In addition to supporting the car body, generating drive and braking force, and providing operational stability on top of the rails, the bogie is equipment that suppresses vibration generated in the car body through running and especially for running at high speed, it is an important piece of equipment whose characteristics determine safety and comfort.

In the Shinkansen high speed test car (type E954), speed has greatly increased from a conventional speed of 275 km/h to 360 km/h. Therefore, new riding comfort issues such as an increase in lateral acceleration when passing through a curve must be resolved. Furthermore, even if speed is increased, riding comfort cannot be lost; in other words, ensuring of riding comfort equivalent or better than that provided by a conventional train is a requirement.

This report describes an outline for the initiatives related to enhancing of riding comfort for the Shinkansen high speed test train primarily from the standpoint of development of a bogie for the high speed Shinkansen and the development of active suspension system and tilt control.

In conjunction with implementation of development for increasing Shinkansen speed, prior to building of a test train car, high speed tests were performed using conventional train (E2 1000 series and E3 series train cars). As a result, as issues related to riding comfort while running at high speed, it was found that initiatives for the following are needed.

- Reduction of vehicle vibration (vibration and elastic vibration of the car body that accompanies micro deformation of the car)
- Suppression of lateral acceleration generated when passing through a curve
- Suppression of vertical shock generated at places where gradient changes

Especially the phenomena generated by curves and places where gradient changes, which were barely felt at the conventional speed of 275 km/h, surfaced for the first time in conjunction with increasing speed to the 360 km/h range for this test.

In order to resolve these issues, the following development concepts were pursued as countermeasures for enhancing riding comfort for the high speed Shinkansen train.

1. Development of a bogie for the high speed Shinkansen with enhanced anti-vibration performance
2. Development of new high performance active suspension system (electromagnetic full active control)
3. Development of tilt control system

Each of these development items are explained in detail below.
Running stability

Hunting occurs more readily at high speed and there are cases where safety is compromised while running at high speed. Here, the bogie must be prepared such that it does not produce hunting through investigation of the stiffness of primary suspension and characteristics of the anti-yaw damper etc.

Furthermore, the Shinkansen must have superior comfort compared to regular train cars. Therefore in the current development, while running speed is being increased, a target was set for having lower vibration generated in the car than conventional train cars. Specifically, the goal for riding comfort was set at a riding comfort level of 80 dB or lower when traveling at 360 km/h. Riding comfort level is an indicator for evaluation of riding comfort in a railway train car and riding comfort is evaluated using the numbers shown in Table 1.

Table 1: Riding comfort level value

<table>
<thead>
<tr>
<th>Riding comfort level value</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 83 dB</td>
<td>Very good</td>
</tr>
<tr>
<td>83 dB and over - less than 88 dB</td>
<td>Good</td>
</tr>
<tr>
<td>88 dB and over - less than 93 dB</td>
<td>Normal</td>
</tr>
<tr>
<td>93 dB and over - less than 98 dB</td>
<td>Poor</td>
</tr>
<tr>
<td>98 dB and over</td>
<td>Very poor</td>
</tr>
</tbody>
</table>

However, of the characteristics required of the bogie for the high-speed Shinkansen, there are those that are in conflict with each other, for example there are cases where increasing running stability works unfavorably when it comes to riding comfort. Here, a detailed investigation based on prior numerical analysis was performed and a specification was found that enables achieving of the various required characteristics at a higher dimension.

For the current development, the policy regarding enhancement of riding comfort of the bogie for the high speed Shinkansen is set to be the following and the basis of various specifications of the bogie were reviewed.

- Reduction of vertical vibration
- Reduction of lateral vibration
- Suppression of roll vibration
- Suppression of lateral acceleration when passing through a curve
- Suppression of vertical shock where gradient changes
- Countermeasures for deterioration of components

Details of the development policy are shown in Table 2 and development items are shown in Fig. 1. In addition, the rigidity of the train car will be significantly enhanced in order to suppress the effect of train car elastic vibration.

Table 2: Policy and Details related to increase in riding comfort

<table>
<thead>
<tr>
<th>Policy</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of vertical vibration</td>
<td>Especially, in order to reduce vertical vibration in the 10 Hz range where people’s senses are sharp, in addition to making the air springs and axle springs much less rigid than they were previously, attenuation characteristics will be revised.</td>
</tr>
<tr>
<td>Reduction of lateral vibration</td>
<td>Set characteristics to reduce lateral vibration to the extent possible without using vibration prevention control. In addition, through applying of vibration prevention control equipment, achieve enhancement of overall riding comfort.</td>
</tr>
<tr>
<td>Suppression of roll vibration</td>
<td>With respect to roll vibration caused by softening of the air springs, consider mounting of anti-roll equipment. In addition, apply train car body tilting control.</td>
</tr>
<tr>
<td>Suppression of lateral acceleration when passing through a curve</td>
<td>Equip the train car body with body tilting control. Consider equipping with anti-roll equipment at the same time.</td>
</tr>
<tr>
<td>Suppression of vertical shock where gradient changes</td>
<td>Suppress generation of shock through optimizing the amount of stroke in the air springs and come up with a stopper.</td>
</tr>
<tr>
<td>Countermeasures for deterioration of components</td>
<td>In order to avoid worsening of riding comfort due to deterioration of oil damper characteristics, a damper with sufficient durability considering increase in load caused by high speed running.</td>
</tr>
</tbody>
</table>

3.2 Implementation of verification testing using a prototype bogie

Progress was made for the development based on the above policy. Three types of bogies with different detailed structures were built and were tested through 400 km/h using our bogie testing machine and other test benches (Fig. 2) and this enabled evaluation of the high speed traveling characteristics (running stability and riding comfort).

A new car body was also built and a test of the vehicle where the bogie and train car body were integrated was also performed. In addition to clarifying issues from the standpoint of enhancing riding comfort, several pieces of knowledge with respect to reduction of noise inside the vehicle and enhancing comfort of the vehicle were obtained.

For the oil damper where deterioration of characteristics largely affects running stability and riding comfort, a new development targeting no deterioration of characteristics in a non-dismantling inspection over 3.6 million kilometers (equivalent of 3 general inspections) was performed. The superiority in endurance was
As the running speed of the Shinkansen high speed test train car will be greatly increased, development of active suspension control system with better performance was pursued. As a result of comparing several types of actuators through bench tests, the electromagnetic actuator that generated the best vibration control performance was selected for use. The electromagnetic actuator has a high response with respect to movement commands and also has superior characteristics such as ability to control vibration over a wide range of frequencies.

Two types of electromagnetic linear active suspension control system made up of different control method and actuators have been implemented on the type E954, and various types of comparison tests were implemented.

confirmed through simultaneous stationary vibration testing (Fig. 3) of a conventional part and the developed part.

3.3 Bogie for high speed test train car

Based on the results of the above bench tests, three types of bogies with different structures (Fig. 4) were built and equipped as high speed test cars. Currently, in order to determine an optimal specification including riding comfort, running safety and stability, bogie strength and maintainability, evaluation is being performed through running tests.

In active suspension control (Fig. 5), an actuator is placed between the bogie and car body that cancels lateral vibration generated in the car body, especially vibrations in the 1 Hz range and enhances riding comfort. Active suspension control system based on air actuators or variable attenuation dampers have already been installed on all but a portion of JR East E2 series and E3 series Shinkansen train. These attenuate lateral vibration while running and achieve a significant enhancement to riding comfort.

As the running speed of the Shinkansen high speed test train car will be greatly increased, development of active suspension control system with better performance was pursued. As a result of comparing several types of actuators through bench tests, the electromagnetic actuator that generated the best vibration control performance was selected for use. The electromagnetic actuator has a high response with respect to movement commands and also has superior characteristics such as ability to control vibration over a wide range of frequencies.
When curving at high speed, lateral acceleration toward the outside of the curve is generated. Especially here where a significant increase in speed is being targeted, unless some type of countermeasure is taken, this will exceed the limit for riding comfort (the standard for consideration of sitting down is a lateral acceleration of less than 0.9 m/s²). Here, we decided to equip our Shinkansen train cars with tilt control for the first time.

For the body tilting control of train cars for conventional lines, there is a pendulum type with a maximum inclination of roughly 5 degrees. However, the conditions of curves on Shinkansen tracks are better than the conditions on conventional lines (curve radius, large cant) and therefore the maximum inclination angle needed is roughly 2 degrees. Here, air spring stroke type body tilting control (Fig. 6) that has the necessary performance, a simple configuration, and that does not require modifications to the bogie structure was employed.

Body tilting control is performed based on curve information prepared beforehand, where the curve is judged based on the point of running and the amount of inclination needed is calculated from the then current speed. Furthermore, air is provided to the air spring on the outside of the curve and the train car body is tilted towards the inside of the curve.

Through development, tilting movement patterns (tilting speed and start of tilting timing etc.) must be investigated sufficiently and in addition, in order to ensure safety in the event of failure, necessary sensors were placed and status monitoring methods as well as the fail detection threshold etc. were carefully verified based on sensor information. Furthermore, the running test was prepared for through the final adjustments in conjunction with actual vehicle characteristics performed through bench tests and when completing the train car.

For the type E954, there are body tilting control devices with 2 different types of control details and electromagnetic valve device structures.

Development of a bogie for the high speed Shinkansen, centered on innovations related to enhancing riding comfort has been discussed. Currently, development is at the stage of investigation being pursued and performance is being evaluated through high speed testing.

In the future, the knowledge that is obtained through the running tests will be used to strive for implementation of safer and more comfortable high speed train cars. Especially consideration of linearity and riding comfort actually felt for vibration control etc. will be investigated further.