Automotive Suspension Systems

An Online Continuing Education Course for Engineers

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Introduction

The suspension system of a vehicle refers to the group of mechanical components that connect the wheels to the frame or body. A great deal of engineering effort has gone into the design of suspension systems because of an unending effort to improve vehicle ride and handling along with passenger safety and comfort. In the horse and buggy days, the suspension system consisted merely of a beam (axle) that extended across the width of the vehicle. In the front, the wheels were mounted to the axle ends and the axle was rotated at the center to provide steering. The early automobiles used the one-piece axle design but instead of being rotated at the center, it was fix-mounted to the vehicle through springs to provide the cushioning of shock loads from road inaccuracies. The wheels were rotationally-mounted at the axle ends to provide steering. The first springs consisted of thin layers of narrow pieces of strip steel stacked together in an elliptical shape and were called leaf springs. In later installations, leaf springs were replaced by coil springs. In front- engine rear-drive vehicles, the front beam axle was replaced by independently mounted steerable wheels. The wheels were supported by short upper and lower hinged arms holding them perpendicular to the road as did the previous axle beam designs. A coil spring was used to support either the upper or the lower arm to provide dampening. Shock absorbers began to be used to dampen shock loads and also to provide resistance to spring oscillations. Later it was learned by shortening the upper arm; wheel tilt (camber) could be controlled to prevent edge loading tires while cornering. The power transmitting drive axle in the rear served as the beam-type suspension with dampening provided by either leaf or coil springs or shock absorbers. When front engine front-drive passenger cars were introduced, the upper arm was rotated up and replaced by a member called a “strut” which contained the concentrically mounted spring and shock. This arrangement provided additional space for transverse mounted engine/transmission modules and the front drive shaft. This same type of suspension was also used in the rear of many cars. Trucks continue to be front engine, rear drive vehicles many using beam-type axle suspension systems in both the front and rear. This course will study the design and application of five currently used suspension systems.

Types of Suspension Components

There are three basic types of suspension components– linkages, springs, and shock absorbers. The linkages are the bars and brackets that support the wheels, springs, and shock absorbers. Springs cushion the vehicle by dampening shock loads from bumps and holes in the road. Shock absorbers use hydraulic pistons and cylinders to also cushion the vehicle from shock loads. They also serve to dampen spring oscillations thus bring the vehicle back to a neutral position soon after being shock loaded by a road obstruction.

Links: There are a number of various shaped links that are used for the different types of suspension systems. They vary from straight bars to forged, cast or stamped metal shapes that best fit to support the springs, shocks, and wheels onto vehicle frames or body structures. The simplest linkage is a straight bar that connects one wheel to the other on the opposite side of the vehicle. Others can be intricately shaped to connect springs, shock absorbers, and wheels to vehicles as explained later.

Springs: There are three different spring types that are used in suspension systems: coil, leaf, and torsion bar. Coil springs are merely wound torsion bars. They are commonly used because they are compact, easily mounted and have excellent endurance life properties. Leaf springs are long thin members that are loaded in bending. They are used as an assembly being comprised of several layers of thin metal to obtain the correct spring rate. Leaf springs serve as both the damping member and the linkage. Torsion bars rely on the twist of a long bar to provide a spring rate to dampen car shock loading. Torsion bars mount across the bottom portion of a vehicle and are more difficult to package than others.

Shock Absorbers: Shock absorbers use a piston and cylinder along with adjustable valves to control the flow of hydraulic fluid to set the damping force in both the retract (jounce) and extend (rebound) positions. Shock absorbers are set to retract under a lower force than to extend. This action absorbs road bump forces and dampens spring oscillations resulting in better vehicle ride and control.

Suspension System Terms

- **Camber**: Looking directly at the front of the vehicle, camber refers to the tilt in (+) or out (-) of the bottom half of the tire.
- **Caster**: Looking directly at the side of the vehicle, caster refers to the tilt rearward (+) of the bottom half of the tire.

- **Toe**: Looking directly at the top of the vehicle, toe refers to the slant in (+) or out (-) of the front half of the tire.
- **Jounce**: Jounce refers to the bounce or vertical movement of the vehicle suspension upward when it contacts a bump in the road.
- **Rebound**: Rebound refers to the movement of the vehicle suspension in the opposite direction of jounce.
- **Shimmy**: Shimmy is an uncontrollable oscillation of the steering system experienced by two opposing wheels.
- **Knuckle**: The knuckle is the suspension component that incorporates the spindle or hub that the wheel bearings and wheels mount on.
- **King Pin**: The king pin is the vertical component in the knuckle that the wheels turn on when the vehicle is steered.
- **Spindle**: The spindle is the long tapered bar-shaped piece that is fitted to the knuckle on which the wheel bearings and wheels are mounted.
- **Hub**: The hub is the hollow part of the knuckle that replaces the spindle in mounting the bearings that support the wheel.
- **Ball Joint**: A ball joint is a fastener or connector that allows movement in all directions.
- **Tie Rod**: A tie rod is a component that firmly connects one wheel of a vehicle to the wheel on the opposite to provide steering.
- **Track Bar**: A track bar is a rod that connects a suspension beam to the frame to give lateral support.
- **Unsprung Weight**: Unsprung weight is the total weight of all components in a vehicle that are not dampened by the springs and shocks like the wheels and other closely associated equipment.
- **Scrub**: Scrub is the lateral movement of a tire against the pavement due to suspension system camber changes during jounce and rebound.

Types of Suspension Systems

Beam Axle: Initially, the front axle of rear-drive automotive vehicles was of a solid beam design. It consisted solely of a fixed continuous member extending across the entire front end of the vehicle connecting the two steerable wheels. This is referred to as a "dependent" suspension system as the two wheels are mechanically linked together as opposed to an "independent" suspension system where the two wheels are not directly linked together. The original Model T passenger cars were rear-drive and had a dependent front suspension system whereby a solid beam axle extended across the entire width of the vehicle connecting the two wheels. The axle was of forged I-beam steel construction and had ends machined to allow the assembly of vertically mounted

kingpins enabling the wheels to rotate to provide for vehicle steering. To dampen the ride, a transverse mounted semi-elliptical inverted leaf spring was installed between the axle and the car body. The two downward curved ends of the leaf spring were fastened to each end of the axle while the higher center section fastened in two closely spaced locations directly to the car frame. (See Figure 1.)

Solid beam axles can also be used for drive wheels where the drive axle assembly itself serves as the solid beam member connecting the two drive wheels of a vehicle such as was used on the Model T. Drive axles contain a number of mechanical components that deliver power from the engine, thru the drive shaft, to the drive axle which diverts it 90 degrees to the wheels of automotive vehicles. Figure 2 has sketches of drive axles acting as solid beam suspension members. The upper sketch has a drive axle mounted on rear trailing suspension arms and dampened by coil springs and shock absorbers. The small bar shown is called the “track bar” and connects to the vehicle frame to serve as lateral support for the drive axle. The lower sketch of Figure 2 depicts a drive axle located in the front of a four-wheel-drive vehicle. The linkage and “tie rod” shown provide for vehicle steering. Figure 3 has a sketch of a drive axle supported by leaf springs. The drive axle center section is an interesting design having three sets of bevel gears to deliver engine power 90 degrees to the two drive wheels. Figure 4 has a section drawing of the center section of a typical drive axle. The first gearset takes power from the vehicle drive shaft and delivers it 90 degrees to a component called the carrier. The carrier houses the “differential”. The differential is an ingenious device that delivers power to each of the two drive wheels regardless of the rotational speed of each such as when a vehicle is traveling around a corner. Drive axles were traditionally used for automotive vehicle rear wheels and for the front of four-wheel-drive automotive vehicles. More recently, many automotive vehicles have gone to front-wheel-drive where the transmission and drive axle are combined and called the “transaxle”.

The advantages of solid beam axles are that they are simple and strong. Also, wheel camber is closely controlled with the wheel held virtually perpendicular to the road during vehicle vertical movement. This is of particular advantage for trucks carrying heavy loads in keeping the wheels 90 degrees to the pavement. A disadvantage of solid beam axles is that there is no camber adjustment made during heavy cornering to keep the wheels off their edges and firmly in contact with the pavement like another form of suspension systems (discussed later). Another disadvantage is, since both wheels are connected together, a vehicle with one wheel encountering a bump or depression on the road sends a shock wave across the entire rear (or front) of the vehicle leading to passenger discomfort and possible “shimmy”. Also, Solid beam axles add high unsprung weight to a vehicle leading to a harsher vehicle ride and passenger discomfort.

Dual-Beam Suspension: Dual-beam front suspension is popular with one U.S. auto manufacturer for light trucks. (See Figure 5.) Dual beam suspensions are considered "independent" suspension systems as the two wheels are not directly connected as they are on the solid beam suspension discussed above. The major advantage of dual-beam suspension is that front shock loads from pavement anomalies are isolated to the side where they are encountered. This is opposed to one-piece front beam suspensions where shock loads encountered on one wheel are transported all the way across the vehicle causing excessive body shock loading and passenger discomfort. The disadvantage of dual-beam front suspensions is that wh mber changes with vehicle vertical movement causing tir crubbing. The dual suspension arms of t tomaker for light trucks overlap each othe zing the above mentioned disadva