Development of an Active Suspension System for Railway Vehicles

by

Yoshiyuki Maruyama / Bogie Trucks Development Sec., Corporate R & D Lab.
Koichiro Ishihara / Dr. Eng., Manager, Bogie Trucks Development Sec., Corporate R & D Lab.
Toshiaki Matsui / Bogie Trucks Design Sec., Kansai Steel Div.
Satoshi Koizumi / Assistant Manager, Bogie Trucks Design Sec., Kansai Steel Div.

Synopsis

The faster a train runs, the more difficult it becomes to provide good ride comfort. We have developed an active suspension system for railway vehicles for such situations. Last year, we used a Series 500 Shinkansen for the endurance test of an active suspension system. The result of endurance test showed the efficiency of an active suspension system, which could provide good ride comfort in high speed running of railway vehicles. We have also made some modifications to the active suspension system to increase its reliability. As a result, an active suspension system for railway vehicle is now ready for utilization.

1. Introduction

From this spring, West Japan Railway Co. has started commercial use of the new Series 500 Shinkansen shown in **Photo 1**. This newly developed train is one of the fastest trains in the world, with maximum speed of up to 300km/h.

This news indicates the current trend of the railway business. Recently, many railway companies have tried to develop high-speed trains. When trains run fast, traditional passive suspension hardly provides good ride comfort. In particular, vibration of the tail end of a train becomes very strong. An active suspension system for railway vehicles has been developed to improve ride comfort in such situations.

We have developed active suspension systems for railway vehicles for a long time[1]. Last year, we used a Series 500 Shinkansen for the endurance test of an active suspension system. The result of this test showed the efficiency of an active suspension system. By adopting an active suspension system, lateral acceleration was drastically decreased and riding comfort improved to an excellent level.

In this test, some modifications to the active suspension system have made for producing commercial products. As a result, the basic technology for an active suspension system has matured and is ready for commercial use.

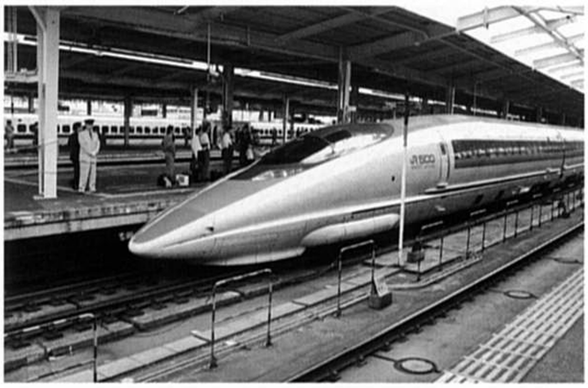

Photo 1 Series 500 Shinkansen

2. System Configuration

Figure 1 shows the schematic diagram of an active suspension system.

The unique feature of an active suspension system is the existence of an actuator between car body and bogie trucks. Both pneumatic and oil hydraulic actuators are available for an active suspension[2]. Since railway vehicles normally carry air compressors, a pneumatic actuator does not need an addi-

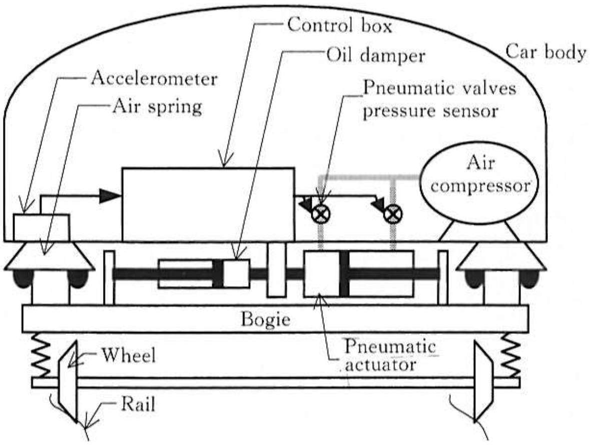

Fig. 1 Schematic diagram

tional power source and is more suitable for railway vehicles.

If we want to fit an active suspension system, the following modifications are necessary.

First, actuator units consisting of pneumatic actuators, pneumatic valves, and pressure sensors are fitted between car body and bogie trucks parallel to an oil damper. This is the most significant difference between railway vehicles which have an active suspension system and which do not have. Pneumatic valves receive the control signal from a control box and govern airflow into the pneumatic actuator. Pressure sensors observe the motion of actuator as a change of pressure inside the actuator and feed back this information to the control box.

Second, the control boxes are carried under the floor or in the equipment room of a car body. Control boxes contain signal processing boards, which receive signals from sensors and generate control signals.

Third, accelerometers are installed in the car floor. These devices detect vibration of the car body. Usually, we use four accelerometers. Two of them are accelerometers to detect yawing and lateral vibration and set in diagonal line of car body. The others are accelerometers to detect rolling acceleration and are set on each side of the car body.

Figure 2 shows the typical location of each component of an active suspension system. **Photo 2** to **Photo 4** show the external appearance of each component.

An active suspension system for a Series 500 Shinkansen is basically identical with the active

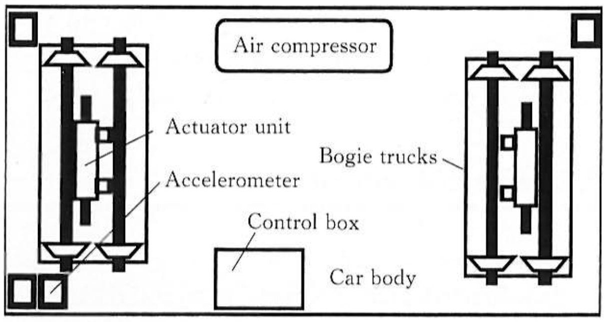

Fig. 2 Typical allocation of components

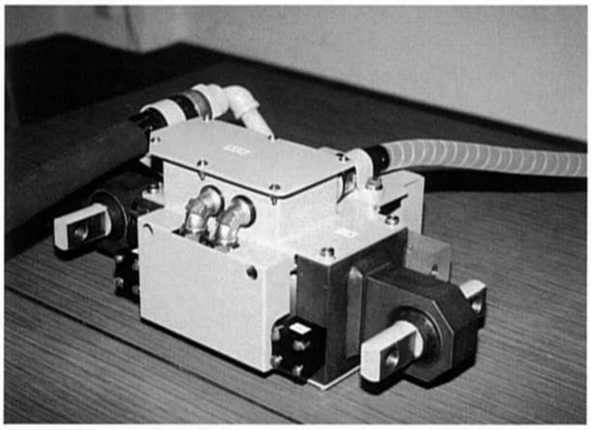

Photo 2 Actuator unit

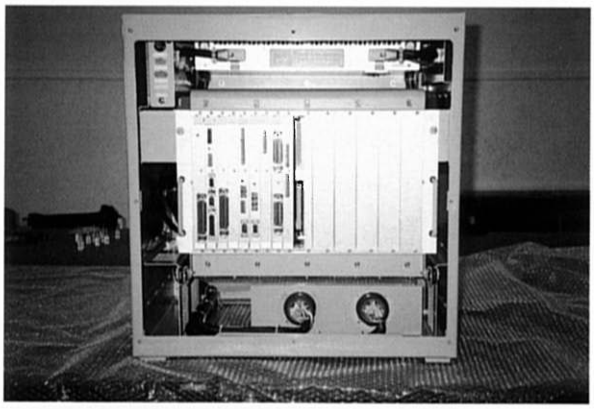

Photo 3 Control box

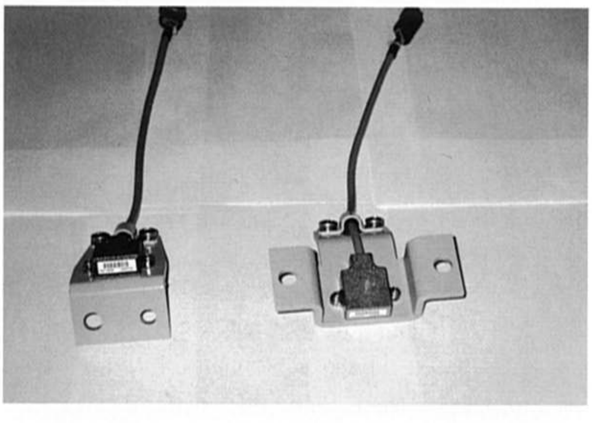

Photo 4 Accelerometer

suspension system for the WIN350 test car, but some functions such as signal ports for external parameter control are omitted for simplicity.

3. Design of Controller

Ride comfort strongly depends on vibration frequency. In particaular, frequencies from 1Hz to 3Hz have the largest effect. Thus, H-infinity theory suitable to obtain frequency range result has been applied to vibration control[3].

The vibration controller is designed to decrease yawing, rolling and lateral mode vibrations. Directions of each mode vibration are described in **Fig. 3**. These three modes are divided by input data from accelerometers and independently generated control signals. Yawing mode vibration is suppressed by a "Yawing Controller" and both rolling and lateral mode vibrations are suppressed by a "Rolling Controller". Before creating the output control signal, the yawing control signal and rolling control signal are recombined. **Figure 4** shows the signal flow of an active suspension system.

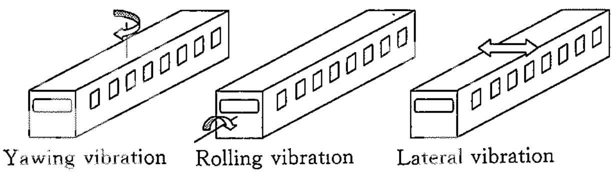

Fig. 3 Vibration mode

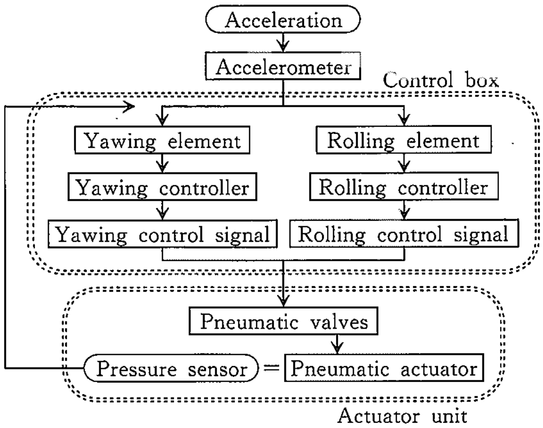

Fig. 4 Signal flow of system

The H-infinity controller for a Series 500 Shinkansen is based on the controller for the WIN350 test car. During the running tests using the WIN350 test car, we tried to improve the performance of the active suspension system. After testing several controllers, two useful controllers were found.

The "Open-air Controller" has its center of weight function near 2Hz where the resonance frequency of yawing mode vibration exists and is suitable for vibration control in open-air.

And so called "Tunnel Controller" have its center of weight function near 3Hz where aerodynamical disturbance are most remarkable and is suitable for vibration control in tunnels. The Tunnel Controller had derived from experience in the test of WIN350 test car and showed remarkable decrease of vibration when train runs in tunnels. However, it is very difficult to set the center of weight function to the resonance frequency of aerodynamic disturbance. because 3Hz is almost the upper limit of an active suspension system's ability to control the vibration. So, Tunnel Controller needs more examination than Open-air Controller.

Figure 5 shows the gain diagram of yawing acceleration and inverse of weight function of H-infinity controller.

In the endurance test of Series 500 Shinkansen, Open-air Controller has been examined.

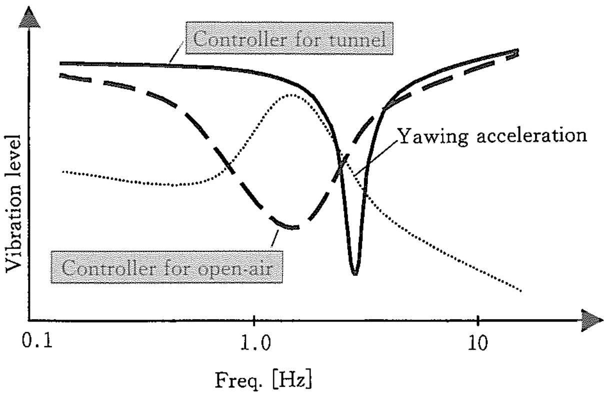

Fig. 5 Gain diagram of controller

4. Test Results

The endurance test on a Series 500 Shinkansen showed the efficiency of an active suspension system.

Figure 6 shows the frequency response analysis of lateral acceleration.

From 1Hz to 3Hz, car body vibration is drastically decreased by an active suspension system. However, from 4Hz to 5Hz and near 0.8Hz, an

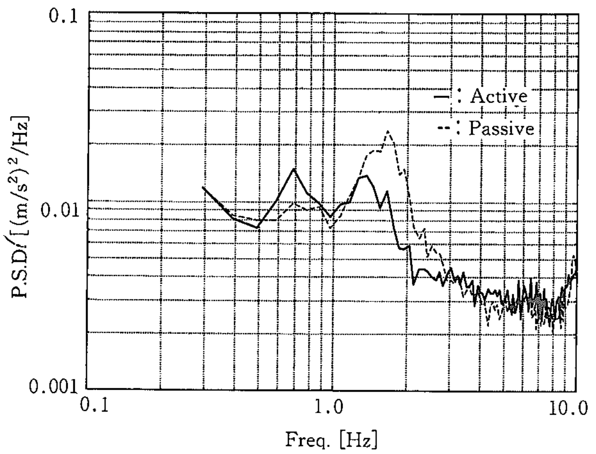

Fig. 6 Frequency response

active suspension system worsens the car body vibration. But in this range, car body vibration affects the ride comfort little. The results of ride comfort analysis presented in **Fig. 7** and **Fig. 8** clarify this point.

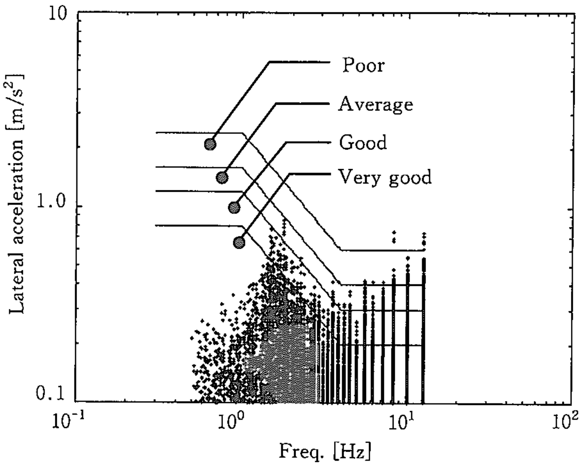

Fig. 7 Riding comfort analysis of passive train

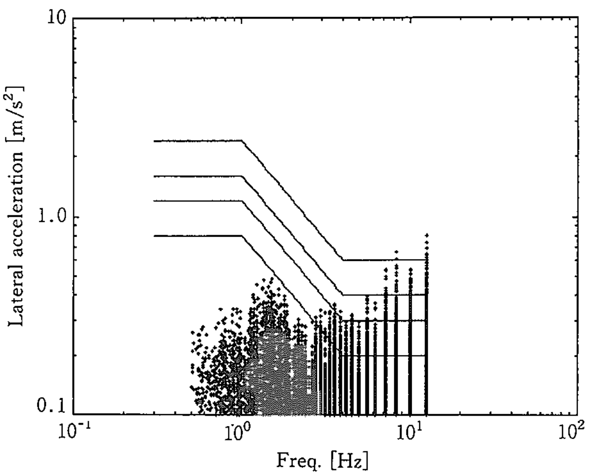

Fig. 8 Riding comfort analysis of active train

From 1Hz to 3Hz, ride comfort of an active controlled car is rated "very good", whereas a passive car is rated "average". Higher than 4Hz, both systems are rated "poor" and do not show any significant difference. This implies the adoption of an active suspension system can provide passenger comfortable travel.

5. Modification for Commercial Use

For a commercial product, not only performance but also reliability is required.

In the test of WIN350 test car we have already obtained good vibration control performance, and the main purpose of the test in the Series 500 Shinkansen is examination of system reliability.

First of all, a monitoring system has been fitted. This system enables the crew to observe the condition of the active suspension system. If an active suspension system suffers problem, the terminal of the monitoring system in the driver's cab shows an alert to the driver.

The second implementation to improve reliability is a self-diagnostic function. As shown in **Table 1** , two sets of diagnostics exist.

"Stand Still Diagnostics" are run every time active suspension system is turned on. This simple check takes about 30 seconds and mainly examines the connections of each component.

"Oscillated Diagnostics" are run by trigger signals from the monitoring system. This detail check takes about 10 minutes and examines the condition of each component of an active suspension system.

In oscillated diagnostics, the controller is putting out signals to the pneumatic actuator to oscillate the car body. And at the same time, the controller checks the input from sensors by comparing them to the stored data of a parameter defining process. If the system does not have any defects, signals from sensors are the same as memorized data. If the system has any defects, signal from sensors have certain differences to the memorized data.

These diagnostics are based on the nature of control parameters. In the parameter defining process, the car body is oscillated by the pneumatic actuator and necessary information for the H-infinity controller, such as magnitude and direction of vibration corresponding to certain signals, reso-

Table 1 Outline of self check

	Stand still	Oscillated
Opportunity	After power on (every time)	After bogie exchange (in periodical overhaul)
Necessary time	About 30 sec.	About 10 min.
How to begin	Auto	External trigger
Item	•Connection of sensor •I/0 signal etc.	•Airtight of actuator •Actuator force •Direction of sensor set up etc.

nance frequency of each mode of vibration and so on, are gathered. As long as control parameters meet the actual condition of the train, an active suspension system functions precisely. In other word, we can know whether an active suspension system functions well or not by comparing the data of the parameter defining process at a certain time.

An active suspension system in WIN350 has already used this function. However, the oscillated diagnostics function in WIN350 could only be managed by experienced operators, and was not suitable for commercial use. In the Series 500 Shinkansen, more sophisticated systems are installed. In the series 500 Shinkansen, the result of oscillated diagnostics are displayed by the monitoring system, and special knowledge is not required to judge the result.

6. Conclusion

Both performance and reliability of an active suspension system have been examined in the endurance test using a Series 500 Shinkansen. The results of testing prove that an active suspension system has enough ability to be a commercial product.

Yoshiyuki Maruyama

Bogie Trucks Development Sec.
Corporate R & D Lab.

Phone: 06(466)6165

References

1) Koizumi et.al. "SUMITOMO METALS", Vol.46, No.4, 1994, pp.57-62

2) Negoro, Sasaki et.al. Theory of mechanism, "Japan Society of Mechanical Engineers", 1995, No.95-1, p.157

3) Hirata et.al. "An application of H-infinity Control for Actual Plant"(H∞制御の実プラントへの応用), 1996, pp. 156-187, SICE