Semi-Active Suspension System

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Vibration due to track irregularities and aerodynamic lateral vibration in tunnels worsen the ride comfort on Shinkansen cars and other high-speed rail vehicles. Since the vibration generating model for the vibration transmitted from trucks is different from that for the aerodynamic vibration that directly exerts force on the car body, the optimized damper characteristics become increasingly different for these two categories of vibration when the vehicle speed becomes higher. This means that optimization of passive suspension parameters alone cannot cope with these two cases.

The semi-active suspension system for Shinkansen cars was developed as a means to solve this problem with its effect to decrease vibration confirmed in running tests, and has been adopted for series 700 and 500 Shinkansen cars.

We developed the semi-active suspension system, the first one of its kind in the world to be used for revenue service trains, with safety and reliability as absolute prerequisite conditions, and have mounted on seven cars in a train-set including the cars equipped with a pantograph, first-class cars with special accommodations, and head/tail cars that are subject to large vibration.

To perform what is called the "sky hook control," the semisuspension system determines the speed of car body vibration from the output of the lateral acceleration sensor mounted on the car body at a position directly above the truck and produces a force in proportion to the vibration speed with a changeable lateral damper on the truck. The damping force of the damper is controlled by changing the combination of throttle holes that pass the working fluid with quick electromagnetic valves. The controller has damping force corresponding to the piston speed for each combination of throttle holes to look for damping force nearest the





Figure 1. Semi-active suspension system of Shinkansen train.

value required for sky hook control. Since this demands the measurement of piston speed, each damper has a built-in displacement sensor. See Fig. 1 for an outline of the semi-active suspension system.

This system also has an electromagnetic valve to release the force in the direction opposite to the damping force that is commanded by the sky hook control to realize Karnopps' method as the performance of hydraulic circuit. Attention is paid to ensure the fail-safe feature so that failure of a part does not lead to a dangerous state. When the power switch is turned off, the damper functions as a normal damper.

Figure 2 shows the ride comfort improved by the semi-active suspension system when a train ran at 300 km h^{-1} in a tunnel. In this test, the semi-active suspension was adopted for cars Nos. 5, 8 to 10, and 13. The car at the tail of the train was installed with one that produces the control force by pneumatic pressure. When trains with and without the semi-active suspension system are compared, the ride comfort was virtually the same on the cars without vibration control, but significantly enhanced on those with vibration control. The damping performance of the semi-active suspension system was close to that of the active suspension system.

It is the case that new types of Shinkansen cars are normally installed with dampers and the semi-active suspension system. Therefore, a new system is still being developed to use changeable dampers of the proportional relief valve type. A semi-active suspension system of this type is used for the series E2 Shinkansen cars that have made their debut recently. According to running test results, the new system has damping performance equal to or over that of the conventional system. The manufacturing cost of the new system is estimated to be 40% lower. An endurance test has also proved that there are no problems in the new system. It is expected that the semi-active suspension system of the proportional relief valve type will be employed in wide ranges.



Figure 2. Effect of semi-active suspension.