Development of single axle truck for new generation commuter vehicles

by

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SUMMARY
Recently the single axle truck was paid attention for new rail vehicles in Europe and other countries. The Japan Railway Engineers’ Association had a project to develop a single axle truck for new generation commuter vehicles especially for trains in suburban area or LRT with light weight and low initial cost from 1997. The objective of this study is to achieve the compatibility between stability and curving performance, and truck response for track irregularities. The main concept is the appropriate setting of the primary and secondary suspension and the use of the connection linkage for traction between car body and truck frame. The computer simulations were made for suitable design to get high hunting stability and low lateral force on curving negotiations. The response for track irregularities was also evaluated by theoretical analysis. One set of the trial truck was made and experiments were carried out on the test stand in the Traffic Safety and Nuisance Research Institute of Ministry of Land, Infrastructure and Transport, Japan, on which it is possible to test not only the hunting stability but also curve negotiation. The test results were evaluated with computer simulations and truck specifications were modified for running test on commuter lines. The final trucks were tested on experimental running test on one of the private commuter lines near Tokyo. The running tests up to 100 km/h were successfully made. Although the little bit large body oscillations were observed at the higher speed region, no truck hunting were occurred and the safety for running stability was proved. For curving performance, the experiments with the very tight curve of 160 m curve radius were made. The measured lateral force of the leading outer wheel was kept in low values and was less than that of the conventional two axle bogie vehicles in comparison. The computer simulations with the multibody dynamics software were also made. From the comparison with experimental results good agreement was found. From these results, a single axle truck was successfully developed and tested. The developed trial truck is expected as a prototype for new generation commuter trains.

1. INTRODUCTION
The use of the single axle truck is increasing for the new generation of rail vehicles in these days. In Europe there are several commercial uses of the single axle truck for LRT, commuter trains and so on. These trials are based on the merits of the single axle trucks[1]. There is only one axle in a truck, so the weight of the truck should be reduced. The simple structure also contributes to the low initial and running cost of vehicles. The low floor vehicle is very attractive to accessibility of passengers for getting on. The single axle truck is suitable for the low floor vehicle for LRT or commuter trains in suburban use. The length of the car body should be shortened to keep the wheel load in the maximum track capacity. However the short body enables to have a wide body because the amount of over hung and deviation in tight curve sections were reduced. So, it contributes to high capacity for commuter trains. The single axle truck has truck frame and secondary suspensions. So, it is very different from the conventional two axle vehicles for freight wagon. There are few theoretical examinations of dynamic characteristics for this type of vehicles. In this study theoretical analysis for dynamic stability and curving performance of the single axle truck were focused. From the results of the theoretical study, design concept for compatibility between stability and curving performance is discussed. Finally trial test trucks were manufactured for running tests.
These examinations were made as a project[2-5] of Japan Railway Engineers’ Association to develop and evaluate the single axle truck for commuter train in suburban area or LRT vehicles in the city area in Japan. The objective of the project is to develop the single axle truck with high performance, light weight and low cost for manufacture and maintenance. This paper describes the summary of the development of the single axle truck by this project. In this project the running performance of the trial truck was examined by theoretical and experimental studies. In tests, stand tests and running test in main lines using one car were made. The layout and photo of the trial test truck is shown in Fig-1. The main concept is the appropriate setting of the primary and secondary suspension and the use of the connection linkage for traction between car body and truck frame. The normal rigid wheelset is used for this truck. For the secondary suspension coil spring is used with bolsterless type. The anti-yaw damper and lateral damper can be set for stability test and compared with the case without dampers.

![Photo and layout of experimental single axle truck](image)

Photo and layout of experimental single axle truck

2. THEORETICAL STUDIES

2.1 Vehicle model

In theoretical studies, a full vehicle model is used as shown in Fig. 2. The truck model is shown in Fig. 3 based on the design concept of the single axle truck described in the previous chapter. The number of the body considered in the model is seven such as one car body, two truck frame, two wheelset, and two linkage of traction. The degrees of freedom are 21: lateral, yawing and rolling motions are considered for car body and truck frame. Only lateral and yaw motion are set for wheelset as usual analysis. For linkage of traction, lateral, vertical, pitching and yawing motion are considered.
Vehicle model with single axle truck

Truck model
2.2 Theoretical estimation of stability

The eigen value analysis was made for examination of stability. It was said that one of the drawbacks of the single axle truck has less stability of hunting motion. So, the main interest in the study is focused on how to avoid low stability for hunting especially body hunting. Another subject to solve for dynamics of the single axle truck is improvement of characteristics of track irregularity response. For this object, the development project also treated as an important theme and the results of examination is reported in another paper [4].

One of the results of calculation of the critical speed of the hunting motion is shown in Fig. 4. The critical speeds caused by truck hunting and body hunting motion were plotted as a variable of the lateral stiffness of the secondary suspension. The large lateral stiffness is desirable for avoidance of truck hunting motion as usual, however, this condition causes body hunting. Then this stiffness should be set to low value as shown in figure. However, the critical speed of the truck hunting must keep appropriate value. In the analyses, primary stiffness and rigidity of the bush of the traction linkage were also examined. Finally suitable values of stiffness were gained to avoid truck hunting and body hunting in operation speed.

![Graph showing critical speed of single axle truck](image)

Critical speed of single axle truck

2.3 Curving simulations

For examinations of the curving performance, numerical simulations using multibody dynamics software A'GEM [6] were made. Figure 5 shows one of the calculation results of curving simulations. The vehicle speed is 65 km/h on the 400 m curve radius with balanced condition.

![Graph showing results of curving simulations](image)

Results of curving simulations
The calculations were made by changing truck parameters and track and running conditions. The effect of the curve radius and stiffness of the secondary suspension were shown in Fig. 6 and 7. Figure 6 shows lateral force acting on the leading wheelset. The results of outer and inner wheel were also plotted in the two cases of stiffness, soft and hard. The lateral displacements of the wheelsets were also shown in the figure. The ratio of lateral and vertical force ($\frac{Q}{P}$), attack angle of the wheelsets of truck were plotted on Fig. 7.

![Lateral force and displacement in curving simulation](image)
Curving performance of single axle truck in curving simulation

The large curve radius condition (R>500m), the single axle truck has superior performance such as very small attack angle and lateral force. In the tight curve condition, the attack angle rapidly increases. Then the lateral force also increases. The flange contact occurred in R<400m. However, the value of the lateral force itself is small. The truck has potentially good curving performance. In the single axle truck, the stiffness of the secondary suspension has an effect on the curving performance like the primary stiffness. For the comparison between soft and hard stiffness of the truck, the bogie angle of soft stiffness case is larger than that of hard one. Then the better performance is expected as usual. However, the attack angle is little bit worse in soft stiffness. Anyway there are not so differences between them.

3. EXPERIMENTS USING TEST STAND

3.1 Test stand
The experimental trial truck was tested for stability and curving performance on the test stand at the Traffic Safety and Nuisance Research Institute, Ministry of Transport, Japan (Now, National Traffic Safety and Environment Laboratory). The outline of the stand test and photo are shown in Fig. 8. Original feature of the test stand is designed for half body with two axle truck. Two wheelsets are set on two roller rigs. In this study, the authors tried to examine the one car body with two single axle trucks. However, the wheelbase of the car is set to 5 m in minimum case and this value is impossible in the test stand. Then, only one truck is set on the rig and another truck was fixed on the base.

The test stand has a function to simulate curving condition. The roller rig can set to yawing to simulate curve radius. The rolling speed of the left and right roller rig can also be set as different speed between inner and outer wheel. Then the curving condition is approximately achieved.
3.2 Stability and curving performance of trial truck
Some results of the stand test are shown in Table 1. Experiments were made in changing several truck parameters such as secondary stiffness, lateral and yaw damper, and so on. The critical speed for hunting exceeds 200 km/h even without anti yaw damper. The condition of the hard secondary stiffness with lateral damper has good stability.

In the curving test, low lateral force was measured in almost experimental conditions. The effects of the stiffness on the curving performance were also similar to the calculation results. Then the theoretical estimation by numerical simulations was verified in the experiments. No remarkable large lateral force was observed for running test.

<table>
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<tr>
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<th>Soft secondary suspension</th>
<th>Hard secondary suspension</th>
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<tbody>
<tr>
<td>with lateral dumper</td>
<td>over 200 km/h</td>
<td>over 200 km/h</td>
</tr>
<tr>
<td>without lateral dumper</td>
<td>about 170 km/h</td>
<td>about 180 km/h</td>
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4. EXPERIMENTS FOR STABILITY IN RUNNING TESTS
The running tests were made in June, 2000 at the section between Inzai-Makino-hara and Imba-Nihon-Idai of Hokusou-Kodan line which is one of the commuter lines in the metropolitan Tokyo area connecting between Tokyo Central and Chiba prefecture in which Narita airport located. The extended section was used just before opening for commercial operation. Up to 100 km/h running tests were made in straight track. A fright wagon is used as the test body for the trial single axle truck because there is no suitable passenger car body for present commuter trains. The traction of the test vehicle is carried out by normal commuter trains of four car set with conventional two axle truck.

The measured lateral oscillations of the body in the running test at 100 km/h were shown in Fig. 9. Although little bit large lateral oscillation on the floor at the trailing truck was observed, no remarkable vibration was observed on the floor at the leading truck. Consequently the performance of the truck up to 100 km/h is proved by running test.
5. EXPERIMENTS FOR CURVING PERFORMANCE IN RUNNING TESTS
The curving tests were also made at the 140 m and 300 m curve radius sections which are tight curve sections in the depot of the commuter line shown in Fig. 10. The measuring of the performance was made in both on-board and rail. Figure 11 shows the method of grand measuring of lateral force of wheel, wheel load and attack angle. The force was measured by strain gauge on the rail. The attack angle of the wheel was measured by laser sensor. The merit of grand measuring is that it is possible to detect attack angle of wheel. Moreover, it is possible to collect data for all axles without sensors on wheel.

Measured body lateral oscillation in the running test at 100 km/h
Track condition of curving test

The lateral forces measured at the high rail in the 140 m curve radius section were plotted on the Fig. 12. The results of the conventional two axle truck for commuter trains also plotted on this figure. The lateral forces of the trail single axle truck are less than that of the conventional truck. Figure 13 shows lateral force and attack angle of the leading wheelset of the single axle truck. The calculation results were also plotted. In the running test, measured date with dry rail condition and wet condition by rain were obtained. The lateral force dramatically reduced in the wet condition in which the friction coefficient is estimated as 0.1 although the attack angle of wheel is almost same. The calculation results also plotted on the figure for comparison with measured one. It was found that good agreements between them were shown. From these investigations, the improved curving performance of the proposed single axle truck was verified.
Lateral force of outer wheel of the leading axle in curving test at R 140 m

Comparison with simulation results of attack angle and lateral force in curving test
6. CONCLUSIONS
A single axle truck for commuter trains was developed from the theoretical examinations under the project of “Development of a single axle truck for new generation commuter vehicles with light weight and low initial cost” at Japan Railway Engineers’ Association. The basic concept is:
1) Appropriate setting of suspension stiffness by theoretical dynamic analyses
2) Use of linkage for traction between car body and truck frame
3) Normal rigid wheelset
The developed trial trucks were examined in stand test and running test in commuter line for hunting stability and curving performance in tight curve. With experiments and numerical simulations of the developed actual truck, superior curving performance and suitable stability up to 100 km/h were verified. For the next step of the development, optimal design of the stiffness and development of new devise for single axle truck is expected. These researches are now under going. The authors hope that this study is helpful to promote the single axle truck for new generation vehicles with simple structure, light weight, low cost, low floor, and short and wide body in Japan.

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