Recent Activities for Research and Development of Railway Vehicle Technology

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The Railway Technical Research Institute (RTRI) has developed a master plan for the fiscal year 2020 and beyond, as a roadmap guiding RTRI towards the realization of its vision: “We will develop innovative technologies to enhance the rail mode so that railway can contribute to the creation of a happier society.” As a matter of course, we also carry out R&D in the vehicle field according to the master plan. This journal carries the six latest research and development results in vehicle fields. In addition, this report outlines four other research results.

**Key words:** vehicle, crashworthiness, vehicle running safety, driving support, vehicle status monitoring, energy simulation

1. Introduction

RTRI started a new Master Plan, ‘Research and Development Creating the Future of Railways RESEARCH 2025’ in FY2020 [1]. As the basic policies of research and development, this Master Plan lists (1) enhancing safety with an emphasis on improving resilience to natural disasters, (2) Developing innovative railway systems based on digital technologies, (3) Creating high-quality results by taking advantage of our collective strength. RTRI is now actively conducting research and development in line with these basic policies in relation to railway vehicles. This issue of the Quarterly Review includes six papers reporting on R&D carried out in line with these basic policies. This paper meanwhile, summarizes four additional papers that have so far obtained outcomes, and gives an overview of vehicle research and development carried out as part of RTRI’s Master Plan.

From the beginning of FY2020, the spread of the COVID-19 pandemic has had a significant impact on society and the way we live, creating a very different context to the one which existed when the Master Plan was drafted. As such, railway-related research and development is also changing, and is under constant review. Consequently, RTRI’s policies and research and development program may change significantly in the future.

2. Research and development in the vehicle field in RESEARCH 2025

Building on the previous Master Plan, RESEARCH 2025 has also set R&D goals which encompass safety, cost reduction, harmonization with the environment, and better convenience. Vehicle research and development is therefore related to all of these four goals. Table 1 lists both fundamental R&D issues and those more directly related to the goals. With an emphasis on issues such as labor shortages due to falling birthrates, an aging population and the subsequent decrease in railway users, the new plan includes research that aims to develop railway technology into the relatively medium-to-long term, such as the utilization of digital technologies.

| Table 1 Major R&D issues related to the vehicle field |
|------------------------------------------------------|
| **Research and development for the future**          |
| Improving labor efficiency by digital maintenance    |
| Increasing Shinkansen train running speeds in harmony with the trackside environment |
| Low-carbonization of electric railway systems through cooperative control of the power network |
| Sophistication of simulation technology               |
| Development of practical technologies                |
| Safety improvements                                  |
| Harmony with the environment                         |
| Improved convenience                                 |
| Running safety and stability of rolling stock        |
| Degradation mechanisms and inspection methods        |
| Friction, wear and increasing longevity of materials |

3. Vehicle research and development

This section summarizes four areas related to vehicle R&D, including projects that have achieved outcomes in the last fiscal year and in FY 2020.

3.1 Impact-energy absorbing structure that suppresses deformation of the aluminum alloy car body in a crash

If a railway vehicle collides with an automobile or another object, for example, in a level crossing accident resulting in severe damage to the railway vehicle, recovery of the vehicle may take a long time, which may affect train services [2]. Thus, to achieve earlier recovery of the vehicle after a level crossing accident, we are studying the basics of a replaceable impact-energy absorbing structure to be applied to a car body made of conventional line aluminum alloy, which is difficult to repair. We propose to place a replaceable impact-energy absorbing structure in front of the underframe (floor structure), which has relatively high strength and stiffness, as shown in Fig. 1.

Since the underframe is to be attached to the existing car body,
we have developed specifications feasible at low cost without the need for large-scale design changes. To verify the effect of this structure, we conducted a crash analysis with a heavy-duty truck (vehicle weight 9.2 tons, no cargo) as the crash object. In the full wrap condition with a crash speed of 54 km/h, a large deformation was observed in the main structural section (i.e. underframe) when there was no impact-energy absorbing structure. However, when the impact-energy absorbing structure was used, it reduced maximum deformation by approx. 77%. Figure 2 shows maximum deformation and reduction rate of the main structural section (i.e. underframe) in the different crash conditions. This result, for example, assuming that a maximum deformation amount of 10 mm is allowed, suggests that early recovery of the vehicle may be achieved if the crash speed is up to about 55 km/h in the full wrap condition, up to about 60 km/h in the 1/2 wrap condition, or up to about 80 km/h in the 1/4 wrap condition, which shows that the impact on operations can be minimized.

3.2 Method for evaluating vehicle running safety by bogie behavior [3]

Railway vehicle running safety is commonly evaluated using lateral force and wheel load measurements, which are cost and labor intensive, because, for example, of the need to change wheelsets to dedicated ones (measuring wheelsets). For this reason, we have constructed a system that can easily evaluate vehicle running safety, with minimal effort and cost, for commercial vehicles by using measured data that can be obtained simply by attaching sensors to the bogie frame without the need for special measuring wheelsets (Fig. 3). We verified the estimation accuracy of wheel load and lateral force based on the main track running test results and examined the validity of the estimation method.

The main track running test results for this system provided us with the following findings:

- The bogie frame yawing angular velocity has a higher correlation with the lateral axle load than with the outer rail side lateral axle load. Even if the wheel/rail friction coefficient drops significantly, for example, due to rainfall, this correlation does not drop significantly (Fig. 4).

- Since the lateral axle load is not easily affected by the wheel/rail friction coefficient, the outer rail side lateral axle load corresponding to the friction coefficient can be estimated if the turning lateral force is calculated using an arbitrary inside rail lateral force / wheel load ratio (equivalent to wheel/rail friction coefficient).

- As a result of investigating that difference in the correlation between the measured and estimated values that is generated from the difference in the filter process, we found that the correlation increases by the low-pass filter process and that effect is large especially in the wheel load.

- The investigation result of the estimation error from the measured values showed that the lateral force was within 4 kN in approx. 80% of the cases. Without the filter, the error of the wheel load...
was remarkable due to the large wheel load of high frequency; however, by 10 Hz filtering, the error fell within 4 kN in approx. 80% of the cases and the difference of the derailment quotient was within 0.1 in over 95%.

From the above, we can conclude that in utilizing this method, the wheel/rail friction coefficient should be set to a large value to secure a margin for estimation error, and the filter process should be performed.

In future, we will acquire bogie behavior data for various railway vehicles to demonstrate the validity of this evaluation method and endeavor to improve the estimation accuracy of high-frequency components (>10 Hz).

3.3 Driver advisory system reflecting driving situation

The advantages of rail freight transport include the fact that, compared to road transport, arrival times can be fixed without the need to worry about traffic conditions and that rail transport consumes a smaller amount of energy per unit of transported volume. Until now, in the driving of freight trains, energy consumption has not been considered as much as the running time, but recently, a driving/maneuvering method has been studied that intends to achieve both together [4]. Therefore, in the driver advisory system, based on the position and speed information from the satellite positioning system, we are developing a system that predicts the speed estimate curve for multiple driving/maneuvering method candidates and, from among these, proposes the one(s) that should be recommended (Fig. 5). With this system, it is possible to support train operation according to operating conditions, promote on-time train operation, and achieve energy-saving driving.

This system predicts the speed estimate curve from the running point based on the position and speed information from the satellite positioning system by using the track information and the train set information about the locomotive and freight wagon. The simulation for the speed estimate curve performs a real-time calculation with the on-board tablet based on the driving energy simulation technology developed by RTRI. In reality, we extracted only the simulation functions with a large effect on the prediction accuracy and implemented them in the driver advisory system.

The system selects driving recommendations from the resulting speed estimate curve candidates, determines support information in line with the driving point, and presents them to the driver in real time by voice output and screen display (Fig. 6).

Further, we conducted actual running tests for freight trains which primarily pass through most stations, and verified the drivability/maneuverability and punctuality using a prototype system. We collected feedback from drivers who said, “We only had to make a few changes to our driving during operation which was good.” In addition, we verified that the train was able to pass stations almost on time with an accuracy of within about 15 seconds from the specified time.

In future studies, we aim to select different trains, for example, in terms of the line section and scheduled speed, to verify the driver advisory system with special emphasis on drivability/maneuverability and punctuality through actual car running tests. In addition, we expect to make improvements to the prototype system, by, for example, (i) speeding up driving recommendation searches by predicting the speed estimate curve, (ii) proposing driving methods with high drivability/maneuverability, (iii) display driving support in a way which does not add any burden on the driver, and (iv) improve point detection accuracy.

3.4 Current difference/acceleration detection type wheel-slip re-adhesion control for one-inverter, four-motor vehicle [5]

Today’s electric trains commonly use a main circuit system, which concurrently drives multiple traction motors collectively using one inverter. It refers to, for example, the 1C2M system, which drives two traction motors with one inverter, or the 1C4M system, which drives four traction motors using one inverter. The traction performance can be expected to be improved for many trains by applying a wheel-slip re-adhesion control method to 1C4M electric train, which is one of the main types of vehicle used in Japan, since RTRI has so far developed such methods for the 1C1M locomotive and 1C2M electric train.

Since the 1C4M electric train controls four traction motors collectively using one inverter, the occurrence of a wheel slip has a large effect on acceleration performance. Therefore, it requires torque control that suppresses wheel slip by effectively using adhesive force. Thus, we have applied, to the 1C4M train electric train, the combined equipment of the “Acceleration Detector”, developed for 1C1M locomotive, and the “Current Difference Detector” for 1C2M electric train (Fig. 7). This can reduce the amount of torque reduction during wheel slip, resulting in improved acceleration performance. The 1C4M electric train has six combinations of current...
differences between four traction motors. However, focusing on the fact that the current of the traction motor on the wheel slipping axle has the characteristic that it decreases from the command value, we interpreted the total decrease in the traction motor current on all axes as the current difference. As a result, we have implemented a simple configuration that can detect the signs of wheel slipping with only one current difference detector set.

We conducted a verification test using a 3M3T suburban train to verify the effectiveness of this control method. The test resulted in higher control of the average torque and improvement of approx. 5% in the average acceleration of the train (Fig. 8). In addition, the ride comfort level (Lt value) has been reduced by approx. 3 dB and the maximum car body vibration has also been reduced by approx. 30%. Wheel-slip re-adhesion control performance can be achieved in over 90% of existing conventional line vehicles by adopting three wheel-slip re-adhesion control methods: this new control method, the one for the 1C1M system, and the one for the 1C2M system. In addition, Shinkansen trains, most of which use the 1C4M method, can use this new control method and, and their acceleration performance can be expected to be improved in the high-speed range.

4. Conclusion

This paper summarized four R&D papers each addressing a technology that is expected to be put into practical use soon. Specifically, it summarized studies on safety improvement (e.g. ensuring safety in a crash with an object such as an automobile, evaluating vehicle running safety) or highly practical studies contributing to harmony with the environment (e.g. energy-saving driving support, improved acceleration performance of electric trains).

In accordance with the Master Plan, RTRI will pursue its work to improve safety, find innovative solutions for the railway system using digital technologies, and generate high-quality results that demonstrate the comprehensive strength of the railways as a system, as well as in the field of railway vehicles.

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