel rim	1,900 kW
Maximum tractive effort	294 kN (30 t)
Engine (output/revolution)	1,324 kW / 1,800 rpm
No. of engines	2
Control system	○ Engine synchronous speed control ○ Voltage control of revolving-field type synchronous generator ○ Voltage and frequency control by means of VVVF inverter ○ Re-adhesion control of wheel slip ○ Axle load transfer compensation control ○ Rheostatic brake control by means of VVVF inverter
Brake system	○ Electric command air brake combined with rheostatic brake

Table 1: Main specifications

3. Improvement of traction system

(1) Newly designed inverter and improved traction motor control

We have redesigned the inverter including change of switching device for the primary purpose of further enhancing the stabilization of traction motor control. From the time of its development, type DF200 has been used GTO (4.5kV – 1.0kA) for switching device. They have changed to the module type IGBT (3.3kV – 1.2kA). Also, for the processing unit, the 16-bit device was changed to a 32-bit high-speed operating unit specifically developed for locomotive. These changes made it possible to improve the efficiency of the device and stability of traction motor control.

The IGBT for switching device made it possible to greatly simplify snubber circuits and contributed to reduction of loss at switching. Furthermore, the cooler for switching devices was changed from heat-pipe type to air-cooled fin panel with no refrigerant, and the structure of the cooler device became simplified.

The maximum tractive characteristics for the speed range of 20 ~ 40 km/hr used to be decided in terms of restriction on the GTO switching loss (under multipulse-mode PWM modulation). With the new design, we have been able to improve the maximum tractive characteristics for this speed range, and establish almost constant output above 20 km/hr. (Please see Fig. 4)

We have used a 32-bit high-speed operating unit to change the traction motor control from slip frequency control to vector control. The use of vector control made it possible to further improve the stability of the traction motor control and slip re-adhesion performance. The slip re-adhesion control early detects the start of slippage by using speed signals from each axle, and it instantaneously reduces the torque of the traction motor in accordance with the amount of slippage, and facilitates re-adhesion.

(2) Newly designed main alternator and improved generating performance

Type DF200 uses revolving field type 3-phase synchronous generator for main alternator. With this improvement, we have redesigned the main alternator to secure the stability of field even with lower engine revolutions so that we can achieve reduction of external noise while idling or operating at a low-notch. In the conventional design, we installed a filter reactor between the rectifier and the inverter device to increase the control stability as the traction system. In the new design, we established circuit constants for the main alternator, after verification by simulation, in order to enable to dispensing with the filter reactor.

In addition to reducing the number of revolution of the engine while standing (idling), we also planned on expanding the voltage range of operating assurance voltage of the auxiliary power supply unit so that a stable behavior of the entire locomotive system can be realized.

Table 2 shows the set up of the number of engine revolutions to accord with idling and each operating notch.

Operating notch	The number of engine revolutions (rpm)	
	After improvement	Before improvement
Notch off (idling)	750	850
1 notch	900	1120
2 notch	990	1180
3 notch	1240	1330
4 notch	1475	1475
5 notch	1610	1610
6 notch	1690	1705
7 notch	1745	1735
8 notch	1800	1800

Table 2: Set up of the number of engine revolutions

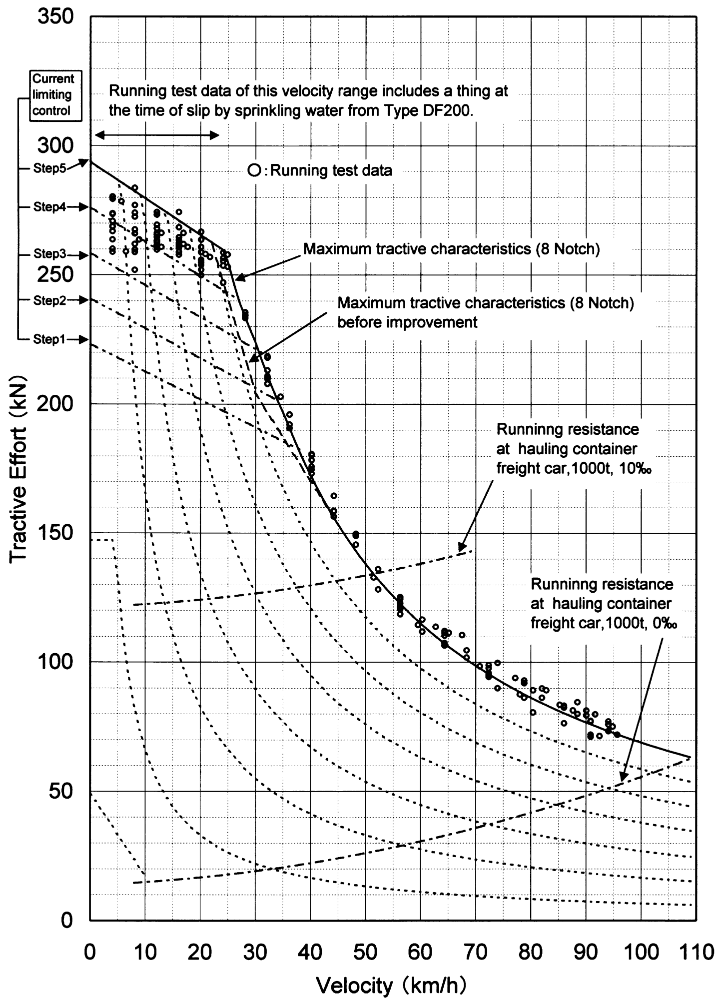


Fig. 4: Tractive characteristics

4. Benefits of improvement

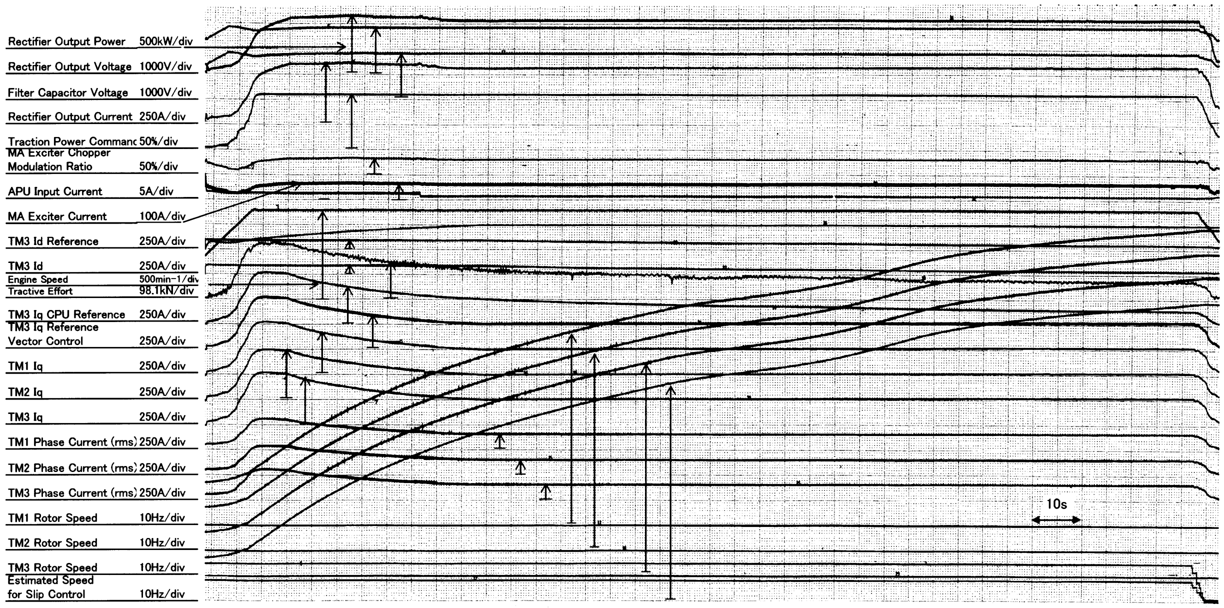
Fig. 4 shows the confirmed results of the tractive characteristics of the post-improvement drive system. In the chart the plot with ○ shows the results obtained from tractive effort measured by the coupler of type DF200 and acceleration of the train. The results of measurements show that the planned performance has been mostly satisfied.

Fig. 5 shows the results of acceleration tests by the maximum characteristics (8 notch) while the locomotive is hauling 880 tons of high-speed container cars. It shows a smooth control from the start to a high-speed range.

The re-designed traction system is of a simple configuration, having dispensed with the filter reactor mentioned earlier.

In the conventional system, we continued using engine control and main alternator excitation control in order to stabilize unstable generating condition when the number of the engine revolutions was undershot in case of notch off. This time, we made it possible to maintain stable generating condition even if we did not use such a supplementary control by having carried out improvement of ability for generation of the main alternator and improvement of auxiliary power supply unit.

External noise level at idling was reduced by 2 ~ 4 dBA (as measured at 12.5 meters from the center of track).



MA: Main alternator, APU: Auxiliary power supply uint, TM: Traction motor

Hauling weight: 880 tons (container freight car)
Shape and gradient of the running tracks: Straight and level (almost)
Conditions of the running surface of rail: Dry

Fig. 5: The results of acceleration test by the maximum characteristics (8 notch)

5. Conclusion

The improvement of the traction system of the diesel electric locomotive (type DF200) characterized by light weight and high-acceleration, high-speed performance has yielded the following benefits:

(1) Tractive characteristics were improved.
(2) Starting acceleration performance was further stabilized.
(3) The traction system was simplified.
(4) The main alternator output control was further stabilized.
(5) External noise was reduced at idling and low-notch operation.