Recent Research and Development into Vehicle Technology

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RTRI was involved in approximately 300 research themes in the fiscal year 2018 to 2019. Among them, 48 were related to rolling stock technology, covering a wide range of themes, in practical, applied and fundamental research, such as: the increase in train running speed and improvement of ride comfort, applied research such as running stability and reliability of rolling stock, and elucidation of the mechanisms leading to wheel wear. The three topics from amongst this research and described in this paper are: “Evaluation of bogie hunting stability,” “Active bogie frame steering system ensuring both running stability and curving performance,” and “Technique for predicting bogies vibration according to running conditions based on the transfer characteristics between axle boxes and evaluated Points.”

Keywords: rolling stock, running safety, speeding up, hunting motion test, steering system, bogie vibration

1. Introduction

As part of its long-term vision “RISING” (Research Initiative and Strategy - Innovative, Neutral, Global) which sets the future direction to be taken by research, and in order to realize this vision, the Railway Technical Research Institute (hereinafter referred to as RTRI) drew up the 5-year basic plan “RESEARCH 2020 - Creating Innovative Technologies” for the fiscal years (FY) 2015 to 2019. During the fourth year of this five-year plan in 2018, each division/laboratory engaged in research linked to rolling stock reviewed their progress, with a view to prioritize work and target outcomes to meet railway operator needs. The change in the total number of Research & Development themes at RTRI, and change in the number of Research & Development themes undertaken by vehicle system laboratories in RTRI for the past 5 years are shown in Fig. 1. There are 9 vehicle system laboratories in total, including the Vehicle Structure Technology Division, Vehicle Control Technology Division and Railway Dynamics Division. Between them, they have engaged in about 40 themes at the beginning of each fiscal year. The total number of themes covered at RTRI shown by points joined by a line in Fig. 1 fluctuates between 270 to 290, and the vehicle system themes correspond to about 15% of the total number.

Fig. 1 Number of themes researched in vehicle related laboratories being implemented (beginning of FY)

When classifying the number of vehicle related areas covered in FY 2018 (48 cases at the beginning of the fiscal year) according to the Research & Development direction, 40% involve “Improvement of safety,” as shown in Fig. 2, a trend generally reflected throughout RTRI, in particular, articles regarding improvement of running safety & collision safety, and diagnostic and assessment technologies. In vehicle systems research the percentage of total number of themes related to “harmony with the environment” and “improvement of user convenience” was higher than that in other RTRI research divisions, i.e. projects including topics such as energy saving measures or trackside noise reduction, and increasing running speeds and ride comfort, etc.

An example of this type of cross-cutting cooperation can be found in work relating to safety of vehicles against cross winds and fire prevention, where the vehicle systems division works in cooperation with the Environmental Engineering, Material Technology, Disaster-prevention Technology, Human Science, etc. divisions in the course of their work.

As examples of recent achievements in vehicle systems research in this regard, the following section gives a brief over view of the outcomes to: “Evaluation of bogie hunting stability,” “Active bogie frame steering system

Fig. 2 Classification of themes according to R&D direction of 9 vehicle system laboratories in FY 2018

ensuring both running stability and curving performance,” and “Technique for predicting bogie vibration according to running conditions based on the transfer characteristics between axle boxes and evaluated Points.”

2. Evaluation of bogie hunting stability [1]

It is possible to evaluate the running stability (hunting limit speed) of a bogie through stationary rotation tests using the roller test rig in RTRI (Fig. 3). However, the critical hunting speed can vary depending on how initial shaking is applied (e.g., excitation conditions of the rollers). If the evaluation result of critical hunting speed is sufficiently higher than the running speed of bogies in commercial operation, this kind of variation does not interfere. In order to evaluate stability in more detail, work is underway to elucidate the conditions that generate hunting oscillation.

When the rotation speed of rollers is gradually increased without excitation, hunting oscillation occurs at a certain speed (“occurrence speed”), and if the rotation speed is gradually decreased from the occurrence speed, the hunting oscillation converges at a certain speed (“convergence speed”). In the range of speed between the convergence and the occurrence speed, the excitation conditions of the roller determine whether the bogie will reach hunting oscillation or not. Therefore, various excitation conditions were tested to experimentally determine the conditions under which hunting oscillation occurs (Fig. 4).

The results indicate that the amplitude of lateral displacement of the wheelset, which occurs immediately after excitation (“initial amplitude”) has an upper limit at which the vibration converges. If the initial amplitude does not reach this upper limit (marked by circles in Fig. 4), after excitation, the vibration converges. On the other hand, when excitation conditions exceed this limit (marked by crosses in Fig. 4), the vibration diverges and reaches hunting oscillation, and the regular amplitude rapidly increases close to the limit, where it contacts the flange. Also, this upper limit decreases steadily as the rotational speed of the wheels increases from the convergence speed to the occurrence speed. Before this test, to compare running stability with different bogie specifications, fixed excitation conditions were used. However, with the results above, it is possible to adjust the excitation conditions so that the initial amplitude becomes constant and make a comparison with reduced variation in the limit speed evaluation values.

Fig. 3 Rotation tests using the roller test rig

Fig. 4 Occurrence conditions of hunting oscillation

The next objective is to develop an analytical or numerical method that quantitatively estimates the relationship between the running speed and the upper limit of the initial amplitude and build a running stability evaluation method that does not require a large-scale stationary rotation test using the roller rig.

3. Active bogie frame steering system ensuring both running stability and curving performance [2]

A bogie frame steering system was developed that features both running stability and curving performance. It accomplishes this by controlling the turning angle of the bogie frame relative to the body, which reduces the lateral force in curved sections, and by operating as a passive yaw damper in high-speed straight sections. Unlike the wheelset steering method, this system does not require a special linking mechanism to be mounted on the un-sprung masses i.e. axle boxes, which prevents increasing the mass of the bogie.

This bogie frame steering system is composed of three elements: the steering control device, which detects a curve and calculates the steering command, the hydraulic steering actuator, which can also operate as a passive yaw damper, and a mechanical bogie angle detection mechanism that prevents reverse steering and miss-steering in straight sections (Fig. 5).

A bogie turning test that simulated a bogie running through a curve, conducted on a commercial line, confirmed that it is possible to reduce the bogie turning moment by approximately 77% through steering control (Fig. 6). Also, a steering stability test confirmed that the system could ensure running stability equivalent to that of current

Fig. 5 Bogie frame steering system

Fig. 6 Reduction of turning moment in bogie rotation test

Fig. 7 Reduction of average lateral force in running test on test track

vehicles. Also, an running test confirmed that it is possible to reduce the average lateral force when passing through a curve with a radius of 160 meters by approximately 56% (Fig. 7).

This system is effective for rolling stock used on intercity services that may be subject to large lateral forces when passing through sharp curves or when the curve passing speed is increased, and it can be installed in existing vehicles equipped with conventional passive yaw dampers.

4. Technique for predicting bogie vibration according to running conditions based on the transfer characteristics between axle boxes and evaluated points [3]

The vibration that occurs in the bogie of a running railway car may be related to the loosening of bolts and fatigue in parts and components. Japanese Industrial Standards [4] (JIS E 4031, "JIS" below) stipulate the vibration resistance properties required in vehicle components, but the values of vibration acceleration specified by JIS were "measured from actual railway cars in operation and provided by related institutions of around the world." Therefore, these values do not indicate whether vibrations were measured during actual operation and under every possible condition, while understanding this issue is important to prevent

incidents such as components becoming detached. Nevertheless, since it is not easy to measure vibrations of a running bogie on a commercial line, it is necessary to develop a method that can easily identify and evaluate different vibration conditions.

With this background in mind, a method is being developed to estimate the acceleration of the evaluated points of a bogie according to running conditions by numerical calculation. This method considers a transfer function that takes axle box acceleration, which is considered to be highly correlated with track displacement (the main cause of bogie vibration), as an input, and acceleration of the evaluated points on the bogie as an output. This transfer function is determined through a vibration measurement test conducted at a depot or maintenance factory ("in-house test" below), which is easier to carry out than large-scale running tests. In the running test, only the axle box acceleration is measured [5, 6].

As a result of such activities, a method was proposed that estimates the acceleration PSD at the evaluated points of a running bogie. This method combines the transfer function between the acceleration of the axle box and evaluated points of the bogie, estimated with the in-house test carried out at a car with the axle box acceleration measured at a commercial line (Fig. 8 and 9). Initially, an impact test in a stationary state was being considered for the in-house test, but it was confirmed that the accuracy of the estimation increases with the use of in-house running data. Also, using the accelerations in the left/right and forward/backward directions of the axle box as inputs, in addition to the acceleration in the vertical direction, contributed to even more accurate results.

However, different vehicle models and running sections resulted in different levels of accuracy. This is thought to be caused by the amplitude dependence caused by the non-linear properties of the spring and anti-vibration rubber, but further investigation is required.

Lastly, considering that vibrations can be caused by track conditions and, depending on the evaluated points in the bogie, also in the electric motor, combustion engine, and drive unit, future plans are to incorporate the influence of these factors into a widened scope of analysis and provide more accurate estimations.

Fig. 8 Outline of bogie vibration estimation method

Fig. 9 Procedure of vibration estimation method (schematic diagram)

5. Conclusions

The findings presented in this article are examples of the results obtained from Research & Development conducted in the field of vehicle technology. Future work will continue focus on improving running safety as well as ride comfort, while other research will concentrate on themes clarifying railway-specific problems, improvement of non-destructive inspection accuracy, labor-saving in maintenance, etc., and deeper cooperation with relevant research divisions.

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