by **Dr. Aly Badawy, Dr. Alois Seewald, Dr. Dirk Kesselgruber** | TRW Automotive

NEW OPTIONS IN VEHICLE DYNAMICS CONTROL

Vehicle manufacturers are increasingly interested in reducing body roll in cornering maneuvers as evidenced by the launch of active roll control systems for BMW 7 series vehicles as well as the new Mercedes SL with active body control. This trend is likely to extend beyond luxury vehicles as manufacturers of vehicles with higher centers of gravity seek technologies that mitigate the rollover tendency of these vehicles.

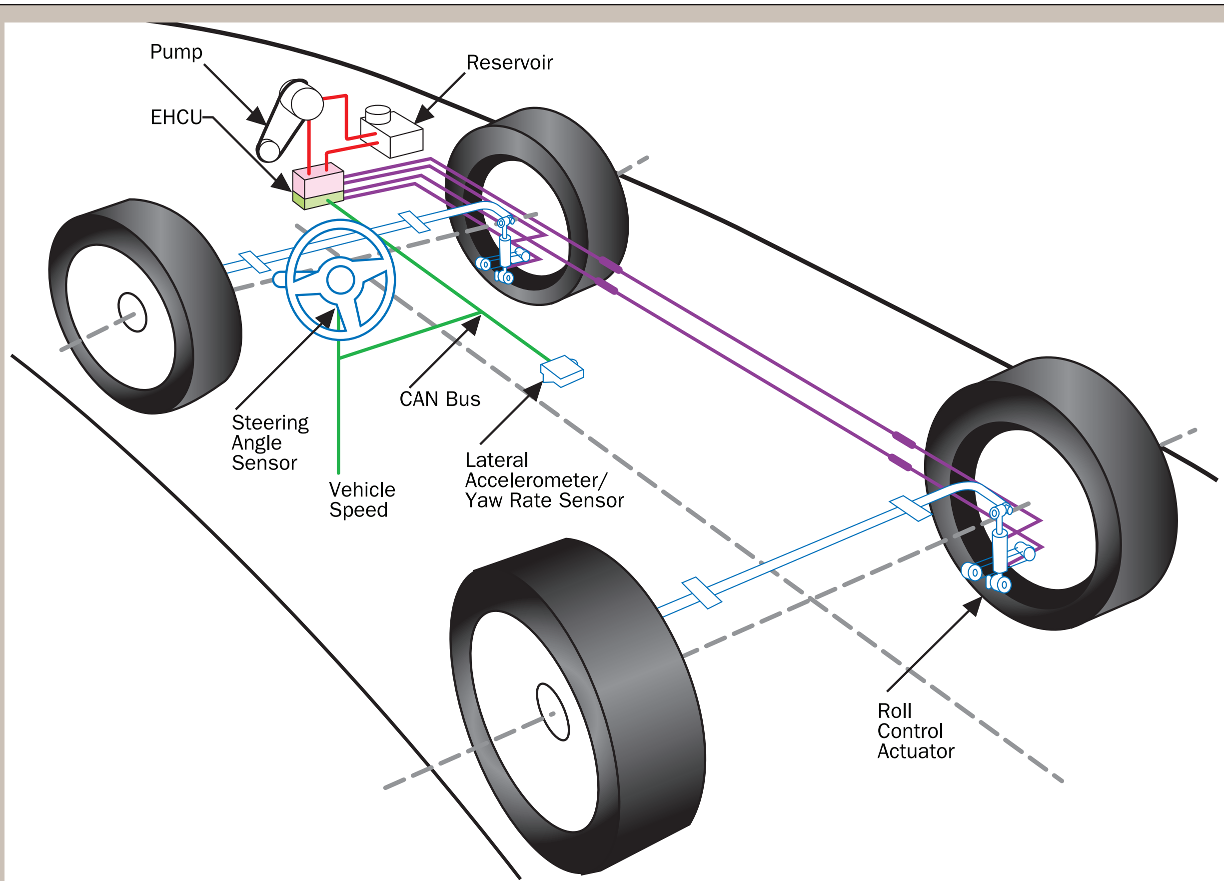

Figure 1. In TRW's active dynamic control systems family, stabilizer bars are activated with a hydraulic roll control actuator.

Intelligent stabilizers have considerable potential to improve handling, comfort and driving safety, which is why they are a crucial part of the broad systems family being offered by TRW Automotive. These systems cover a breadth of technical concepts and price ranges to accommodate manufacturers of mid-size and full-size vehicles.

HOW ADC TECHNOLOGY WORKS

TRW Automotive's active dynamic control system (ADC) family is based on active stabilizer bars, where the rigid drop link at one end of the sway bar is replaced with a hydraulic roll control actuator (Figure 1). The actuator is connected to an electrohydraulic control unit (EHCU) via hydraulic lines. The EHCU controls the actuator pressure and oil flow direction based on driving conditions monitored through sensor data. This data is supplied by a steering angle sensor, a lateral accelerometer and a yaw rate sensor linked to the system via a CAN bus.

The ADC system uses existing anti-lock brake and stability control system signals provided by the communication bus to reduce sensor costs in the vehicle. The ADC receives hydraulic power from an engine-driven or electrohydraulic power pack, depending on the steering system configuration. The main components, the EHCU and the active stabilizer with the roll control actuator, are shown in Figures 2 and 3.

TRW's active dynamic control family consists of three types of systems:

1. The ADC1 system has one active stabilizer bar. The primary function is controlling the lateral dynamics of the vehicle by adjusting the roll moment distribution to the actual driving condition. Depending upon the individual requirement, the car operates in different modes from highly active to stable. Due to the roll stiffness vs. balance relationship in a single actuation system, the ADC1 is useful for sporty cars, where body roll is less of an issue. ADC1 is capable of reaching an under-/oversteer range of about ±30%.

2. Active roll control (ARC) expands the ADC1 system by adding an actuator on the second axle and attaching it to the same hydraulic circuit. ARC's function is mainly body roll compensation with no controlled effect on the lateral dynamics of the vehicle, since the system allows for one degree of freedom. ARC compensates body roll up to a lateral acceleration rate of about

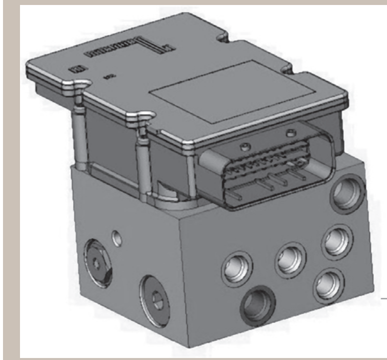

Figure 2. An electrohydraulic control unit (EHCU) consists of an ABS-based coil-integrated module and a hydraulic control unit equipped with valves to modulate pressure. The top electronic portion receives inputs from various sensors.

Figure 3. An active stabilizer bar includes a roll control actuator, a stabilizer bar, bushings and a rigid drop link.

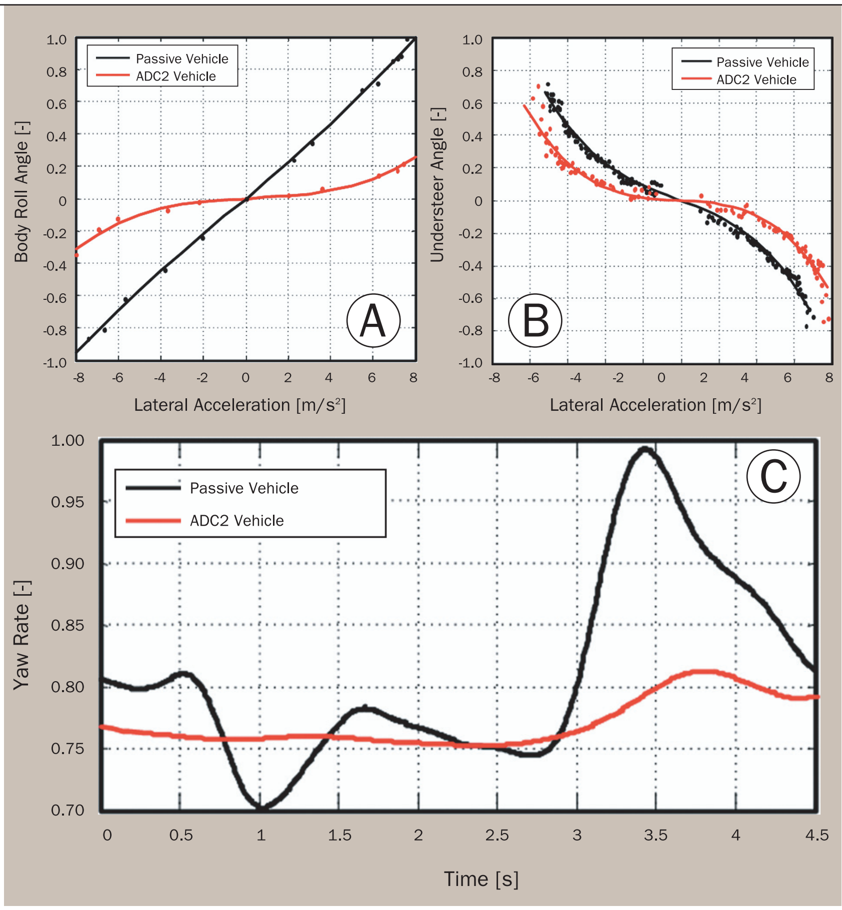

Figure 4. Vehicle test data for an an upper-size sedan vehicle demonstrates body roll and yaw control with an ADC 2 system. Data includes normalized body roll angle over lateral acceleration (a), normalized understeer angle over lateral acceleration (b), and normalized throttle-off reaction (yaw rate) over time (c).

0.4 g. From this point, the system allows vehicle body roll equal to that of the passive car. This results in a roll angle reduction of about 50%. Therefore, ARC is primarily targeted for large sport utility vehicles (SUVs) and light trucks with a naturally high roll rate.

3. The ADC2 system represents the high end of the active dynamic control family. It combines the lateral dynamic control capabilities of the ADC1 system with the body roll control function of the ARC system. ADC2 has two degrees of freedom by controlling the two hydraulic circuits (front and rear) independently. ADC2 compensates body roll up to a lateral acceleration of 0.5g and expands the understeer range to about ±40%. ADC2 is ideal for sporty luxury cars and SUVs from the mid-size to premium segments.

Figures 4a and 4b show an example of body roll and yaw control with an ADC2 system in an upper-size sedan vehicle (vehicle test data). The diagrams plot the body roll angle and the understeer caused by steering wheel angle input over lateral acceleration. The body roll angle is extracted from step steer maneuvers, the understeer angle from a constant radius turn. The black curves represent the passive vehicle without ADC, the red curves show the performance of the same vehicle equipped with an ADC2 system. The y-values are normalized to the maximum value and are for illustrative purposes.

Figure 4a shows that the ADC2 vehicle has a strongly reduced body roll angle. The improvement is close to 100% (full roll compensation) up to a lateral acceleration of 0.4 g. At the limit, the body roll improvement is approximately 70%. This improvement is apparent and an untrained driver will feel this significant effect.

Figure 4b gives the steering wheel angle taking into account the “Ackermann-Angle” i.e., the additional steering effort due to understeer or the so-called “understeer angle.” The curves show that the steering effort necessary to keep the vehicle on a constant radius is significantly lower on the ADC2 vehicle, requiring less steering effort for the same cornering performance. In addition to the steering improvement, the ADC2 vehicle achieves a higher lateral acceleration level in this maneuver, resulting in an enhanced margin of safety during emergency driving conditions.

Taking the “Ackermann-Angle” into account, the yaw gain improvement due to ADC2 is about 15%—the ADC2 vehicle behaves more neutral. To demonstrate that the conflict between neutrality and stability is resolved by the ADC2 dynamics controller, a throttle-off test at limit was performed at the end of the constant-radius turn.

Figure 4c demonstrates the result of this test. At approximately 2.5 seconds, the throttle-off event takes place. Two effects are observable: The ADC2 vehicle stays more stable during the limit cornering before the throttle-off event, while the passive car has higher yaw oscillations.

After the throttle-off event, the passive car shows a strong overshoot (33% of the steady-state level) in the yaw rate while the ADC2 vehicle reaction is only 9% and is

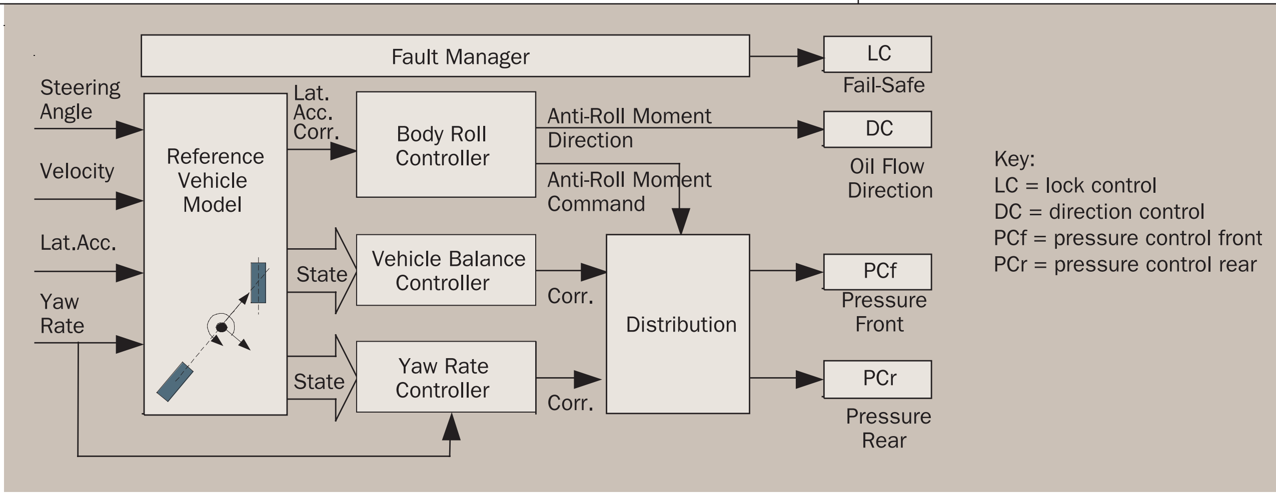

Figure 5. TRW's active dynamic control strategy enables inputs from various sensors to be used to calculate the current lateral dynamic behavior of the car as well as the expected behavior of the vehicle 200 ms in advance. This data can then be used to realize a body roll controller, vehicle balance controller, and yaw-rate controller value.

considerably smoother.

The ADC2 vehicle stays more stable and controllable during this maneuver.

A view of TRW's active dynamic control strategy in Figure 5 helps explain the full vehicle dynamics control capabilities of this product family. A vehicle reference model uses the sensor signals (steering angle, velocity, lateral acceleration and yaw rate) to compute the current lateral dynamic behavior of the car, and the expected behavior of the vehicle 200 ms in advance (vehicle state prediction). These values are used to realize three functions:

1. Body roll controller: a predicted (corrected) lateral acceleration signal is used to compute the total required anti-roll moment and its direction to keep the body flat in any transient (initial roll) and steady-state driving condition. Note that providing additional sensor signals, such as body-roll acceleration, allows additional functions for the body-roll controller, like active roll damping.

2. Vehicle balance controller: a predicted vehicle state is used to define a correction value for the front and rear stabilizer bar to define the open-loop vehicle balance. This balance affects the general under-/oversteer characteristics of the vehicle.

3. Yaw rate controller: the demanded yaw dynamic (yaw rate, yaw damping, etc.) for the vehicle is compared with the sensed yaw rate that results in a yaw rate error. The controller computes a correction value for the front and rear stabilizer bar based on the calculated error.

The required anti-roll moment and the correction values are combined in a "distribution-block" that allocates the stabilizer forces between front and rear axle and computes a required system pressure demand. The lock control (LC), direction control (DC) and pressure control (PC) inputs are controlling the components in the EHCU to realize the pressure control, the directional control and the fail-safe function. A fault manager is observing all internal controller states and comparing them with the sensor values to detect any failure and revert the system to a fail-safe state.

LOOKING AHEAD

Simulations and tests have confirmed the benefit of using modular architecture for vehicle dynamic integration, which suggests that active dynamic control systems are ideal products for system integration. ADC systems, along with braking, steering, adaptive cruise control and other technologies will use common sensors and software and evolve as a harmonious system. Today, prototype installations are under way to validate the interaction between these advanced automotive technologies.

In addition, TRW is researching ways that these active systems can share data and activate passive safety systems in pre-crash scenarios where appropriate. The future direction of vehicle dynamic control systems and their interaction with occupant safety systems represents another exciting frontier for the automotive industry. ■

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