A Tilt Control System Focused on Preventing Motion Sickness

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We developed a tilt control system (Fig. 1) focused on preventing motion sickness, an indisposition that is thought to be caused by lateral vibration at a frequency of approximately 0.3 Hz. To reduce the vibration at such low frequencies, it is essential to tilt the car body to precisely match the track curve profile. For this purpose, we developed a new system that detects train position with high precision and determines target tilt values (by drawing a tilting pattern for all sections of track) to optimize the relation between ride comfort and motion sickness. After that, we developed a highly responsive pneumatic actuator for “active” tilt control that follows the tilting pattern. It should be noted that the tilting patterns match track irregularities in both straight and curve sections of track. For reference, typical tilting cars in Japan adopt “passive tilting systems” that tilt car bodies by centrifugal force (Fig. 2).

The new position detecting system combines GPS measurement, an on-board track curvature database and wheel rotation counts. It first uses GPS to determine an approximate running position and then collates the track curvature for several hundred meters before and after the running position with that measured by the car body (using a value of car body yaw angular speed divided by the running speed). The system then uses wheel rotation counts to refine the current running position (Fig. 3), with errors of ±4 m as verified through running tests.

If the track profile at the running position is known, it is possible to predict car body vibration that fluctuates as the car body proceeds. To achieve this goal, we devised a process to estimate (1) car body lateral acceleration, (2) its changing rate (jerk), (3) car body roll angular speed and (4) its changing rate (angular acceleration) based on the running speed. The process then refers to the curvature/cant of the track stored in a database installed on the car body and we developed a technique to calculate the minimum value of the formula for tilt angle by using the physical quantities (1) to (4) above as parameters.

We adopted a term “JTM pattern” to describe the process that determines the values of the target tilt angle calculated for all locations in each curve (Fig. 4). In particular, the process places a larger weight on the lateral acceleration having a component of 0.3 Hz. This reduces the vibration in this frequency band and mitigates the effect of motion sickness.

The tilt angle control based on the JTM pattern requires a high-response high-output actuator. Such characteristics are easily attained with hydraulic or power-driven actuators.

After comparing the merits/demerits of different actuators, we adopted a low-cost pneumatic actuator featuring high performance characteristics to insulate the vibration in high-frequency bands (Fig. 5). The servo valve of the conventional pneumatic tilting actuators (a pressure control valve) is replaced by a flow control valve to improve air flow characteristics. The hydraulic damper, which is called a tilt damper, is normally used in parallel but was removed to decrease the resistance against tilting motion, while changing the actuator control mechanism to compensate for the control stability that would otherwise be lost. This was done by adding an acceleration feedback to the actuator in addition to the normal displacement feedback. To confirm the effect of the highly responsive actuator that follows the JTM pattern to mitigate motion sickness, we implemented a simulation using multi-body dynamics, while using the motion sickness dose value (MSDVy) as the value to evaluate motion sickness. See Fig. 6 for the results. The MSDVy decreased 45% and 25%, respectively, from that of the passive tilt system and the conventional tilt control system respectively, while ride comfort remained unchanged as the vibration at high frequencies did not increase.

The rolling stock installed with a tilt control system is highly important in Japan, a small country enclosed with sea coasts and studded with mountainous areas that result in areas with highly curved track. We are now making efforts to improve the car body tilting technology further, thereby aiming at implementing rolling stock featuring high-level curve negotiating performance that will be at the forefront of passenger transport services.

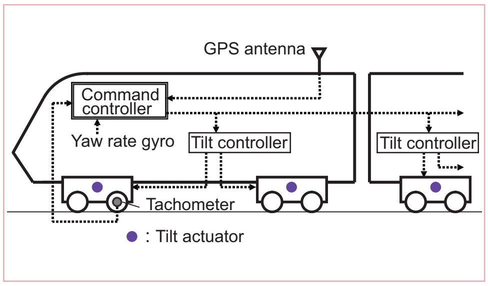

Fig. 1 System configuration of proposed tilting system

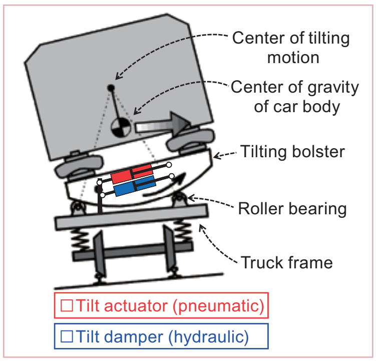

Fig. 2 Structure of tilting vehicle in Japan

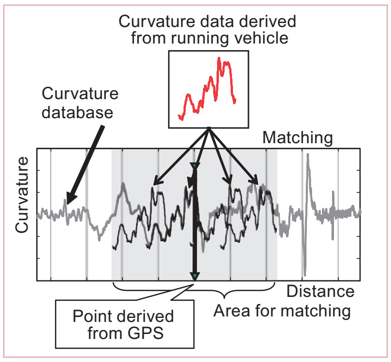

Fig. 3 Curvature matching

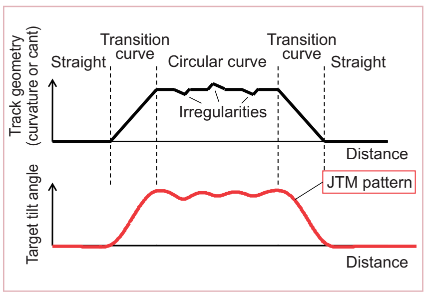

Fig. 4 Example waveform of JTM pattern

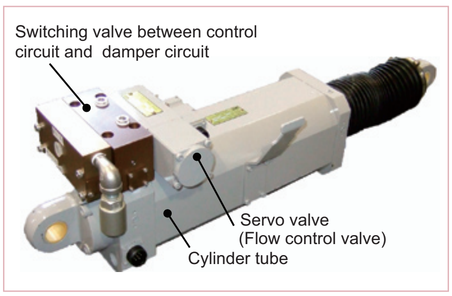

Fig. 5 High performance pneumatic tilt actuator

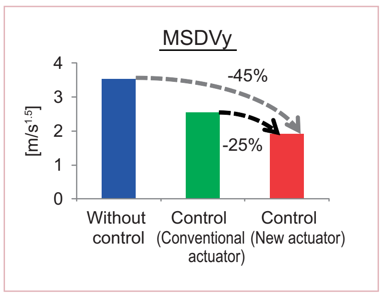

Fig. 6 Improvement of motion sickness (simulation result)