TIRE SLIP CONTROLLER

Another benefit of the ABS is that the brake pressure modulator can be used for ACC as explained earlier and for tire slip control. Tire slip is effective in moving the car forward just as it is in braking. Under normal driving circumstances with power train torque applied to the drive wheels, the slip that was defined previously for braking is negative. That is, the tire is actually moving at a speed that is greater than for a purely rolling tire (i.e., $r_w\omega_w > U$). In fact, the traction force is proportional to slip.

For wet or icy roads, the friction coefficient can become very low and excessive slip can develop. In extreme cases, one of the driving wheels may be on ice or in snow, while the other is on a dry (or drier) surface. Because of the action of the differential (see Chapter 6 and Fig. 6.30), the low-friction tire will spin, and relatively little torque will be applied to the dry-wheel side. In such circumstances, it may be difficult for the driver to move the car even though one wheel is on a relatively good friction surface.

The difficulty can be overcome by applying a braking force to the free spinning wheel. In this case, the differential action is such that torque is applied to the relatively dry-wheel surface, and the car can be moved. In the example ABS, such braking force can be applied to the free spinning wheel by the hydraulic brake pressure modulator (assuming a separate modulator for each drive wheel). Control of this modulator is based on measurements of the speed of the two drive wheels. Of course, the ABS already incorporates wheel speed measurements, as discussed previously. The ABS electronics have the capability of performing comparisons of these two wheel speeds and of determining that braking is required of one drive wheel to prevent wheel spin.

ABS components have another important application in relationship to vehicle safety. This application of ABS technology is in a vehicular electronic system that is called enhanced stability system (ESS). Although major components of the EVS are part of ABS, the primary purpose is to improve the directional stability of vehicles during maneuvers involving steering inputs. The EVS is discussed in Chapter 10, which is devoted to electronic safety-related vehicle systems because the end goal of EVS is to improve vehicle safety. An entire section of Chapter 10 is devoted solely to EVS with multiple references to relevant portions of this chapter.

Still another safety-related application of ABS or its components is automatic braking. This topic is also covered in detail in Chapter 10. Although major components of ABS are involved in automatic braking, there are sensor inputs to automatic braking that are beyond those discussed in this chapter for ABS application. These involve sensing the environment surrounding the given vehicle that is explained in Chapter 10. Also explained in Chapter 10 is the application of automatic braking to a collision avoidance system.

Antilock braking can also be achieved with electrohydraulic brakes. An electrohydraulic brake system was described in the section of this chapter devoted to ACC.

Recall that for ACC a motor-driven pump supplied brake fluid through a solenoid-operated "brakes" apply valve to the wheel cylinder. For ACC application of the brakes, the apply and isolation valves operate separately to regulate the braking to each of the four wheels.

ELECTRONIC SUSPENSION SYSTEM

An automotive suspension system consists of springs, shock absorbers, and various linkages to connect the wheel assembly to the car body. The purpose of the suspension system is to isolate the car body motion as much as possible from wheel vertical motion due to rough-road input. Fig. 7.20 depicts,

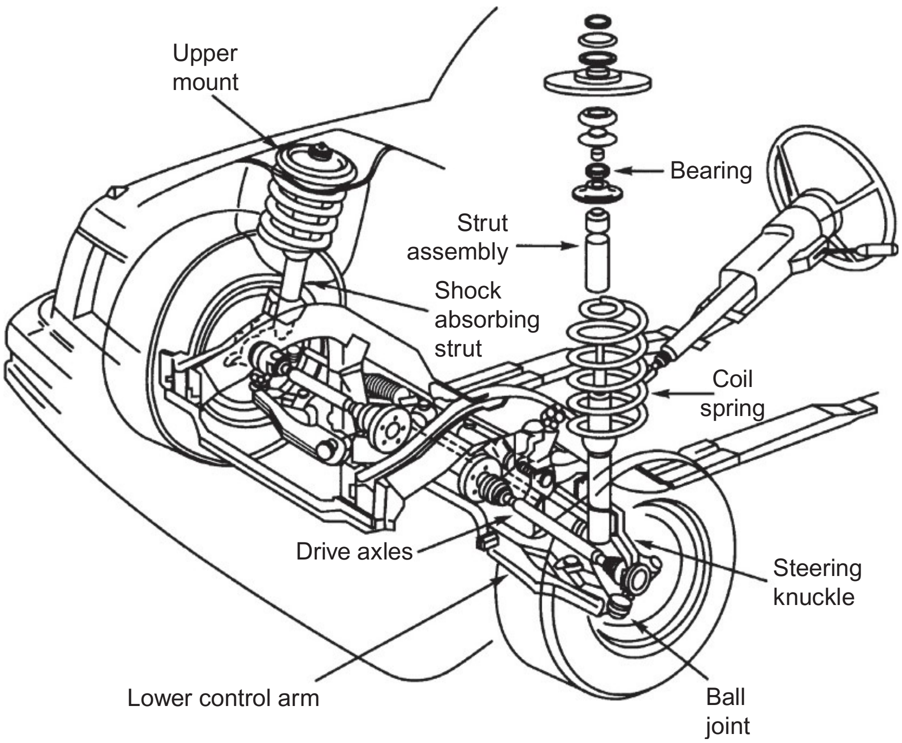

FIG. 7.20 Illustration of front suspension system.

schematically, the suspension system for the front wheels of a front-wheel-drive car. In essence, a suspension system is a mass, spring, damping assembly that connects the car body (whose mass is called the "sprung" mass to the wheel/axle, brake, and other linkages connected to them, which are called the "unsprung" mass).

The two primary subjective performance measures from a driver/passenger standpoint are ride and handling. *Ride* refers to the motion of the car body in response to road bumps or irregularities. *Handling* refers to how well the car body responds to dynamic vehicle motion such as cornering or hard braking.

Damping in the suspension system is provided by the shock absorber portion of the strut assemble. Viscous damping is provided by fluid motion through orifices in a piston portion of the strut. The structure and details of a strut are given later in this chapter, but the interested reader can look ahead to Fig. 7.23. For the present, attention is focused on the influence of strut damping on ride and handling. Generally speaking, ride is improved by lowering the shock absorber damping, whereas handling is improved by increasing this damping. In traditional suspension design, the damping parameter is fixed and is chosen to achieve a compromise between ride and handling (i.e., an intermediate value for shock absorber damping is chosen).

In electronically controlled suspension systems, this damping can be varied depending on driving conditions and road roughness characteristics. That is, the suspension system adapts to inputs to maintain the best possible ride, subject to handling constraints that are associated with safety.

There are two major classes of electronic suspension control systems: active and semiactive. The semiactive suspension system is purely dissipative (i.e., power is absorbed by the shock absorber under control of a microcontroller). In this system, the shock absorber damping is regulated to absorb the power of the wheel motion in accordance with the driving conditions.

In an active suspension system, power is added to the suspension system via a hydraulic or pneumatic power source. At the time of the writing of this book, electronic control of commercial suspension systems is primarily semiactive. In this chapter, we explain the semiactive system first, then the active one.

The primary purpose of the semiactive suspension system is to provide a good ride for as much of the time as possible without sacrificing handling. Good ride is achieved if the car's body is isolated as much as possible from the road surface variations. The vertical input to the unsprung mass motion is the road surface profile. For a car traveling at a steady speed, this input is a random process. Depending upon the nature of the road surface (i.e., newly paved road vs. ungraded gravel dirt road), this random process may be either a stationary or a nonstationary process. For the following discussion, we assume a stationary random process. A semiactive suspension controls the shock absorber damping to achieve the best possible ride without sacrificing handling performance.

In addition to providing isolation of the sprung mass (i.e., car body and contents), the suspension system has another major function. It must also dynamically maintain the tire normal force as the unsprung mass (wheel assembly) travels up and down due to road roughness. Recall from the discussion of antilock braking that braking and lateral forces depend on normal tire force. Of course, in the long-term time average, the normal forces will total the vehicle weight plus any inertial forces due to acceleration, deceleration, or cornering.

However, as the car travels over the road, the unsprung mass moves up and down in response to road input. This motion causes a variation in normal force, with a corresponding variation in potential cornering or braking forces. For example, while driving on a rough curved road, there is a potential loss of steering or braking effectiveness if the suspension system does not have good damping characteristics. We consider next certain aspects of vehicle dynamics to understand the role played by electronically controlled suspension.

The geometry for describing the vehicle motion relative to the suspension is depicted in Fig. 7.21A and B. In this figure, three major axes are defined for the vehicle: (1) longitudinal, (2) lateral, and (3) vertical. The ECEF inertial coordinate system axes are denoted (x',y',z'). The vehicle body axes are denoted (x,y,z).

The longitudinal axis is a line in the plane of symmetry through the center of gravity (CG) parallel to a ground reference plane. The ground plane is the plane through the wheel axles when the vehicle is sitting on an exactly horizontal plane. In this configuration, the deflection of the front and rear springs due to vehicle weight depends upon the location of the CG along the longitudinal axis. Fig. 7.21A is a side view of the vehicle depicting the body longitudinal axis x (fixed to the vehicle).

This figure also depicts the x-axis for the vehicle at rest with the x'-axis that constitutes an inertial (e.g., ECEF) reference. In this figure, the x-axis is deflected by a "pitch angle" α_p relative to the x'-axis. The vertical displacement of the CG is denoted δz_{cg} in the figure and is called heave. The front and rear springs are assumed to be identical right (r) and left (l). The front suspension spring rate is denoted K_F and the rear K_R. Viscous damping is also assumed to be symmetrical right and left and has linear damping coefficients D_F and D_R for front and rear, respectively (in the present, simplified model).

Fig. 7.21B depicts the vehicle in a front view for which the body lateral axis (y) is shown in the rest position by the dashed line y' and in the deflected position by the solid line. The angle ϕ_R is the "roll" angle about the longitudinal axis. The z-axis is orthogonal to the x–y plane through the CG. The y'- and z'-axis are part of the inertial reference for the following discussion on vehicle dynamic motion.

~~pressure in the bladder, yielding a variable spring rate suspension. In conjunction with a suitable control system, the pneumatic springs can automatically adjust the vehicle height to accommodate various vehicle loadings and to increase spring "stiffness."~~

ELECTRONIC SUSPENSION CONTROL SYSTEM

The control system for an exemplar electronic suspension system is depicted in the block diagram of Fig. 7.28. The control system configuration in Fig. 7.28 is generic and not necessarily representative of the system for any production car. This system includes sensors for measuring vehicle speed, steering input (i.e., angular deflection of steered wheels), relative displacement of the wheel assembly and car body/chassis, lateral acceleration, and yaw rate. The outputs are electrical signals to the shock absorber/strut actuators and to the motor/compressor that pressurizes the pneumatic springs (if applicable). The actuators can be solenoid-operated (switched) orifices or motor-driven variable orifices or electromagnets for RH fluid-type variable viscosity struts. Certain vehicles may also be equipped with automatic electrically operated brakes (such as explained in the discussion of ACC and in Chapter 10) for stability-enhancement purposes.

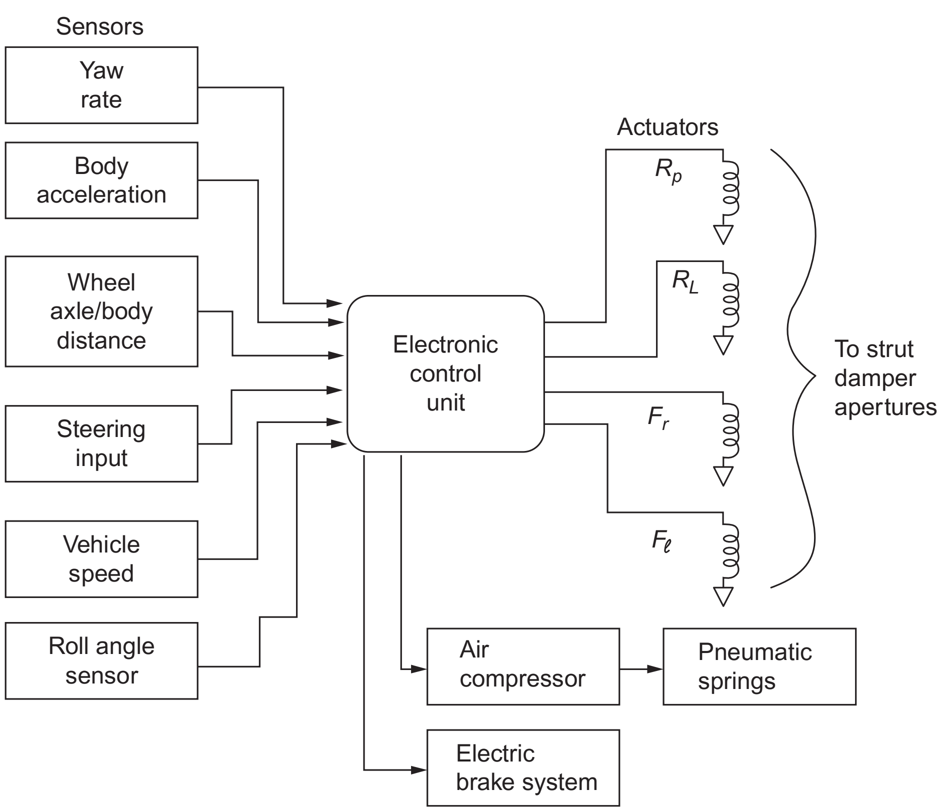

FIG. 7.28 Example electronic suspension system configuration.

The control system typically is in the form of a microcontroller or microprocessor-based digital controller. The inputs from each sensor are sampled, converted to digital format, and stored in memory. As explained above, the body acceleration measurement can be used to evaluate ride quality. The controller makes this evaluation based upon $\tilde{a}_s$ or similar metrics for body motion. The relative road/wheel axle displacement d can be used to estimate tire normal force, and damping is then adjusted to try to optimize this normal force.

Body roll angle (ϕ_R) or the yaw rate sensor (r) provides data that in relationship to vehicle speed and steering input measurements can be used to evaluate cornering performance. In certain vehicles, these measurements combine in an algorithm that is used to activate the electrohydraulic brakes for enhanced stability during extreme maneuvers. The details of automotive stability-enhancement are explained in Chapter 10 along with analytic models.

Under program control in accordance with the control strategy, the electronic control system generates output electrical signals to the various actuators. The variable damping actuators vary either the oil passage orifice or the RH fluid viscosity independently at each wheel to obtain the desired damping for that wheel.

There are many possible control strategies, and many of these are actually used in production vehicles. For the purposes of this book, it is perhaps most beneficial to present a representative control strategy that typifies features of a number of actual production systems.

The important inputs to the vehicle suspension control system come from road roughness-induced forces and inertial forces (due, for example, to cornering or maneuvering), steering inputs, and vehicle speed. In our hypothetical simplified control strategy, these inputs are considered separately. When driving along a nominally straight road with small steering inputs, the road input is dominant. In this case, the control is based on the spectral content (frequency region) of the relative motion. The controller (under program control) calculates such variables as $\tilde{a}_s$ or $\widetilde{d}$ (from the corresponding sensor's data). Whenever the amplitude of the spectrum near the peak frequencies exceeds a threshold, damping is increased, yielding a firmer ride and improved handling. Otherwise, damping is kept low (soft suspension).

If, in addition, the vehicle is equipped with an accelerometer (usually located in the car body near the CG) and with motor-driven variable aperture shock absorbers, then an additional control strategy is possible. In this latter control strategy, the shock absorber apertures are adjusted to minimize sprung mass acceleration in the 2–8 Hz frequency region, thereby providing optimum ride control. However, at all times, the damping is adjusted to control unsprung mass motion to maintain wheel normal force variation at acceptably low levels for safety reasons. Whenever a relatively large steering input is sensed (sometimes in conjunction with body roll angle and/or yaw rate measurement), such as during a cornering maneuver, then the control strategy switches to the smaller aperture, yielding a "stiffer" suspension and improved handling. In particular, the combination of cornering on a relatively rough-road calls for damping that optimizes tire normal force, thereby maximizing cornering forces.

~~ELECTRONIC STEERING CONTROL~~

~~The steering system of a car consists of a mechanism for rotating the front wheels of the car about an axis that is nearly vertical in response to steering wheel angle changes. The basic mechanism is shown schematically in Fig. 7.29.~~

~~The force/torque of the steering wheel is influenced by the actual orientation of the pivot axes relative to the car body vertical axis. The fore/aft angle is known as camber angle. An increase in this angle relative to vertical increases steering torque; it also increases restoring torque (also called aligning torque),~~