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Development of Large-Angle Rear-Wheel Steering producing superior Vehicle dynamics performance and Natural steering feeling

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In the 1980's, rear-wheel steering systems (4WS) that were widely spread in Japan had positive effects on a handling property at a low velocity and vehicle stability at a high velocity. However, almost all the rear-wheel steering systems disappeared due to high cost and unnatural feeling at the time of steering.

This Paper describes the new 4WS systems developed to solve the unnatural feeling in all velocity and to have the superior vehicle dynamics performance as well. In addition, this new system has some coordinated control features with electronic stability control systems (ESC) so as to achieve a stable vehicle motion especially in low mu serface. This new 4WS system is adopted in a flagship model of Toyota motor corporation in 2022.

Fig.1 shows the 4WS control system diagram that the system uses steering wheel angle δ_{MA}, steering wheel speed $\dot{\delta}_{MA}$ and velocity V as an input, then calculates and outputs rear wheel steering angle δ_r by a feed-forward control considering the target angle offset request from ESC. The stationary controller gain C_{20} and the transient controller gain C_{21} are configured from the target stationary gain of side-slip angle β_0^* and the target transient response of yaw rate γ_1^*.

Fig.2 shows the overview of 4WS features in order to achieve both vehicle dynamics performance and natural feeling. It is storongly recognized that the unnatural feeling received by the driver and expressed as "snake feeling", for example, during anti-phase steering at a low velocity is a characteristic of rear-wheel steering, and there are many vehicles limiting control amounts. As a result of investigations, it is revealed that the unnatural feeling can be solved by the linear characteristics of the lateral acceleration against the transient response of yaw rate especially in both vehicle forward and reverse (1, 2). In addition, the 4WS controller gain shall be slightly reduced at a quite low velocity in reverse so as to produce controllable parking maneuver (3). For more controllable handling property the ratio of δ_r to δ_{MA} shall be configured, because decreasing the side-slip angle to improve the maneuverability increases the yaw rate gain against δ_{MA} (4). The actuator stroke speed control using the estimated low velocity is necessity for natural and smooth behavior in start and stop movement (5). The 4WS system can contribute the stable turning under high lateral acceleration force by improving the under-steering behavior (6). For the vehicle agility, the yaw rate response at middle velocity and the lateral acceleration response at high velocity shall be emphasized respectively (7). And it is also important to configure β_0^* with respect to vehicle characteristic at high velocity (8).

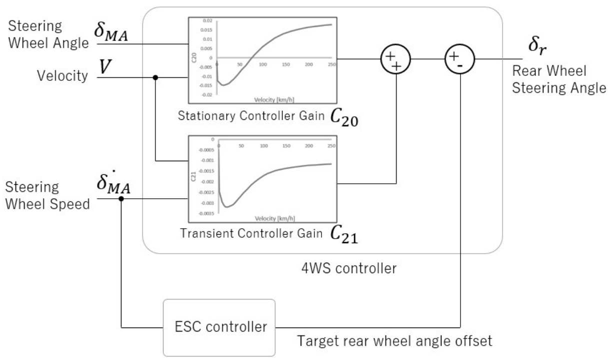

Fig.1 4WS control system diagram

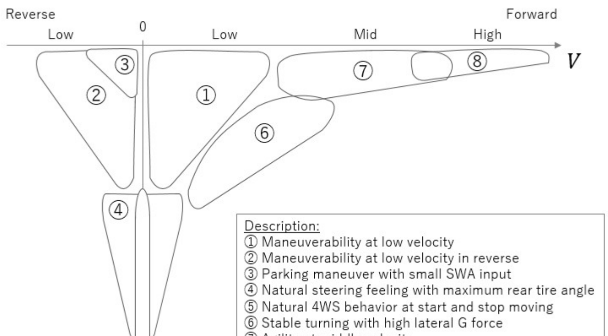

Fig.2 4WS features mapping

The new 4WS system produces the coordinated control in 4WS and ESC, without front-steering system. Especially the μ split control and over/under steering control algorithms can improve the robustness of vehicle dynamics performances even in low mu serface. These new 4WS features gave us the superior vehicle dynamics with natural steering feeling.