TRAINING HANDBOOK 3000

STEERING AND SUSPENSION PRINCIPLES

Ford

SERVICE TRAINING

VOL. 67 S10 L2

STEERING AND SUSPENSION PRINCIPLES

TRAINING HANDBOOK 3000 • VOL. 67 S10 L2

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STEERING AND SUSPENSION SYSTEM

INTRODUCTION

The direction of movement of an automotive vehicle is controlled by means of the front wheels. The control or guidance of the direction, exerted through manual and mechanical manipulation of the front wheels, is called steering.

STEERING SYSTEMS

The steering system of an automotive vehicle is composed of the steering gear, the steering wheel and the steering linkage. All of these components are designed to make it possible for the driver to turn the front wheels to guide the car.

By steering **linkage,** we mean a system of links, rods, tubes and levers used to transmit motion from the steering gear to the front wheel steering spindles. By steering **gear,** we refer to a device made up of gears, or gears and rollers to transmit driver steering effort to the steering linkage to allow control of the direction of the vehicle.

SUSPENSION

Ford automotive vehicles are mounted on wheels by means of a suspension system in order to minimize the jolting effect caused by irregularities in the surface of the road. By the suspension system, we refer to the parts on which the wheels are mounted, the spring mountings, and the springs, taken as one unit. These mountings and springs make up the suspension system. Because of sharp distinctions in front end and rear end suspension, they are classified separately and studied as such.

The front wheel assemblies are involved directly in both suspension and steering. The rear wheel assemblies, to the extent that they are in or out of correct alignment with the front end, also have a direct involvement with steering.

This interrelationship and interdependence of the steering and suspension systems makes it impossible to consider either of these systems without some attention to its involvement with the other.

Therefore, this handbook deals with the principles of **both** steering and suspension. It provides an explanation of wheel alignment factors and the allied areas of suspension, steering gear, steering linkage, wheels and tires, as employed on current Ford models.

Key definitions are set forth as required in the text, and are gathered also in the quick-reference section at the end.

FRONT SUSPENSION

The front suspension (Fig. 1) consists of the devices used to attach the wheels to the vehicle, springs for cushioning the vehicle and load from the impact caused by the wheels striking irregularities in the road surface. Springs, shock absorbers and tires all assist in "soaking up" the shock of such impacts before they can be transmitted through the frame to the passengers.

There are two basic types of front suspension in use today. They are the **solid-axle** type (Figs. 1 through 4) and the **independent** type shown in Figs. 5 and 6.

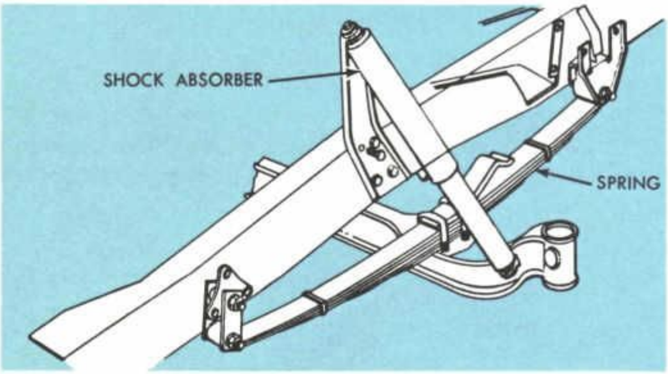


Fig. 1—Axle-Type Front Suspension

Both types include **spindle assemblies,** which pivot to turn the wheels for steering; **kingpins** (spindle bolts) or **ball joints** for the spindles to turn about; **steering linkages** to connect the spindle assemblies to the steering gear and **springs** to cushion the ride.

Each type will be covered as it is employed in current Ford passenger car and truck lines.

AXLE-TYPE FRONT SUSPENSION

We have already seen (Fig. 1) the classic illustration of an axle-type front suspension. Many Ford trucks are equipped with variations of this front suspension design. Twin I-Beam suspension is of the independent type, but, because it uses I-Beam axles it is included in this section of the handbook.

SINGLE I-BEAM FRONT SUSPENSION

The forged Single I-Beam front suspension axle design (Fig. 2) is used because it offers great resistance to up-and-down and twisting forces.

This solid I-Beam front axle with long leaf springs is used mainly on medium and heavy truck series. With this type of axle suspension, tire wear is kept at a minimum, while durability and front-end stability are sustained at a maximum.

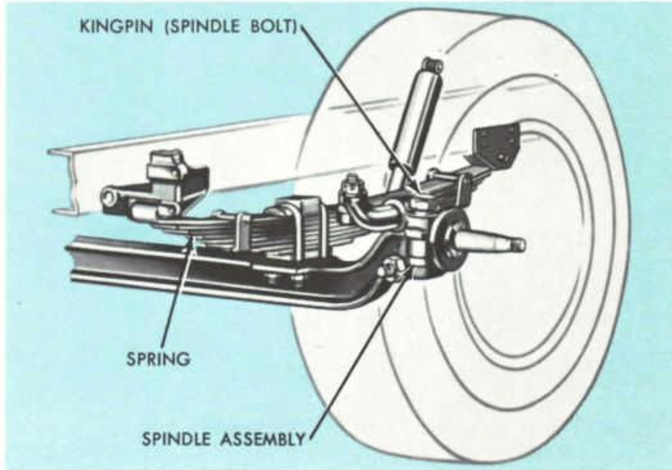


Fig. 2—Single I-Beam Front Suspension

MONO-BEAM FRONT SUSPENSION

The Bronco, and the Ford F-100 4x4 use the Mono-Beam front suspension with coil springs (Fig. 3). On this suspension, the front driving axle is connected to the frame by two large forged steel radius arms through heavy-duty rubber bushings which soak up road vibrations.

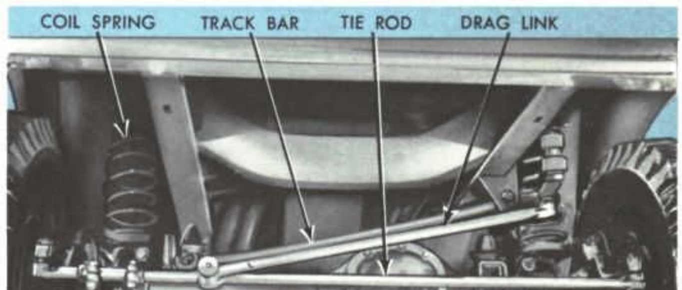


Fig. 3—Mono-Beam Front Suspension

A one-inch diameter front track bar maintains lateral stability and axle alignment, thereby increasing kingpin and wheel bearing life. High deflection-rate coil springs and double-acting hydraulic shock absorbers soak up road shocks and bumps.

TWIN I-BEAM FRONT SUSPENSION

The Twin I-Beam front suspension (Fig. 4) gives each wheel its own solid I-Beam axle, I-Beam radius arm and coil spring in order to sustain alignment, cushion the load, and soak up road shocks and vibrations.

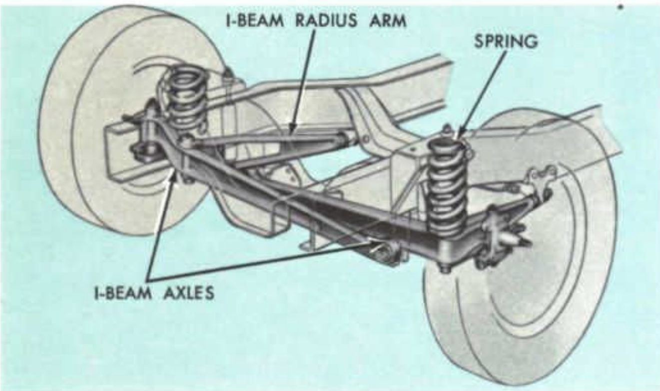


Fig. 4—Twin I-Beam Front Suspension

The design and construction of Twin I-Beam front suspension almost eliminates the dip or dive present in other suspensions when making a quick stop. The solid design built into this suspension allows both caster and camber . . . two wheel alignment factors we'll cover further on . . . to be locked in at the factory, thereby reducing the need for these adjustments in the field.

The Twin-I-Beam front suspension is used on the Ford F-100 through 350 series (except in 4x4) in conjunction with coil springs to cushion the load. On the Ford F-250 4x4, a rugged leaf spring **Hotchkiss Drive**-type front suspension is used. (By Hotchkiss Drive, we mean that all driving and braking forces are transmitted through the leaf springs to the frame.) This suspension includes extra-large double-acting hydraulic shock absorbers to cushion the unit and to withstand constant off-road use.

INDEPENDENT FRONT SUSPENSION

All Ford passenger cars, and the Ranchero in the truck series, use the independent front wheel suspension system. The independent front wheel suspension with coil springs makes it possible to obtain an entirely different type of wheel action than is possible with the beam-axle design. Independent front suspension makes a suspension unit of **each** front wheel. This gives each front wheel the ability to conform to road surface variations and still maintain a level load plane without regard to the independent action of the other front wheel.

This differs from the solid axle in which one wheel could **not** drop into a road depression without affecting the position of the other wheel. Thus, when the position of one side of the axle was raised or lowered, the wheel had to be moved from its plane of rotation. The gyroscopic effect of a rapidly spinning wheel would oppose this out-of-plane movement, affecting the ride and handling qualities of the vehicle.

LONG- AND SHORT-ARM SUSPENSION

The type of independent front suspension currently in use on Ford products (Fig. 5) is called the long- and short-arm suspension because it uses upper and lower control arms of different lengths.

At first glance, the reason for using upper and lower control arms of different lengths may not be clear, but a careful examination of Fig. 5 and 6 will explain the advantage. If the arms were equal in length, the distance between the two front tires would change as the car passed over irregularities in the road. This spreading and retracting action would actually drag the tires sideways and result in very rapid tire tread wear from the scuffing and scrubbing action. To offset this, the upper control arm is made shorter—which makes the radius it describes also shorter. This brings the top of the wheel in faster than the bottom control arm. As a result, the tread distance is not changed and side scuffing of the tires is greatly reduced. This topic is discussed further in the section on "Front End Alignment."

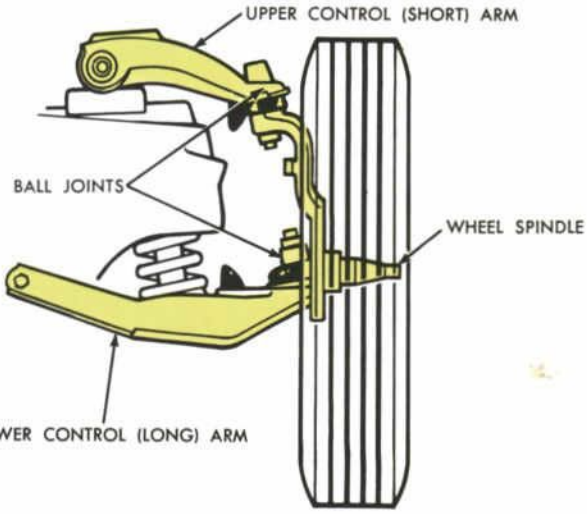


Fig. 5—Long- and Short-Arm Suspension

The upper and lower control arms are attached to the frame.

The wheel spindle is attached to the outer ends of the upper and lower control arms by ball joints (Figs. 5 and 6). The ball joints act as a pivot in much the same manner as the conventional kingpin.

There are two methods of installing the coil springs in current Ford models. In some installations, the coil springs are mounted between the lower control arm and a pocket in the frame (Fig. 6, Views A & B). In other installations, the springs are mounted between the upper control arm and a spring tower above the frame or underbody member (Fig. 6, View C).

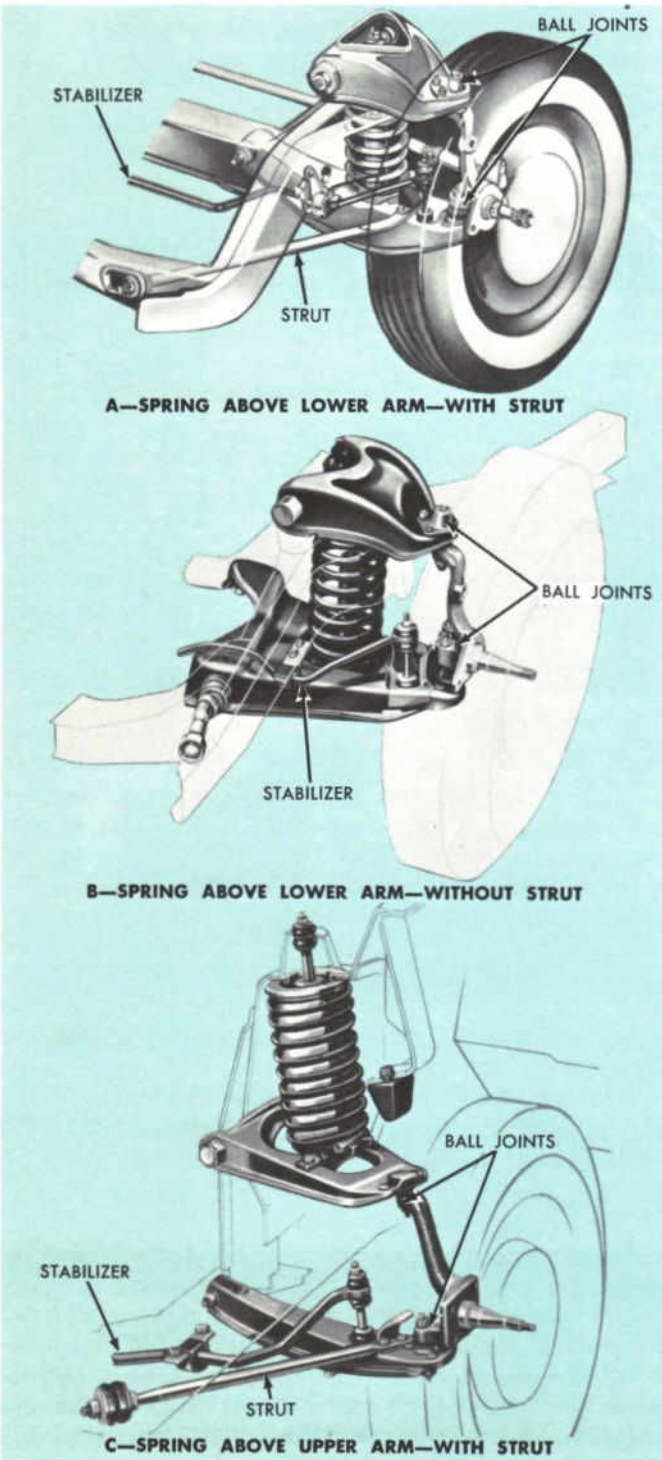


Fig. 6—Ball Joint Front Suspensions

When the lower arm is attached to the frame or underbody at one point only, as shown in Fig. 6, Views A & C , a strut is used to position the lower arm.

To control body roll, all independent suspension installations employ a **stabilizer** or sway bar, attached to the frame and to the suspension lower arms. A stabilizer is a device employing the torsional resistance of a steel bar to reduce car side roll (body roll) and to prevent too great a difference in the spring action at the two front wheels.

Body roll is the leaning out of the car body caused by centrifugal force as the car rounds a turn. This tends to compress the outer spring and expand the inner spring. When this occurs, the stabilizer bar is twisted. The resistance of the bar to the twisting effect combats the tendency toward differences in spring height to prevent excessive body roll.

SPRINGS

Although coil springs are now used on all Ford passenger car independent front suspensions, the semi-elliptic leaf spring (Fig. 7) is still used in certain truck series. The semi-elliptic spring, successor to the full-elliptic spring, is attached to the frame side members by a **bracket** and a **shackle,** (Fig. 7) or by a bracket and a **slipper spring pad** (Fig. 9).

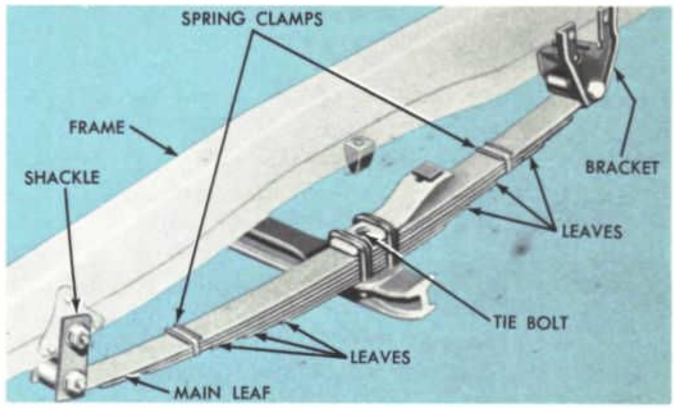


Fig. 7—Semi-Elliptic Leaf Spring

The spring is made up of **leaves** of successively diminishing length, with the shortest leaf at the bottom of the spring, and the longest, or main leaf, at the top. A bolt is installed through holes at or near the center of the spring leaves. This bolt is referred to as the spring **tie bolt.**

Clamps are placed around the spring assembly at several points to help distribute the load more evenly over all spring leaves when the spring rebounds after passing over an obstruction in the road, or when a wheel drops into a depression in the road surface. Without these clamps, most of the rebound load would be placed on the main leaf and would often cause main leaf damage.

SPRING ATTACHMENT

One end of the spring is attached to a bracket on the frame by means of a bolt passing through a bushing pressed into the spring eye (Fig. 8). The bushing contains an inner and outer shell, with a molded rubber bushing between the shells. As the spring bends or flexes, the spring eye turns back and forth with respect to the spring bracket. The rubber bushing deflects or twists to allow this movement. The vehicle weight is carried through the rubber bushing, which acts to damp or reduce vibration and noises and to prevent these noises and vibrations from reaching the car frame and body.

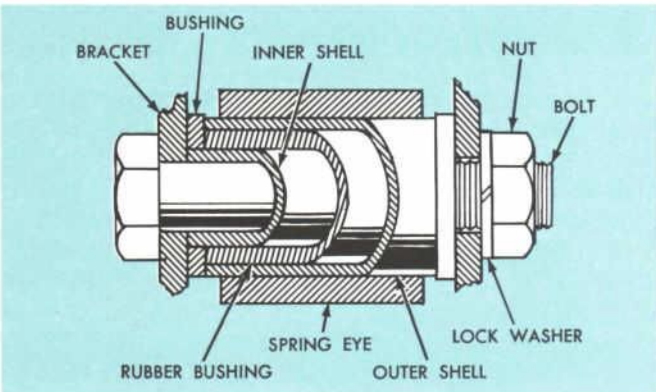


Fig. 8—Spring Eye Bushing

Spring Shackles

As the leaf spring bends or flexes, the straight-line distance between the spring eyes change. If the spring were attached rigidly to the frame at both ends, it would not bend or flex, because the distance between the two eyes would remain constant. To allow the springs to flex, a swinging or sliding support is employed (Fig. 9). These devices all serve to allow the spring eye distance to change as the spring bends.

Passenger cars always use a shackle to permit this movement while heavy trucks usually employ the slipper-type mount. The spring shackle or slipper arrangement is used at the rear of the front spring. The front of the spring is attached to a spring hanger with a bolt and bushing. In this arrangement, the leaf springs also serve to position the axle laterally and fore-and-aft with respect to the frame.

The best springs, by themselves, are not sufficient to give the desired control of the vehicle suspension system. At best, the spring is a compromise between stiffness and flexibility. It must be soft enough to flex and absorb road shocks, but not so soft that it continues to rebound and flex after striking a road surface irregularity. A continued flexing and re-

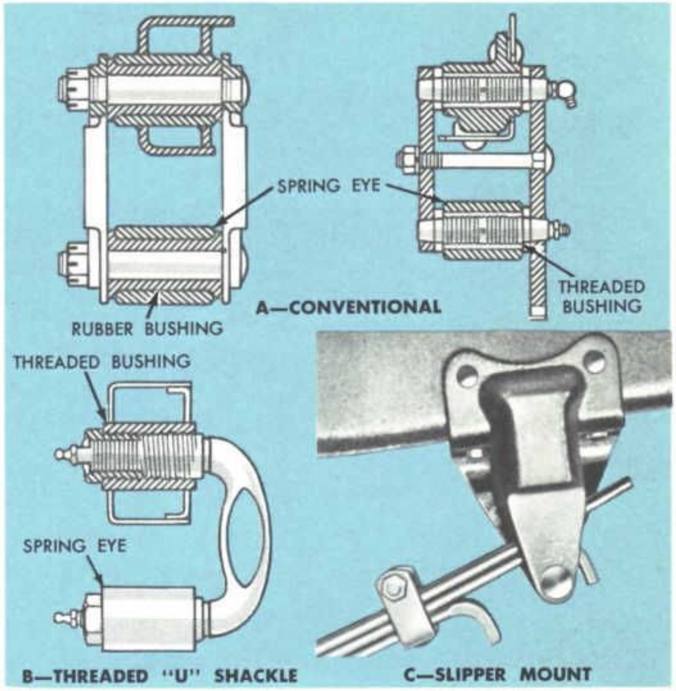


Fig. 9— Conventional Shackle: Threaded "U" Shackle; Slipper-Type Arrangement

bounding would result in a rough ride and loss of control. If the spring were stiff, the rebounding and flexing after a bump would be greatly reduced, but it would transmit too much road shock to the vehicle frame, giving a stiff, jolting ride.

The most obvious solution to this problem is the use of a spring flexible enough to absorb road shock and a device to control the rebounding and flexing action of the soft spring. This device is called a shock absorber.

Various types of shock absorbers have been used in the past, such as friction, compressed air, and hydraulic. These shock absorber types were the forerunners of the conventional absorber as we know it today.

SHOCK ABSORBERS

DOUBLE-ACTING SHOCK ABSORBER

The Ford shock absorber is a direct-acting, double-action unit; that is, it controls both the rebound and compression. The shock absorber is bolted to the axle or control arm at one end and to the frame at the other end (Fig. 10). Metal-to-metal contact is prevented by using rubber insulators between the mounting points and the shock.

Any up or down movement of the car body, with respect to the wheels, causes the shock absorber to extend or to telescope (lengthen or shorten).

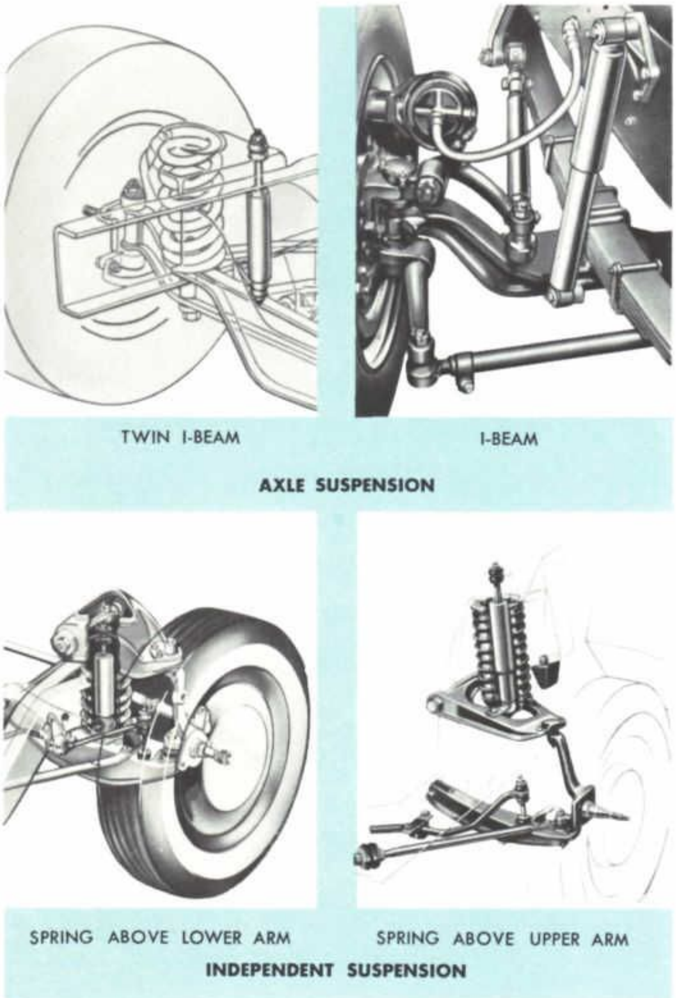


Fig. 10—Typical Front Shock Absorber Mountings

Shock Absorber Operation

When the shock absorber telescopes (shortens) as a result of spring compression (Fig. 11), the piston moves toward the compression head and the fluid must follow in two paths. One path is through the piston, and the other is through the compression head and into the reservoir. Fluid is displaced through the piston skirt restriction ports, under an O-ring protector and through the carrier orifice. The velocity of the fluid flow is determined by the severity of the bump causing the spring compression. As the velocity of the fluid flow increases, the pressure also increases. This pressure lifts the O-ring assembly against the bypass spring, permitting a controlled fluid flow. At the same time, the fluid displaced by the piston rod passes through the compression head orifices. As the piston velocity increases, the fluid is forced through the compression valve restriction, opening the valve against the valve spring.

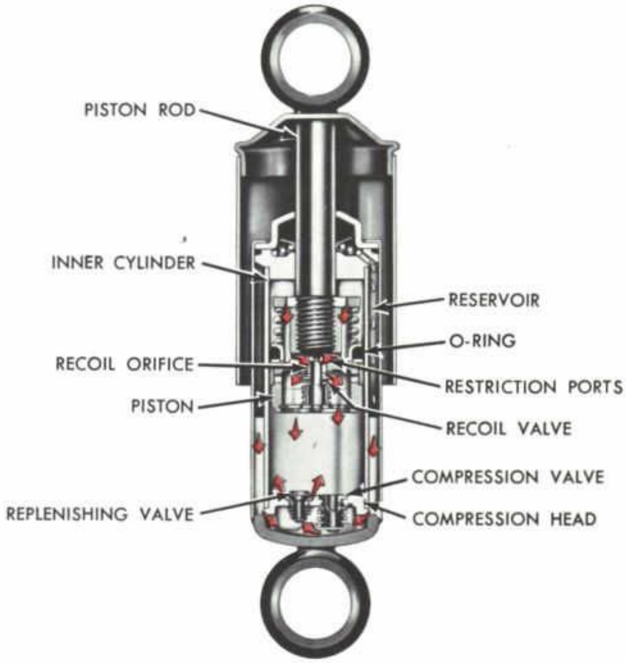


Fig. 11—Shock Absorber — Recoil Stroke

REAR SUSPENSION

The rear suspension in many ways parallels front suspension. A rear axle is necessary to support the car. It also supports the springs to cushion the ride and the shock absorbers to control spring action. There are two very basic differences between front and rear suspension in conventional passenger cars.

- The rear axle must not only support the car but also drive the car.
- The rear wheels always remain in the parallel, straight-ahead position. They are not used to steer the car.

RIGID-TYPE AXLE

While independent front wheel suspensions are the rule on most passenger cars, independent rear suspensions are rare because springing the rear or driving wheels independently is very costly—involving constant-velocity universal joints and slip yokes in the axle shafts. Rear wheel geometry is not critical and does not warrant independent suspension, since the rear wheels do not steer the car. So we find rigid driving axles in all Ford passenger cars.

Briefly, the rear driving axle is constructed of a central differential housing and tubular axle shaft housings (Fig. 12). The solid axle shafts are supported in the housing by bearings and are splined to the differential side gears and to the wheel hubs (brake drums).

The weight of the car is supported by the axle shafts, and the axle housing is attached to the springs, so that the axle assembly and wheels are the rear **unsprung weight,** that is the weight that is not supported on the springs. A means is provided to transfer driving, braking and accelerating forces from this axle housing to the frame of the car.

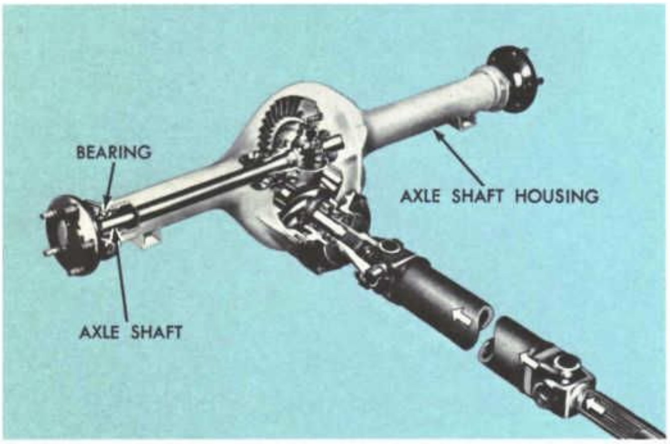


Fig. 12—Typical Rear Axle

HOTCHKISS DRIVE

The Hotchkiss drive, although an early development in the evolution of the motor car, is still used on many vehicles. In this drive, two semi-elliptical leaf springs are attached by spring clips to the axle housing tubes and by brackets and shackles to the frame (Fig. 13). In this design, the springs transfer the wheel braking and driving torque from the axle to the frame.

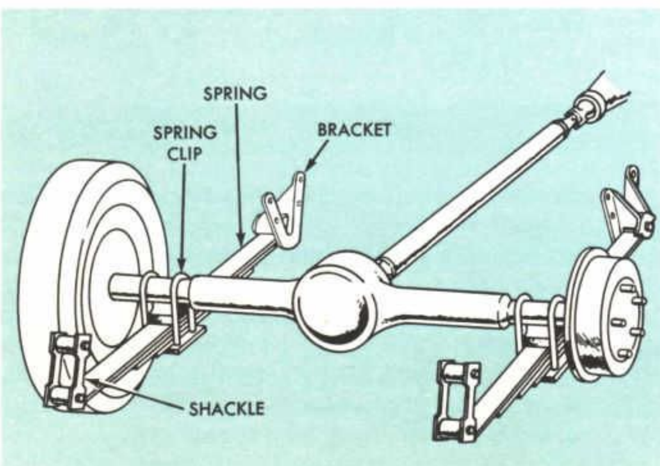


Fig. 13—Hotchkiss Drive Suspension

A characteristic of the Hotchkiss drive is the spring torque windup. When the vehicle is accelerated or braked, reaction to the torque on the wheels tends to twist the axle housing. With no suspension arms or torque tube, this twisting action distorts or "winds up" the spring (Fig. 14). Thus, many vehicles will squat down at the rear under acceleration or nose down in the front while braking as the spring either lowers or raises the rear end. The effect of torque windup on the attitude of the car

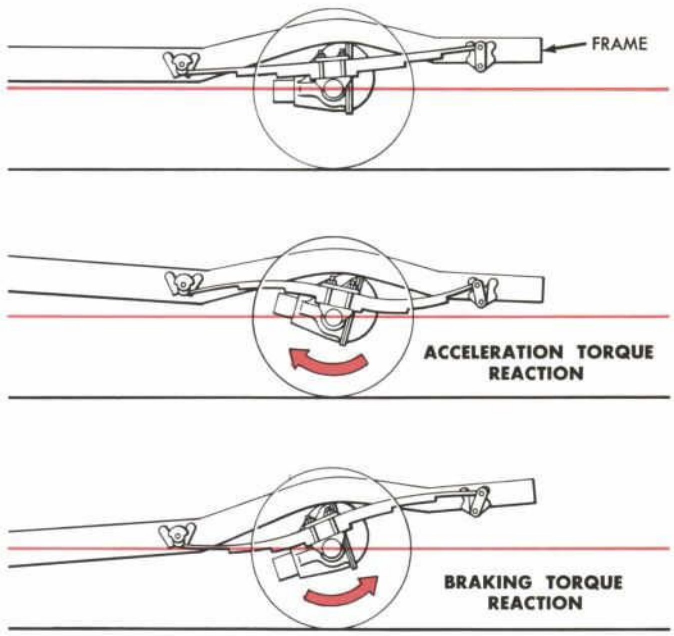


Fig. 14—Spring Windup

depends on where the axle is located on the spring. Positioning the axle near the center of the ellipse reduces the tendency to squat or nose down.

FORD COIL SPRING REAR SUSPENSION

A coil spring rear suspension (Fig. 15) is used on some Ford-built cars. In this suspension, a rigid rear axle with flanged axle shafts is suspended from the frame by a coil spring and shock absorber at each side. The lower spring seats are welded to the axle housing and the upper seats are part of the frame.

Suspension Arms

Three suspension arms, one upper and two lower, permit the axle to move up-and-down but prevent fore-and-aft movement of the axle. The arms also transmit braking and driving forces to the frame. A **track bar is** connected between the axle housing

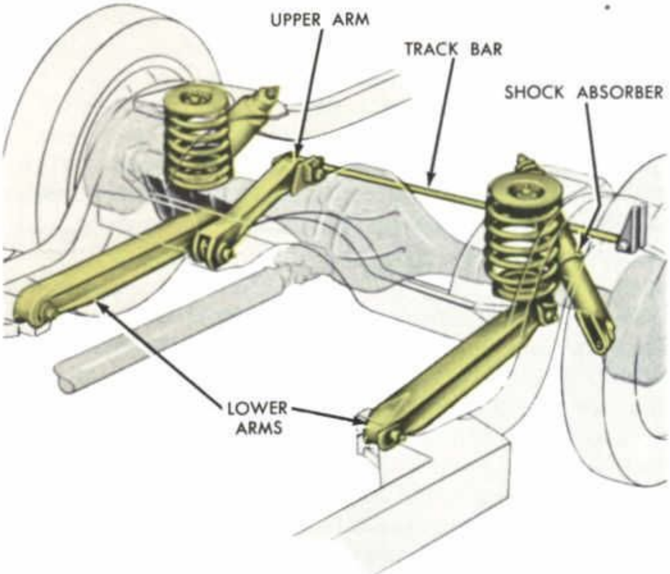


Fig. 15—Coil Spring Rear Suspension

and frame siderail to prevent lateral movement or sway.

TRUCK REAR SUSPENSIONS

In medium and light-duty trucks, the rear suspension is similar to the automobile's Hotchkiss drive. In heavy-duty trucks with tandem axles Hotchkiss drive is not used, but torque arms are provided to handle accelerating and braking forces.

Springs

Truck rear springs (Fig. 16) may be of several types, such as the conventional single stage (View A), two stage, progressive (View B) or variable rate (View C). Many trucks have auxiliary springs (View D) available.

A **two-stage** effect is accomplished with flatter shorter lower leaves which do not function until the vehicle is heavily loaded. Thus, there is less springing for a more comfortable ride at light load.

In the **progressive** design (Fig. 16, View B), two sets of leaves are used to suit heavy and light load conditions. The upper leaves soften the ride with light loading. As the load increases, the stiffer lower leaves progressively combine with the upper leaves.

Variable-rate springs (Fig. 16, View C) use radius leaves to link the spring mount on the axle to the forward spring bracket. The radius leaves handle the accelerating and braking forces, leaving the main spring free to support and cushion the load. Variable spring rate is achieved through cam-shaped pads in the mounting brackets, which change the length

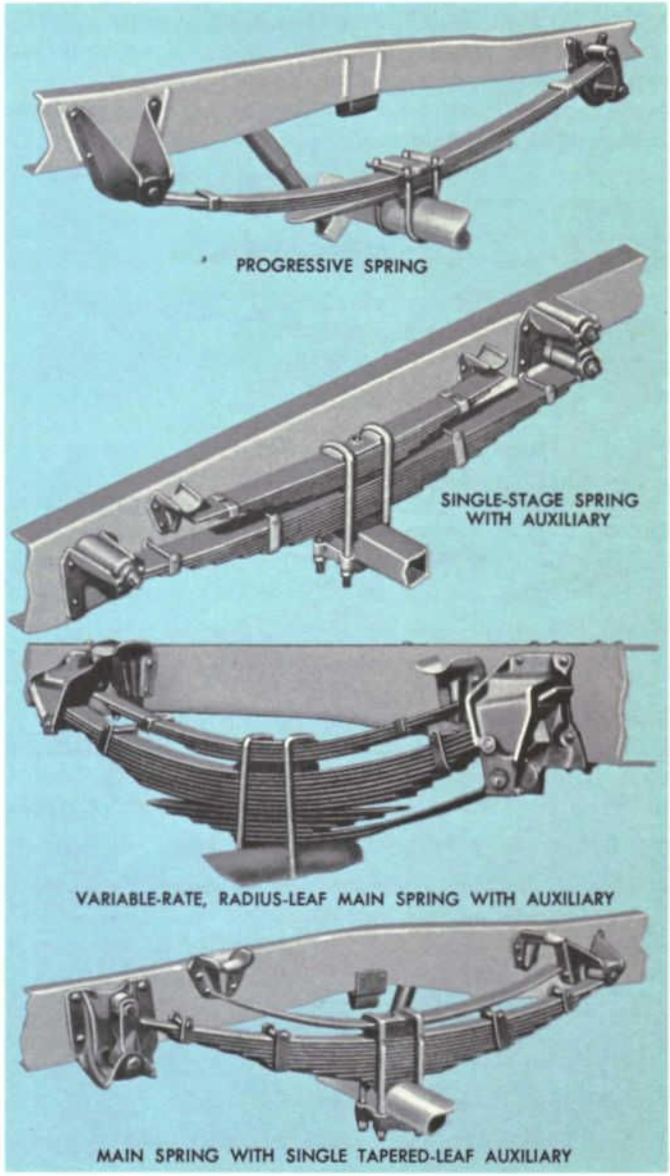


Fig. 16—Truck Rear Spring Design

of the main spring, and thus its rate, as the load changes. The spring becomes shorter and stiffer when heavily loaded; it lengthens and becomes softer under light load.

Auxiliary rear springs (Views C and D) are mounted on top of the main springs and have free ends. With heavier loads, the ends contact spring pads for increased capacity and stability. In light loading, only the main spring is in operation.

PAGE AND PAGE SUSPENSION

The Page and Page rear suspension system (Fig. 17) is used with a tandem rear axle—one driving

axle and one "dead" axle that simply supports the load. Rocker (equalizer) arms and torque rods are provided to distribute the weight in various percentage combinations depending on traction requirements of the driving axle.

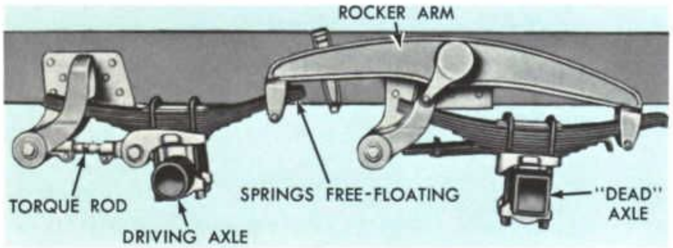


Fig. 17—Page and Page Suspension

Driving and braking forces are transmitted through the torque rods. The springs are free-floating on cam surfaces of the equalizer arm ends and brackets, used at all pivot points to reduce road shock and eliminate the need for lubrication.

HENDRICKSON SUSPENSION SYSTEM

In the Hendrickson suspension system (Fig. 18), both axles are driving axles as well as supporting the load. The springs are mounted on equalizing beams between the two axles. The equalizing beams operate in conjunction with torque arms to transfer driving and braking forces to the frame. They also distribute the load between the two axles and maintain positive axle alignment.

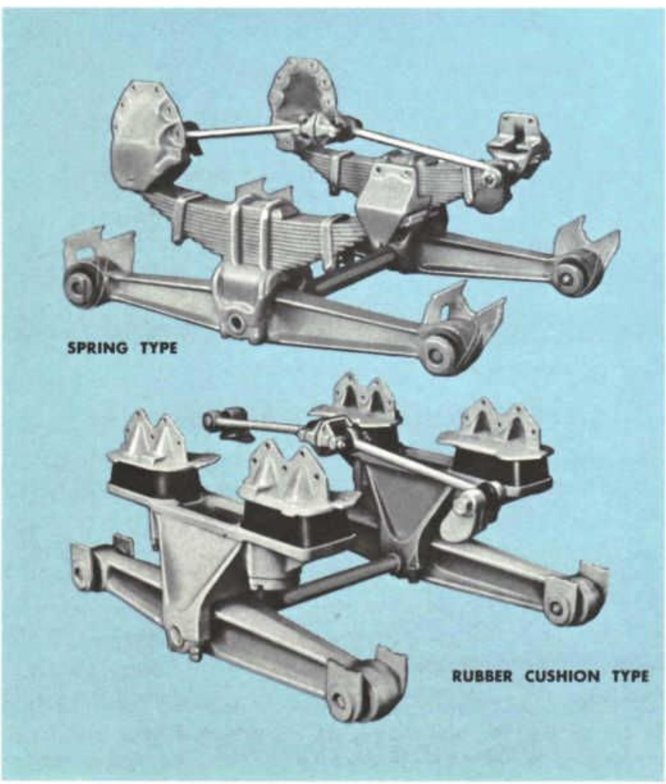


Fig. 18—Hendrickson Suspensions

Variations of the Hendrickson system include rubber load cushions or two-stage rubber shear springs instead of leaf springs, and an extended-leaf suspension with two-stage spring action.

CONCLUSION

Disregarding the steering function, the rear suspension design and operating characteristics are closely related to the front suspension. Spring rates and shock absorber design are closely matched to prevent a harsh ride which could result from unmatched components. The location of the rear axle is determined to a great degree by the vehicle's center of gravity and the need to distribute the vehicle's weight as evenly as possible between the front and rear axles.

Drive shaft universal joint angles also must be considered in rear suspension design. This is particularly true with Hotchkiss drive where spring windup can often tip the rear axle excessively, causing severe working angles. The rear coil spring suspension not only provides a quieter ride, but also solves many of the problems of axle location and drive shaft angularity.

MANUAL STEERING

The steering control of automotive vehicles is exerted through the front wheels. The front wheels turn on spindles which can be swiveled. A linkage (Fig. 19) controls the degree of swivel and holds the wheels in alignment. The linkage is connected through gears or cams to a steering wheel installed at the position occupied by the driver.

The leverage or mechanical advantage necessary for the driver to steer the vehicle with only small effort exerted at the steering wheel is supplied by the steering gear. The driver is assisted at all times by this mechanical advantage in his control of the

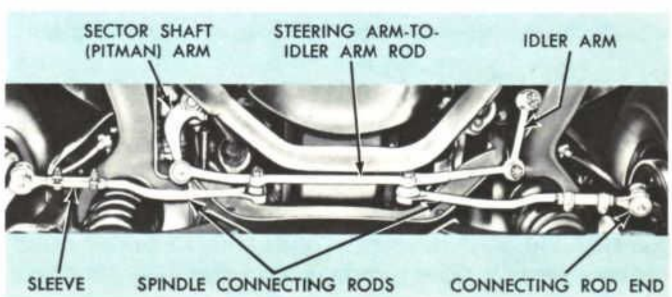


Fig. 19—Typical Steering System

vehicle, especially when the vehicle is stopped and the driver must overcome the frictional resistance of the tires on the road surface. When the vehicle is in motion and strikes an irregularity in the road surface, the mechanical advantage of the steering gear prevents the shock from being transmitted to the driver through the steering wheel.

A good manual steering system eases the handling of a vehicle and thereby, reduces driver fatigue. It does this by absorbing wheel road shock without transmitting this shock to the driver. The driver is able to transmit steering effort to the wheels without getting road shock feedback caused by the wheels passing over irregularities in the road surface. This is known as the "nonreversible" feature of the steering gear.

The conventional steering gear (Fig. 20) consists of a steering gear shaft with a **worm gear** on one end which is connected to the steering wheel either directly or through some type of flexible joint. A **cross shaft** passes at right angles to the worm gear, and engages with the worm gear either through gear teeth, a round steel peg or pegs, or a roller gear. In some instances, a ball nut rides on the worm gear and a gear or notched arm on the cross shaft is engaged with this nut.

Ball or roller bearings are used to support both ends of the worm gear and are adjustable to remove end or side play from the worm gear. The cross shaft is supported by bushings, needle bearings, or a combination of the two, and provision is made to control worm and cross shaft clearance. All parts are enclosed in a cast housing which is partly filled with lubricant. Seals are used to prevent the entry of dirt or the loss of lubricant in the housing. Provision is made to bolt the steering gear housing to a rigid area, such as the frame.

The mechanical advantage referred to is the ratio of the force which performs useful work of a machine to the force which is applied to the machine. When we say, then, that gear box ratios vary from 15-1 to 27-1, we are saying that the force applied to the steering wheel by the driver is multiplied by from 15 to 27 times by the steering gear. The steering wheel movement from full right to full left (lock-to-lock) averages from four to six turns. These are approximate figures, and some exceptions do exist.

Unfortunately, the nomenclature of steering gear parts is not consistent with all manufacturers. For example, the steering gear worm sector in Fig. 21 is variously known as the cam lever shaft, Pitman shaft, or roller shaft, but regardless of terminology, the function of the part remains the same.

Let us turn now to the principal types of steering systems used in current Ford products; the Gemmer worm-and-roller steering gear, and the recirculating ball steering gear.

All Ford passenger vehicles and light trucks equipped with conventional (manual) steering use the recirculating ball-type gear. The Ford F-500 truck models and above use the Gemmer worm-and-roller gear, when so equipped.

GEMMER WORM-AND-ROLLER STEERING GEAR

The Gemmer worm-and-roller steering gear uses rollers instead of a sector gear on the sector shaft. The roller may have one, two or three teeth which are meshed with the worm gear. The roller is mounted on needle roller bearings. As the roller is free to turn, the friction developed by a wiping action of the gear is eliminated, thus reducing gear wear and steering effort.

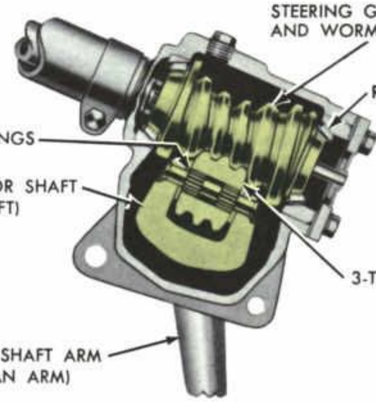


Fig. 20—Gemmer Worm-and-Roller Steering Gear

When the worm is rotated, the roller teeth must follow along. This action causes the shaft to rotate. One end of the Pitman arm is attached to the shaft, therefore, this rotation causes the other end of the Pitman arm to swing. This motion is carried to the steering linkage as lateral movement.

RECIRCULATING BALL STEERING GEAR

A variation of the worm and sector steering gear design is illustrated in Fig. 21. It is the recirculating ball-type gear. A sliding nut is used which has threads that are meshed to the threads of the worm with continuous rows of ball bearings between the two. The ball bearings are recirculated through two outside loops. The sliding nut has teeth cut on one face which mate with teeth on the sector. As the steering wheel is rotated, the nut is moved up or down on the worm. Since the teeth on the nut are meshed with the teeth on the sector, the movement of the nut causes the sector shaft to rotate and swing the Pitman arm.

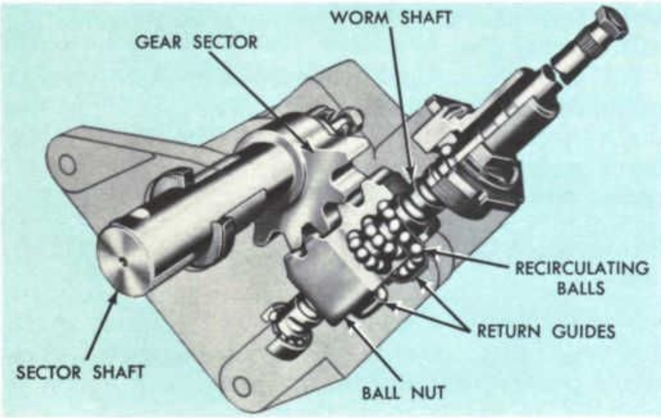


Fig. 21—Recirculating Ball-Type Gear

This novel construction results in a friction-free contact between the nut and the worm. When the steering wheel is turned to the left, the ball bearings roll between the worm and the nut, and work their way upward in the worm groove. When the ball bearings reach the top of the nut, they enter two guides and are directed downward into the worm groove at a lower point. When the steering wheel is turned to the right, the ball bearings circulate in the opposite direction.

Adjustments are provided for worm bearing preload and sector-to-nut relationship.

STEERING LINKAGES

Now that we've seen how mechanical advantage is gained in the steering gear, we can go on to see how the rotary output of the steering gear cross shaft or sector shaft is transmitted through various types of linkages to turn the front wheels for steering.

In simplest terms, a steering linkage (Fig. 22) consists basically of a Pitman arm, a drag link, tie rods and steering arms, connected to each other by ball joints or ball sockets. Before we look at any particular type of linkage, let's define the functions of these parts and see what other names some of them go by.

Pitman Arm

The **Pitman arm** or **sector shaft arm** is splined on the steering gear sector shaft. When the sector shaft turns, the Pitman arm swings in an arc. The swinging end of this arm is connected to the drag link.

Drag Link

The **drag link** or **relay rod** or **steering connection link** or **steering arm rod** transfers the swinging mo-

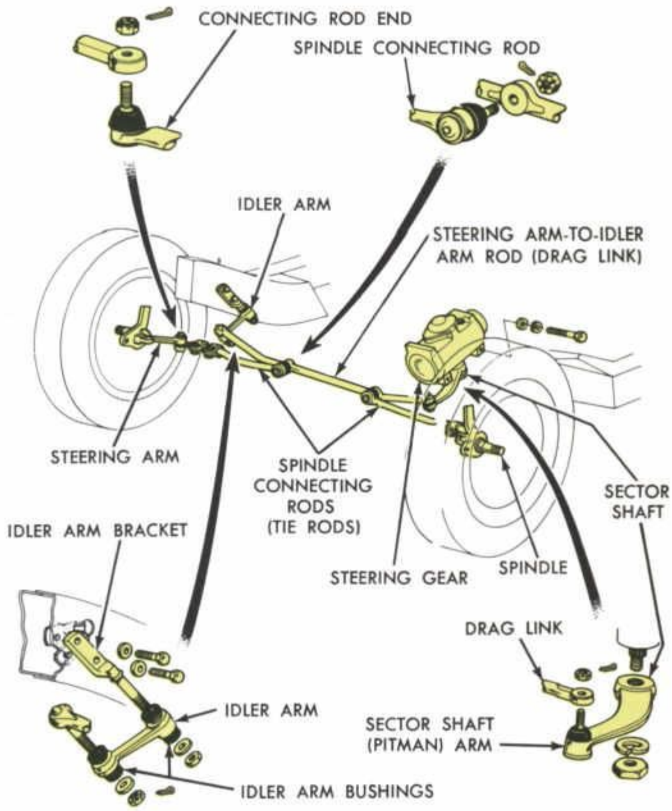


Fig. 22—Basic Steering Linkage

tion of the Pitman arm to a linear or back-and-forth motion. It can also change the direction of the Pitman arm motion, depending on the type of linkage. The drag link is connected either to the tie rods or to an intermediate steering arm. This will be discussed later.

Tie Rods

Tie rods are connecting rods. They transmit movement of the drag link to the spindle steering arms.

Steering Arms

The **steering arms** or rods are part of, or attached to, the steering spindle assemblies. When the steering arm moves, the spindle assembly rotates on the kingpin or suspension arm ball joints.

IDLER ARM (PARALLELOGRAM) LINKAGE

A common steering linkage used with independent front suspension and found on Ford products is the idler arm or parallelogram linkage (Fig. 23). This linkage actually forms a parallelogram with the center line of the wheel spindles.

In this linkage, the drag link is actually a rod connecting the Pitman arm to an **idler arm** at the

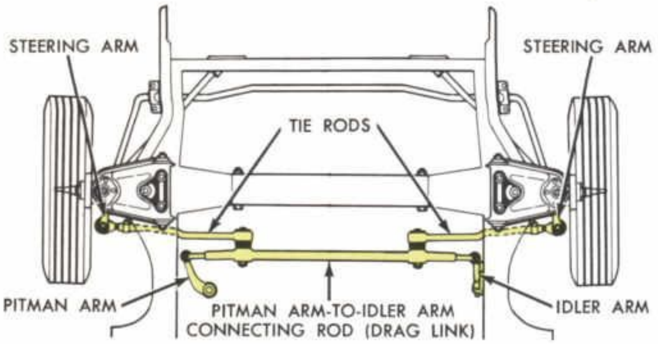


Fig. 23—Idler Arm Linkage—Parallelogram

opposite end of the frame. Tie rods connect this rod to the spindle steering arms. Adjustment of the tie rod length is provided in threaded sleeves which are locked by clamps.

Idler Arm Design

The idler arm is mounted parallel to the Pitman arm. It pivots in a support attached to the frame (Fig. 24) when the steering linkage moves back-and-forth. Rubber bushings in the idler arm attachment twist as the wheels turn off center and provide a force to help return the wheels to center.

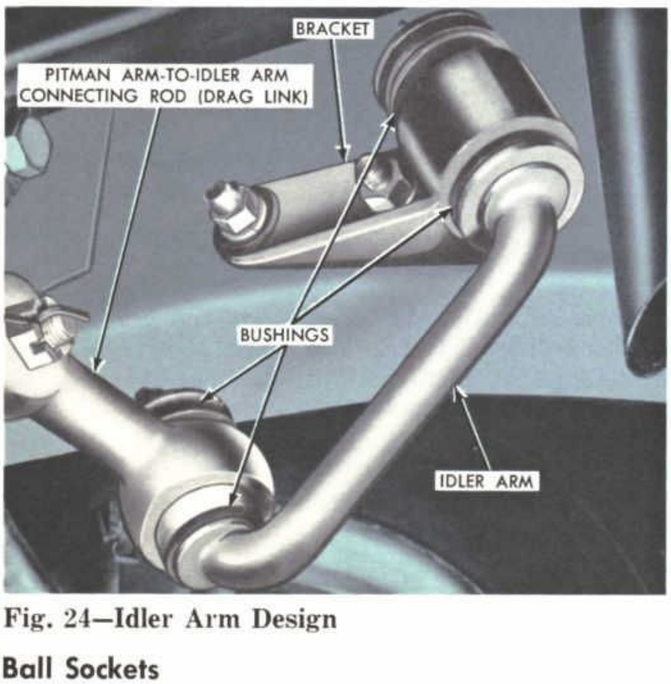


Fig. 24—Idler Arm Design

Ball Sockets

Ball sockets or ball joints (Fig. 25) are used to connect the steering connecting rod to the Pitman arm and idler arm. They are also used at the ends of the tie rods—hence the name **tie rod end.**

Formerly, these ball sockets required lubrication at short mileage intervals. Today, the development

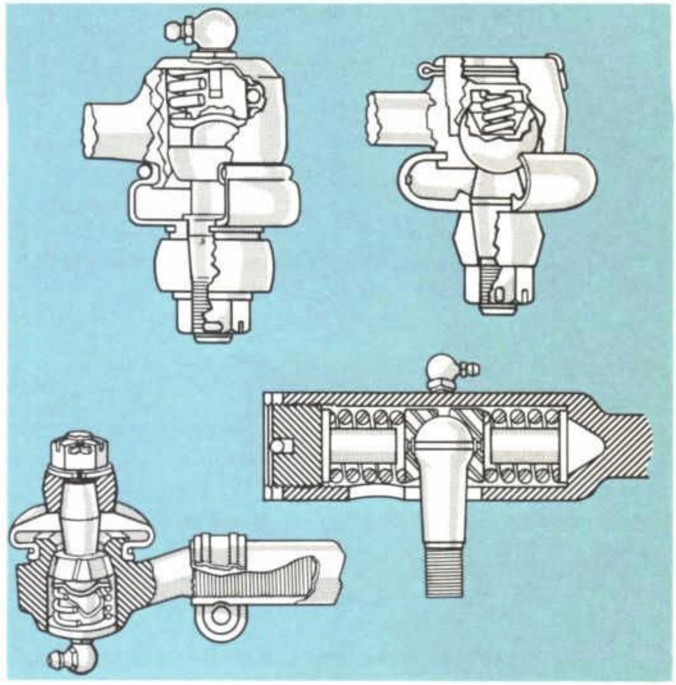


Fig. 25—Ball Sockets—Tie Rod Ends

of improved seals and lubricants has extended these intervals to 36,000 miles or more in the Ford product line.

Tie Rod Design

Tie rods in the idler arm linkage are usually equal in length, and are approximately the same length as the suspension lower control arms. The drag link is attached to the frame through the Pitman arm and idler arm, while the spindle steering arms are fastened to the steering tie rods at one end and the steering arms at the other end. As the frame raises and lowers when driving over a rough road surface, the position of the spindle steering arms does not change appreciably. Since these arms are attached to the steering spindle, the distance between the spindle and the road does not change appreciably either.

Parallel Tie Rod and Drag Link

The drag link and tie rods should be almost parallel. However, the top view in Fig. 26 shows these rods not parallel. As stated earlier, when the car frame lowers as the car goes over a bump, or as the load is increased, the **drag link** is also lowered while the steering spindle arm height remains unchanged. When the drag link moves down, the angle between it and the tie rods decreases. The tie rod ends must spread out as shown in the bottom view in Fig. 26. This action forces the spindle steering

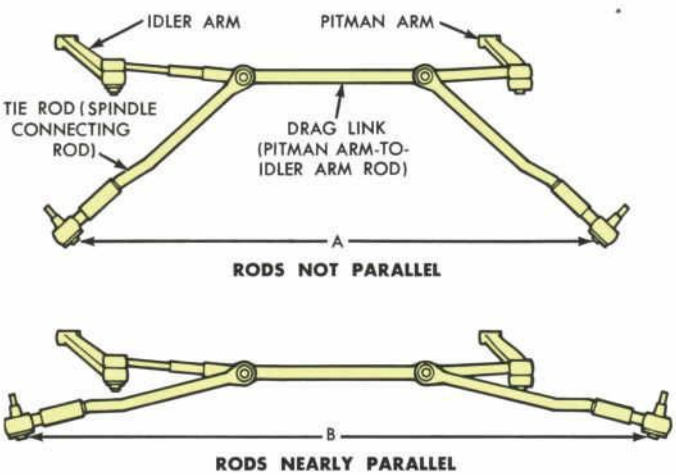


Fig. 26—Drag Link and Tie Rod Relationship

arms out and affects wheel alignment. However, if the rods are positioned as in the top view in Fig. 26, changes in frame height will have a minimal effect on the distance between the tie rod ends and will cause a minimum change in wheel alignment.

TRUCK STEERING LINKAGE

A typical steering linkage used with solid axles on Ford trucks is illustrated in Fig. 27. The drag link is connected to the Pitman arm at one end and to the intermediate arm at the other. The intermediate arm is often an extension of the steering spindle arm. This third arm provides a bell-crank action to change the fore-and-aft motion of the Pitman arm and drag link to cross movement of the tie rod.

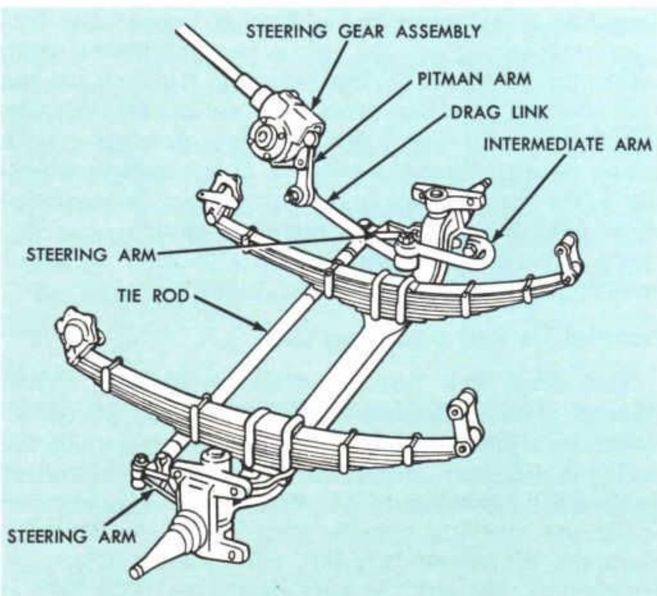


Fig. 27—Solid Axle Steering Linkage

Cross steering can be obtained without resorting to intermediate arms and levers (Fig. 28). One tie rod is attached to the drag link at one end and the right wheel steering spindle arm at the other end.

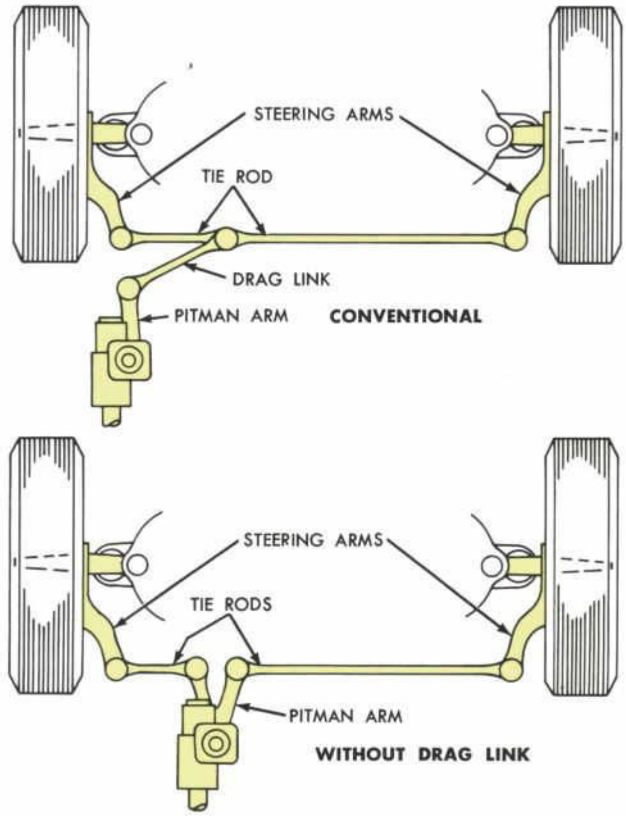


Fig. 28—Cross Steering

A second tie rod is attached to the first tie rod with a ball socket and to the left steering spindle arm. Another method, illustrated in Fig. 28, has both tie rods attached to the Pitman arm.

MALLEABLE CONSTRUCTION

All steering linkage parts are malleable and will bend, distort or deflect rather than fracture under extreme shock loads. This toughness and malleability are necessary to avoid the complete loss of control which would occur if any part were to break.

POWER STEERING

Ford power steering uses a booster arrangement that is set into operation when (a) the steering wheel is turned, and (b) the effort required to turn the wheel exceeds a certain predetermined limit.

The booster then provides most of the force required to do the steering. Compressed air, electrical mechanisms and hydraulic pressure have been used to provide this booster force, but hydraulic pressure is now employed on the vast majority of modern power steering systems. The fluid used to provide this hydraulic pressure in Ford products is automatic transmission fluid type A.

Linkage-type power steering systems (Fig. 29) make use of three major components:

- A continuously operating hydraulic pump to provide fluid under pressure.
- A piston and cylinder assembly linked to the steering gear or steering linkage to provide the steering assist.
- A steering control valve assembly to direct the fluid to the proper side of the piston.

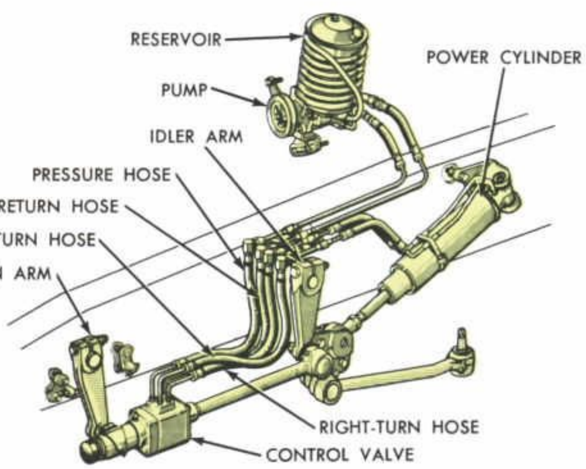


Fig. 29—Power Steering System

Although there are many variations of power steering design and application, all variations fall into three general classifications. The **linkage type,** the **semi-integral type** and the **integral type.** In the linkage type, the power assist is provided by attaching the power cylinder and piston to the steering linkage and frame. In the **integral** power steering, the cylinder and piston assembly is part of, and is contained in, the steering gear housing. The basic difference in the first two systems is that power is applied to the linkage in one design and to the steering gear cross shaft in the other.

Semi-integral power steering (Fig. 30) is a combination of the two systems mentioned above. It incorporates a hydraulic control valve on a single stud cam and lever mechanical gear. Steering effort applied to the steering wheel actuates the valve, which in turn, directs hydraulic fluid from the power steering pump to a power cylinder located in the linkage.

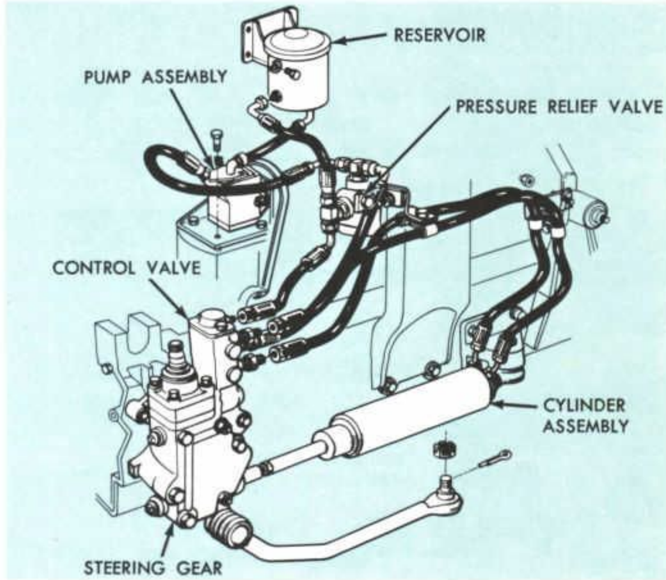


Fig. 30—Semi-Integral Power Steering

The power cylinder used in this system is similar to that used in the linkage-type power steering system.

The semi-integral power steering system is used on the larger model Ford trucks.

ROSS SEMI-INTEGRAL GEAR POWER STEERING

The Ross HPS-type power steering gear, which is used on the W-Series Ford truck, is a semi-integral hydraulic steering gear which incorporates a hydraulic control valve on a single stud cam and lever mechanical steering gear. Steering effort applied to the steering wheel actuates the valve, which in turn, directs hydraulic fluid from the power steering pump to a power cylinder located in the linkage.

The power cylinder used with this unit is a Bendix-design cylinder and is similar to those used with the separate-unit power steering system.

All power steering systems are designed to reduce steering effort. However, some resistance to turning must be retained to provide the driver with some "road feel" which is the feeling the driver gets when the car is in motion. This feeling is most important to the driver in sensing and predetermining car steering responses.

An experienced driver can detect the point at which the wheels start to drift sideways, and whether or not more or less turning effort is required to stabilize the car.

A complete power steering system requiring no driver effort, would eliminate this "feel of the road" and result in a hard-to-handle, unsafe vehicle.

LINKAGE-TYPE POWER STEERING

The linkage-type power steering system (Fig. 31) consists of a conventional steering gear, steering linkage, a hydraulic pump, a power cylinder and a control valve. The steering linkage used in the linkage-type power steering system is slightly modified to accommodate the power cylinder. It is essentially an idler arm (parallelogram) linkage.

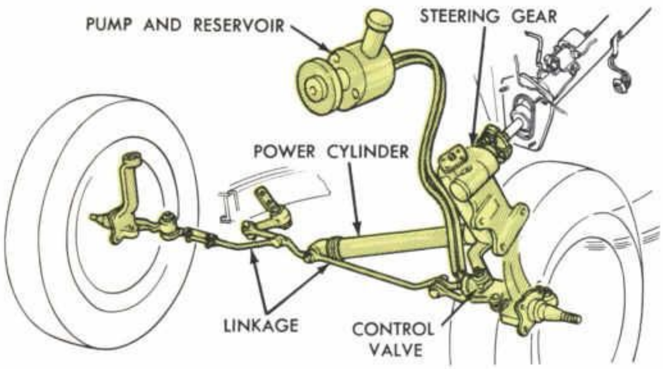


Fig. 31—Linkage-Type Power Steering

The power cylinder is attached to the steering gear connecting rod or drag link. The cylinder piston rod is anchored to a bracket on the frame side rail. The hydraulic pump is mounted on a bracket attached to the engine. It is driven by a V-belt through the engine crankshaft.

Fluid under pressure is delivered from the pump to the control valve. Steering wheel movement is transmitted through the steering gear to the Pitman arm. The control valve directs fluid to the appropriate end of the power cylinder in response to Pitman arm movement, where it exerts the force needed to provide the desired steering assist.

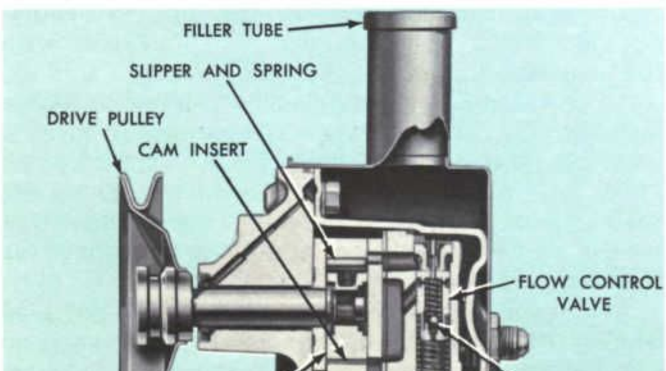


Fig. 32—Ford-Thompson Pump

POWER STEERING PUMP

Most of our power steering systems employ a slipper-type pump (Fig. 32). The major components of this pump are the spring-loaded **slippers,** the carrier, the cam-shaped insert and the flow control valve. A pressure relief valve is incorporated in the flow control valve.

Pump Operation—Idle

With the engine operating at idle speed, the pump output is sufficiently high to provide the desired power assist for turning the front wheels (Fig. 33).

The flow control valve operates within a chamber. The chamber is open to pump pressure at one end, and open to the pump outlet pressure line on the other end. A spring is enclosed in this chamber. Two pressures act on opposite sides of the control valve. Pump pressure is exerted on one side of the valve. Meanwhile, pressure from the pump outlet line and the enclosed spring exert pressure on the other side of the valve.

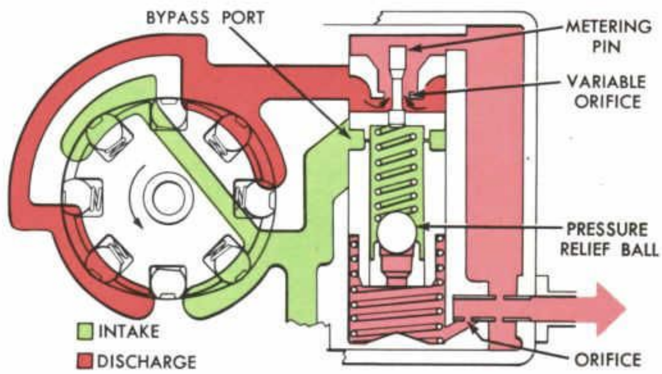


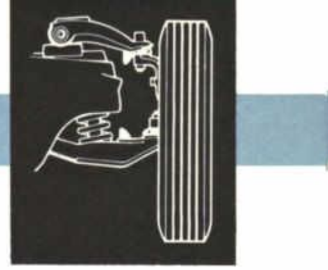
Fig. 33—Pump Operation—Idle

When the combined pressure of the outlet line and spring is greater than the pump pressure, the valve is held in its closed position (Fig. 36).

Pump Operation—Flow Control

When the engine speed is increased, pump speed also increases. At these higher engine speeds, the pump is capable of delivering more fluid than is needed to satisfy the power steering system demands. As this increased output tries to pass through an orifice ahead of the pump outlet line, a pressure differential is created at the two sides of the flow control valve. This difference in pressure causes the flow control valve to move to the position shown in Fig. 34.

When this occurs, a passage is opened which allows fluid to return to the intake side of the pump, and allows the excess fluid to recirculate.



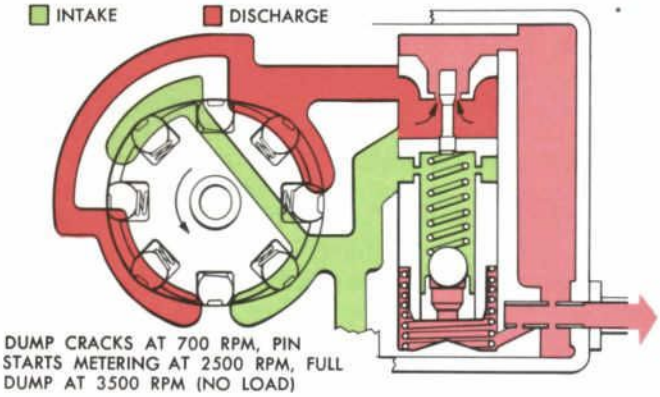


Fig. 34—Pump Operation—Flow Control

Pump Operation—Pressure Relief

A pressure relief valve is built into the flow control valve to prevent the pump pressure from exceeding design limits. When the pump pressure reaches a predetermined limit, the relief spring compresses (Fig. 35), and the relief valve is moved off its seat. With the relief valve off its seat, a pressure differential is created at the ends of the flow control valve. This pressure differential allows the flow control valve to open wider and relieves the pressure by allowing a greater volume of fluid to be recirculated.

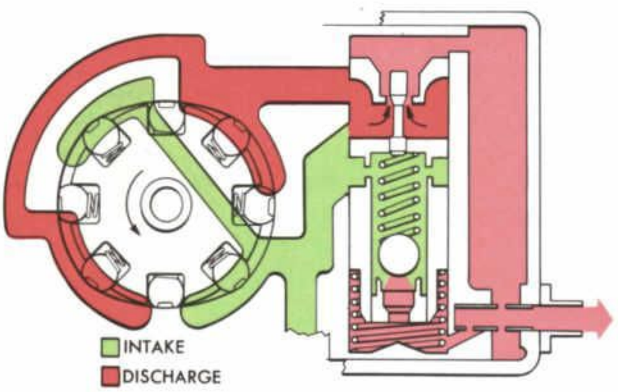


Fig. 35—Pump Operation—Pressure Relief

STEERING CONTROL VALVE

The control valve (Fig. 36) is connected to the steering linkage on the linkage-type power steering system. A valve spool is built into the valve body. Centering springs are used to hold the valve in the centered position for straight-ahead driving. Any movement of the Pitman arm causes the valve spool to move and opens a series of ports directing fluid to one side or the other of the power cylinder, depending on the direction of spool movement.

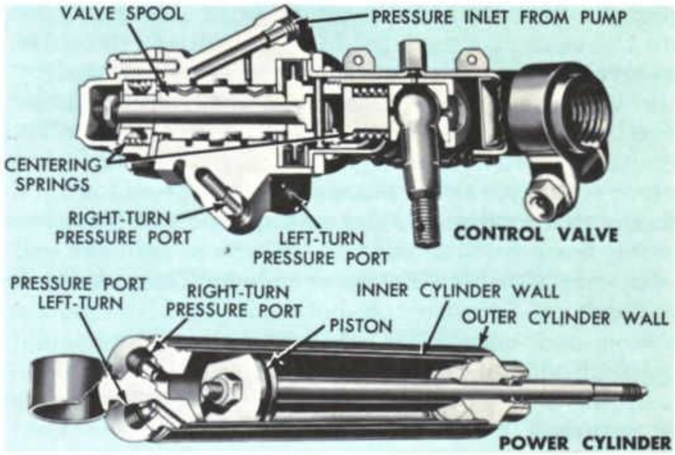


Fig. 36—Control Valve and Power Cylinder

POWER CYLINDER

The power cylinder (Fig. 36) is attached to the steering gear drag link and the power cylinder piston is anchored to the frame side rail. As fluid is directed to one side of the piston by the control valve, the wheels are turned to the left. As fluid is directed to the other side of the piston, the wheels are turned to the right. Two lines connect the cylinder to the control valve. One line is a return line and the other is a supply line during a left turn. The functions of the lines are reversed during a right turn.

FLUID FLOW

Straight-Ahead Driving

When the steering wheel and the front wheels are in the straight-ahead position (Fig. 37), the control valve main spool and the reaction limiting

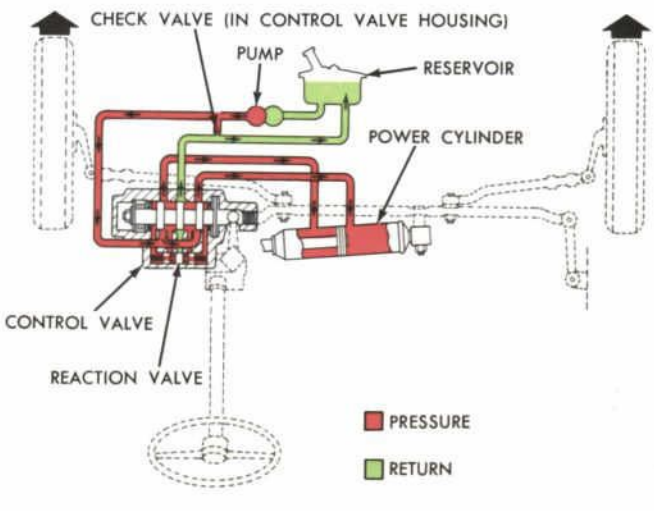


Fig. 37—Fluid Flow—Straight-Ahead Driving

plunger are held in their center or neutral positions by the centering springs. In this position, the three grooves in the valve housing are interconnected by the main valve spool lands and grooves. The large reaction areas of the main spool and the reaction limiting valve are interconnected by passages and grooves in the small plunger, which are connected to the main valve cylinder passages. Fluid from the pump flows to both ends of the power cylinder and both control valve reaction chambers. This results in a balanced pressure on both sides of the power piston and both sides of the control valve main spool. Fluid, in excess of the volume required to keep the power cylinder and reaction chamber filled, is returned from the control valve to the fluid reservoir.

Left Turn

When the steering wheel is turned left and the turning effort at the Pitman arm becomes great enough to overcome the resistance of the centering spring, the main valve spool is moved to the right (Fig. 38).

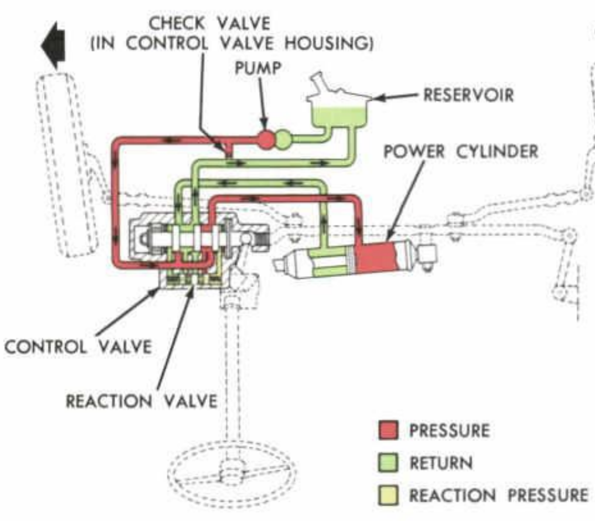


Fig. 38—Fluid Flow—Left Turn

With the valve spool in this position, fluid flow is directed to the right side of the power cylinder and to the right side of the control valve reaction chamber. The fluid in the left side of the power cylinder is free to return to the fluid reservoir. Fluid pressure in the right side of the cylinder forces the cylinder and the attached steering linkage toward the right, providing the desired power assist for a left turn. Fluid in the left side of the cylinder is displaced by the piston and cylinder movement and is forced into the reservoir.

A combination of forces from the main spool centering spring and the fluid pressure in the reaction chamber at the right end of the main spool tend to return the spool to its center position.

Pressure in the reaction chamber is proportional to the pressure being applied to the power cylinder until it reaches a predetermined value. The effort required to turn the wheel against this reaction pressure provides the driver with the "feel" of the road. When the force exerted by the Pitman arm drops below the centering spring force and reaction force, the valve spool returns to its center position, closing the ports to the power cylinder and ending the power assist. No more power assist will be provided until the driver exerts enough force through the steering gear to the Pitman arm to overcome the centering spring force.

Right Turn

In a power-assisted right turn (Fig. 39), the main spool of the control valve is moved to the left. Fluid under pump pressure is directed into the left side of the power cylinder to move the cylinder and steering linkage toward the left. The fluid in the right side of the power cylinder is forced out of the cylinder and is returned to the fluid reservoir. The main spool centering spring and the fluid pressure in the reaction chamber at the left side of the main spool tend to return the main spool to its center position in the same manner as when making a left turn. However, the forces act in the opposite direction. When making a right turn, the reaction limiting feature of the control valve operates in the same manner as when making a left turn, also, except in the opposite direction.

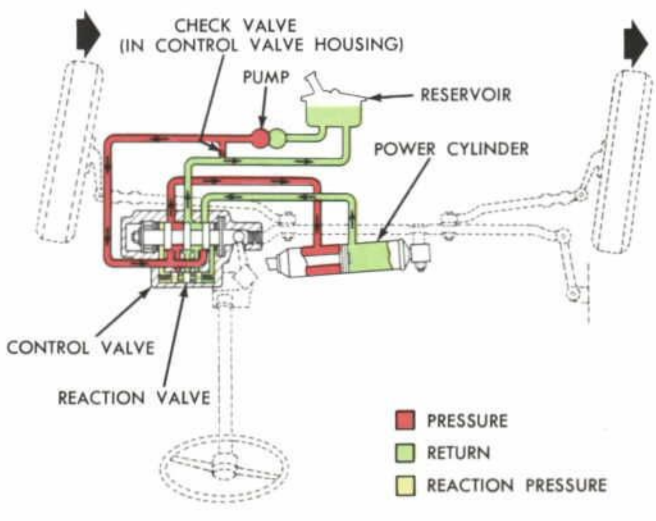


Fig. 39—Fluid Flow—Right Turn

When the steering linkage is moved away from the straight-ahead position, in either direction, the torsion-type rubber idler arm bushings are twisted. After the turn is completed, the twist in the bushings and the normal effect of the front end geometry return the wheels to the straight-ahead position.

REACTION LIMITING VALVE OPERATION

During parking or when making sharp turns at a slow speed, the steering wheel rim pull reaches a predetermined value. The small plunger in the reaction limiting device of the control valve moves in the opposite direction to the main valve spool. This action compresses the spring at the end of the reaction plunger to open the line between the reaction chamber and the center groove of the control valve. Thus, the pressure in the reaction chamber never exceeds a predetermined value. However, the pressure in the cylinder can raise to a higher level,depending on the amount of movement of the main spool and the pump maximum pressure. Since the pressure in the reaction chamber determines to a large extent the force required to park the car, limiting this pressure will also limit the parking effort.

ROAD SHOCK AND BLOW-OUT RESISTANCE

When road shock is translated into movement of the steering linkage, the valve housing becomes the movable part of the control valve instead of the valve spool. Movement of the valve housing causes an increase in pressure in the power cylinder which counteracts and absorbs the force of the shock.

OPERATION WITHOUT PRESSURE SUPPLY

If for any reason operating pressure is lost, a check valve, located in the return outlet of the valve body, permits fluid to flow from one side of the piston to the other, eliminating all resistance.

Any manual movement of the Pitman arm is transmitted to the valve spool which moves approximately 0.060 inch against its stop to transmit the full manual effort to the steering linkage.

With the spool off-center, fluid is displaced from ahead of the piston through the control valve and the check valve. It then returns to the opposite side of the power cylinder piston. Thus, manual movement of the cylinder is not restricted by forcing fluid through the pump and steering effort is not appreciably increased over that required for the conventional steering system.

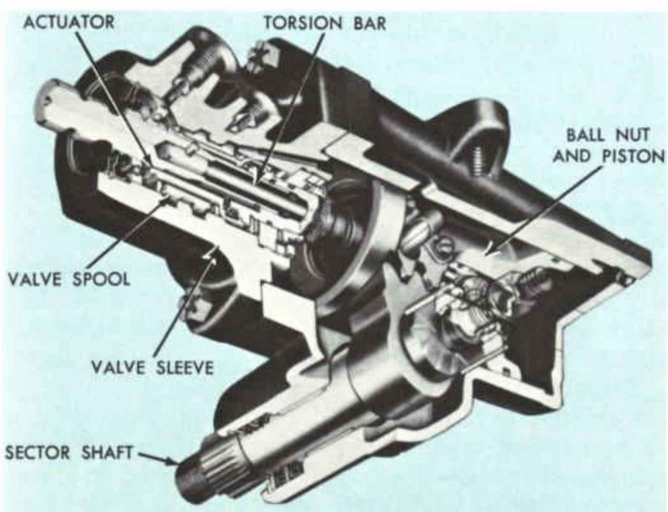


Fig. 40—Integral Torsion Bar Power Steering Gear

FORD AND BENDIX INTEGRAL-TYPE POWER STEERING

The integral-type Ford and Bendix power steering systems use a roller-type hydraulic pump and a torsion bar-type steering gear, which has a control valve and a power cylinder in the gear housing. The hydraulic pump operation is the same as previously outlined for the linkage-type power steering system.

TORSION BAR UNIT

The torsion bar-type power steering unit (Fig. 40) includes a rack and piston, and a worm and ball nut assembly which is meshed to the gear on the steering sector shaft. This steering unit also includes a valve spool, a valve sleeve and a torsion bar assembly, which is mounted on the end of the worm shaft. The valve spool in this unit is actuated by the twisting action of the torsion bar.

The torsion bar-type power steering gear is designed so that all the components are in one housing. This design makes possible internal fluid passages between the valve and cylinder, which eliminates all external lines and hoses, except the pressure and return hoses between the pump and the gear assembly.

The power cylinder is an integral part of the gear housing. The piston is double-acting, in that fluid pressure may be applied to either side of the piston. The one-piece piston and power rack is meshed to the sector shaft.

CONTROL VALVE

The operation of the hydraulic control valve is governed by the twisting of the torsion bar. All effort applied to the steering wheel is transmitted directly through the torsion bar to the ball nut and worm assembly. Any resistance to the turning of the front wheels results in a twisting of the bar. The twisting of the bar increases as the front wheel turning effort increases. The control valve spool, actuated by the twisting of the torsion bar, directs fluid to the side of the piston where the hydraulic assist is required.

The lower end of the torsion bar is splined to the lower end of the inside diameter of the worm shaft. The upper end of the worm shaft is splined to the inside diameter of the torsion bar and upper end of the input shaft assembly. The spline fit is sufficiently loose so that the upper end of the torsion bar and input shaft assembly can twist in the actuator, and thus move the actuator up and down. This movement results when the short length of helical splines on the inside diameter of the actuator engage the outside diameter of the input shaft. The actuator is held in the spool by a snap ring. Therefore, as the torsion bar twists, its radial motion is transferred into axial motion by helical threads. Thus, the valve spool is moved off-center, and fluid is directed to one side of the piston or to the outer.

Restricting the fluid flow to one side of the piston increases the fluid pressure proportionately as the front wheels are turned.

ROAD FEEL

The resistance of the torsion bar gives the driver a feel of the road at all times. The more the torsion bar twists, the greater the feel of the road. Also, the more the torsion bar twists, the greater the power assist in steering to the driver.

FLUID FLOW

Straight-Ahead Driving

When the power unit is not assisting in the steering effort, the valve spool is in the neutral, or straight-ahead position (Fig. 41). The fluid flows

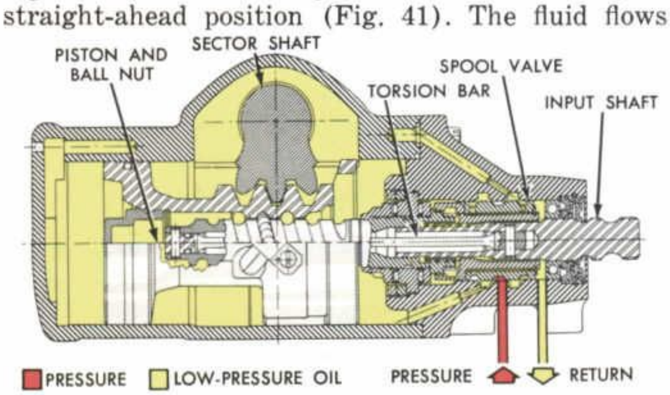


Fig. 41—Fluid Flow—Straight-Ahead Driving

from the pump, through the open center valve, and returns to the pump through the worm bearing. Therefore, no area of the valve spool or steering gear is under high pressure. Pressure in the neutral position is approximately 30 psi at normal operating temperatures.

The pump has no influence on the valve spool. However, when the pump operates, the spool, the housing and the power cylinder are always full of fluid.

Right Turn

When the steering wheel is turned to the right, the worm shaft resists turning because of the normal resistance of the front wheels to the turning action. Thus, the torsion bar will start to twist.

For a right turn (Fig. 42), the valve spool moves upward, allowing fluid from the pump to enter against the upper side of the power piston. The fluid on the lower side of the piston is free to return through the valve to the pump. Therefore, the power assist is to the upper side of the piston, pushing it downward and providing assistance in turning the sector shaft.

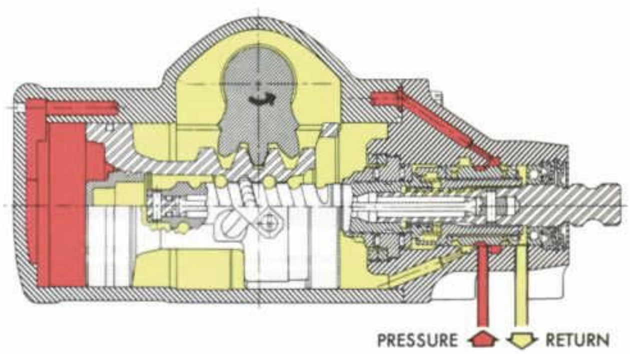


Fig. 42—Fluid Flow—Right Turn

Left Turn

If the steering wheel is turned to the left, it will cause a similar action, but in the opposite direction (Fig. 43). The torsion bar twists to the left, moving the valve spool downward and allowing fluid from the pump to enter against the lower side of the power piston. Fluid on the upper side of the piston is free to return through the valve to the pump. The power assist, therefore, is to the lower side of the piston, pushing it upward. The instant the driver stops applying effort to the steering wheel, the valve spool is returned to its neutral position by the unwinding of the torsion bar.

Although suspensions, steering gears and linkages are entities by themselves, together they contribute to a common condition—alignment. However, they are joined by two other important factors of alignment, the wheel and tire assembly and the angles of front end geometry. We can obtain a better appreciation of this inter-relationship by considering

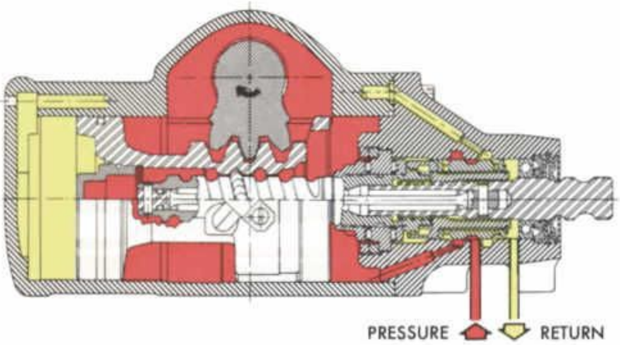


Fig. 43—Fluid Flow—Left Turn

front end alignment, first, and then weighing the influences brought to bear upon it by the wheel and tire assembly and the front end angles.

The main difference in the Semi-Integral Power Steering System has been covered on page 13 of this book. Additional information, if desired can be found in Courses 3000.3 and 3000.6 instructor's notes.

FRONT END ALIGNMENT

Alignment means the ability of a vehicle to follow a true course on the highway with minimal steering effort on the part of the driver. Any looseness in the steering wheel, shake, wobble, or pulling, whether constant or intermittent, cannot be tolerated because of its tiring influence on the driver. Absolute steering control by the driver at all times is essential.

Such steering control involves the harmonious relationship of four factors—wheels and tires, angles, steering gear and linkages, and suspensions. We have covered the steering gear and suspensions factors already. Only the wheel and tire assembly and the angles of alignment remain. However, each of these is a vital factor in the alignment of a vehicle.

The wheel and tire are parts of the wheel assembly (Fig. 44). This assembly includes the hub and drum, bearings, hub cap and any ornamental rings or fixtures—everything, in short, that turns on the spindle.

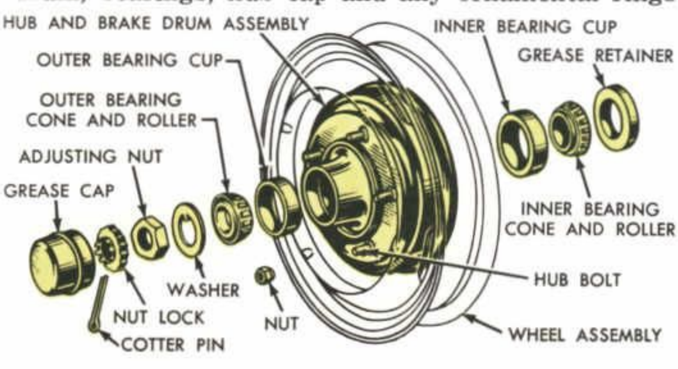


Fig. 44—Wheel Assembly

Balance is important throughout the automobile. It is of crucial importance in the wheel assembly. The tolerance here is so exacting as to make it possible for a small pebble, caught between the treads of a tire, to exert enough influence, under centrifugal force at high speed, to place the entire wheel assembly in a state of severe imbalance.

TIRE AND WHEEL BALANCE

The wheel assembly revolves as a unit, with the tire cushioning the ride, giving firm support to the vehicle, and developing traction. Furthermore, the wheel assembly contributes to directional stability, with the tire absorbing all of the stresses of accelerating, braking, and the centrifugal force in turning.

On today's modern highways, the wheel assembly may rotate at speeds as high as 1200 rpm. This high speed develops great centrifugal force. If the wheel assembly is heavier at any one point, dangerous and uncomfortable vibrations will result. Wheel assemblies with this condition are said to be out-of-balance. Because the front wheels are connected to the steering and suspension systems, it follows that any condition causing the wheels to vibrate as they turn will seriously affect the life of all of the suspension and steering parts. It also makes the vehicle unsafe and uncomfortable to drive.

Wheel balance falls into two general categories—static balance and dynamic balance.

STATIC BALANCE

Static balance simply means that the weight of the wheel and tire assembly is distributed equally around the axis of wheel rotation (the spindle). If this static balance condition exists, the wheel will have no tendency to rotate by itself, regardless of its position (Fig. 45). If this static balance condition does not exist, the wheel will always rotate until the heaviest spot is at the bottom. When a wheel is out-of-balance statically, centrifugal force acting on the heavy spot will cause the wheel to "tramp" or "hop" as the vehicle is driven down the road. The speed at which "tramp" or "hop" occurs is dependent on the

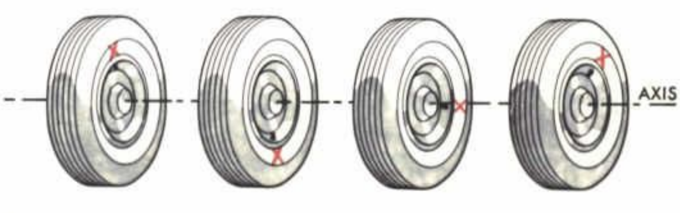


Fig. 45—Static Balance

degree the wheel is out-of-balance. In general, the greater the wheel imbalance, the lower the speed at which the "tramp" or "hop" becomes evident.

DYNAMIC BALANCE

Simply stated, dynamic balance means balance in motion. If a wheel and tire assembly is in dynamic balance, it must also be in static balance. However, it does not follow that a wheel and tire assembly which is in static balance is also in dynamic balance.

Earlier, we discussed the conditions for static balance. The requirements for dynamic balance not only include the equal distribution of weight around the axis of rotation, but also equal weight distribution with regard to the center line of the tire and wheel (Fig. 46). A simple experiment will illustrate the

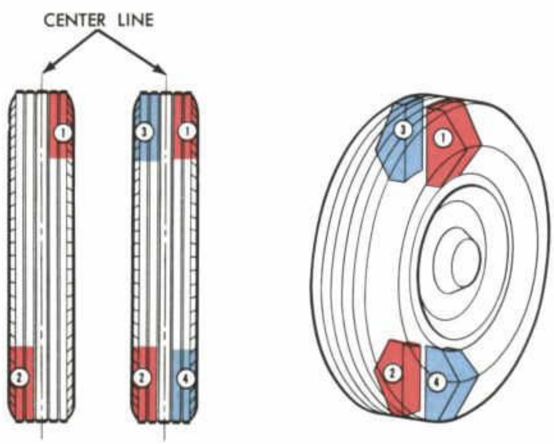


Fig. 46—Weight Distributed Equally Around Tire Center Line

principle and the need for dynamic balance. If a weight is attached to a string, as in Fig. 47, and is swung around slowly, centrifugal force will cause the weight to rise and make a small angle with the axis of rotation. As the speed is increased, the weight will rise further, until the weight is at right angles (90 degrees) to the axis of rotation. Any weight will always try to rotate at a 90-degree angle to the axis of rotation. To further illustrate this principle, equal weights can be attached to the ends of a stick as in Fig. 48. If the stick is mounted on a pivot as shown and the stick is spun around, the path of rotation will be at right angles to the stick. With this arrangement, the stick is in dynamic balance.

If the weights are shifted, as in Fig. 49, the stick is still in static balance. However, when the stick is rotated the weights attempt to rotate at right angles to the axis and "1" moves up while "2" moves down,

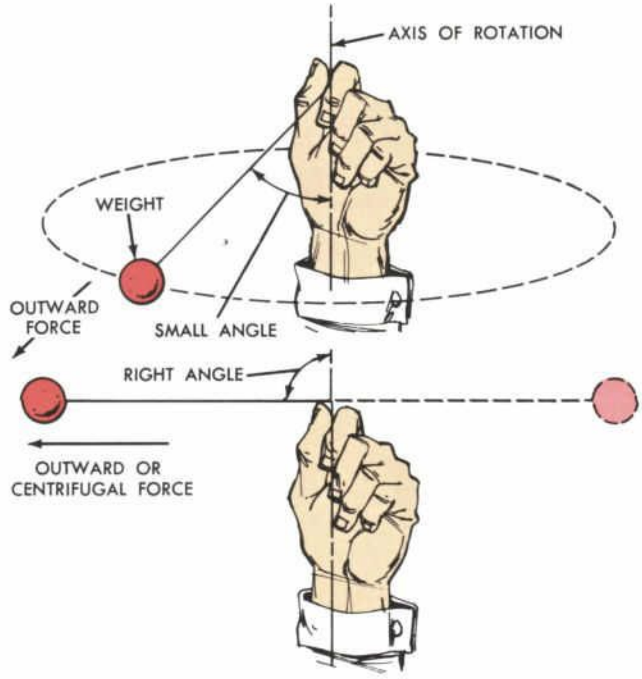


Fig. 47—Centrifugal Force

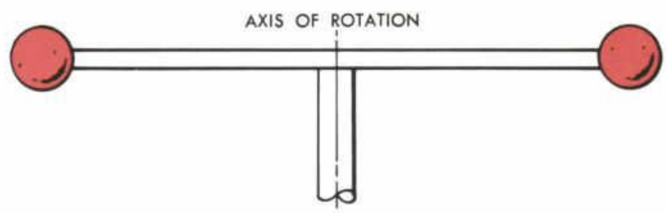


Fig. 48—Equal Weights in Static and Dynamic Balance

forcing the pivot out of its vertical axis. When the stick has turned 180 degrees, weight "1" has moved to the position where weight "2" had been and weight "2" has moved to the position of weight "1". This has reversed the earlier condition. The stick and its axis of rotation are forced in the opposite direction. This reversal, each 180 degrees of rotation, causes the pivot to wobble from side-to-side. Dynamic imbalance of a wheel assembly causes the same action to take place, resulting in the wheel spindle wobbling.

If a wheel is rotated at high speed with the static balance achieved by placing the weight in segments 1 and 2, as shown in Fig. 46, the tire and wheel will tend to wobble. This is because the weights are trying to reach a point that is exactly perpendicular to the center of rotation, due to the action of centrifugal force. With the weights on opposite sides of the center point, the wheel assembly will tend to wobble each half revolution as the heavy weights try to line

FRONT END ALIGNMENT

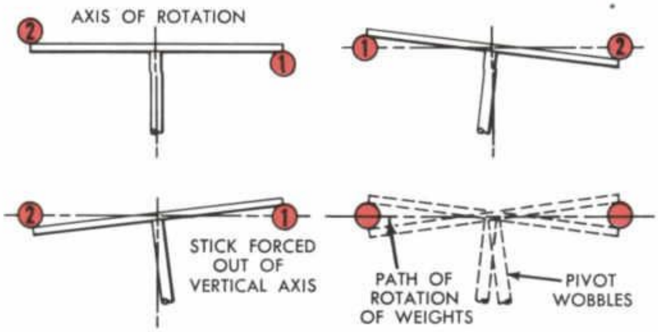


Fig. 49—Dynamic Imbalance

up with the rotation center. To compensate for this dynamic imbalance, weights must be installed in segments 3 and 4 as shown in Fig. 46. By installing the weights in this manner, dynamic balance is achieved and static balance is unaffected.

Wheel imbalance must not be confused with out-of-round tires or with excessive wheel runout caused by bent wheels or hubs.

ANGLES OF ALIGNMENT

There are five front end angles. All of these angles are factors in wheel alignment. These angles are camber, caster, ball joint or kingpin inclination, toe-in and steering or toe-out angle on turns. All of these angles are closely related, and vary according to speed, road surface, accelerating, braking, weight distribution and cornering (Fig. 50). For these reasons, front end specifications may vary between various models in the Ford car and truck line.

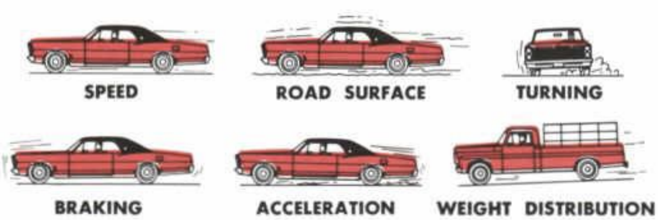


Fig. 50—Front End Loads and Forces

When the effect of the combined angles is complementary, or harmonious, a definite and beneficial influence is exerted on stability and steering control.

CAMBER

The principles of tilting and dishing wheels are hand-me-downs from the carriage industry. When reference is made to the tilting of wheels in automotive nomenclature, it is called camber.

If the top of the wheel is tilted outward (Fig. 51), the wheel has positive camber. If, on the other hand,

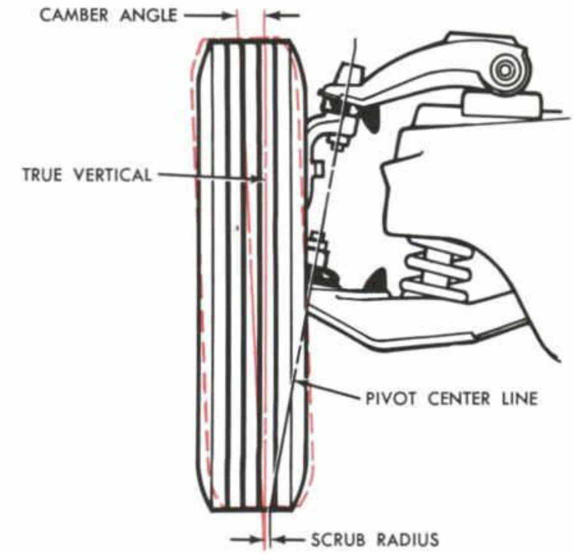


Fig. 51—Positive Camber

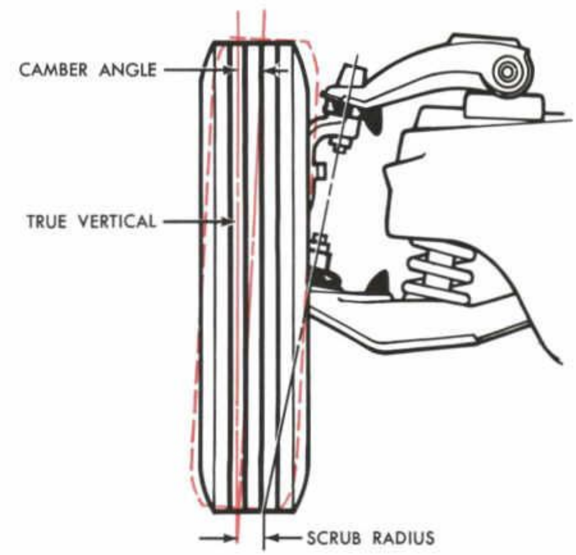


Fig. 52—Negative Camber

the wheel is tilted inward at the top, it has negative camber (Fig. 52). Zero camber exists when the center line of the wheel and tire is the true vertical line with the road surface, or, more simply, when the wheel is straight up-and-down. Wheel camber is the angle formed by the center line of the wheel and the true vertical. It is measured in degrees. This angle is obtained by tilting the wheel spindle.

Steering on early vehicles was difficult for two reasons. First, the pivots, or kingpins, tended to bend under normal loads because the length of the spindle acted as a lever on the pivot. Second, the point of

road contact of the tire was outboard of the pivot center line, a relatively large distance, causing the wheels to fight or pull in going over rough roads.

Scrub Radius

Scrub radius (Fig. 53) is the distance between the extended center line of the steering axis and the center line of the tire at the point where the tire touches the road.

Scrub radius makes it difficult to turn the wheels to right or left. Since the pivot is inboard of the point of road contact, the tire does not pivot where it is in contact with the road, but has to move forward or backward as the steering wheel is turned, thus increasing the steering effort. This distance, or scrub radius, has a direct effect on the ease of steering, road shock transmitted to the steering wheel, and the use of 4-wheel brakes.

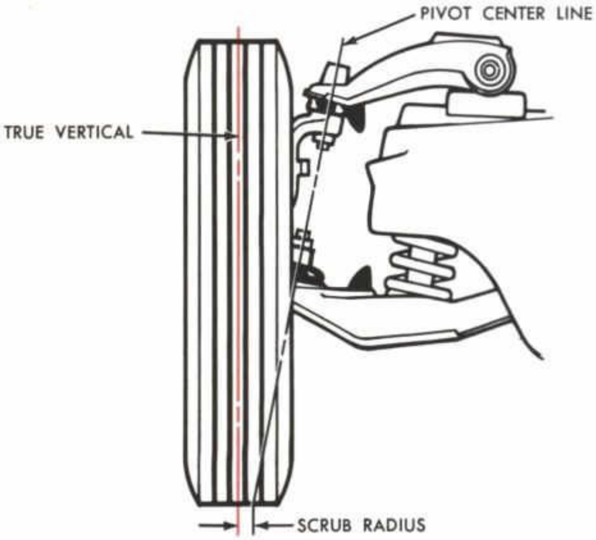


Fig. 53—Scrub Radius

The greater the scrub radius, the longer the lever arm acting against the steering wheel, and the greater the forward or rearward movement of the wheels as they are turned from the straight-ahead position. By adopting the principle of tilting the wheel outward at the top (positive camber), the point of road contact of the tire is brought more nearly under the pivot center line. This reduces scrub radius and consequently reduces pivot binding, road shock and steering effort.

Maximum tire life and mileage are obtained when the average **running** camber is zero. This means that when driving with an average load at an average driving speed, the center line of the wheel is almost perpendicular to the road surface. Because wheels with positive camber tend to roll outward (Fig. 54),

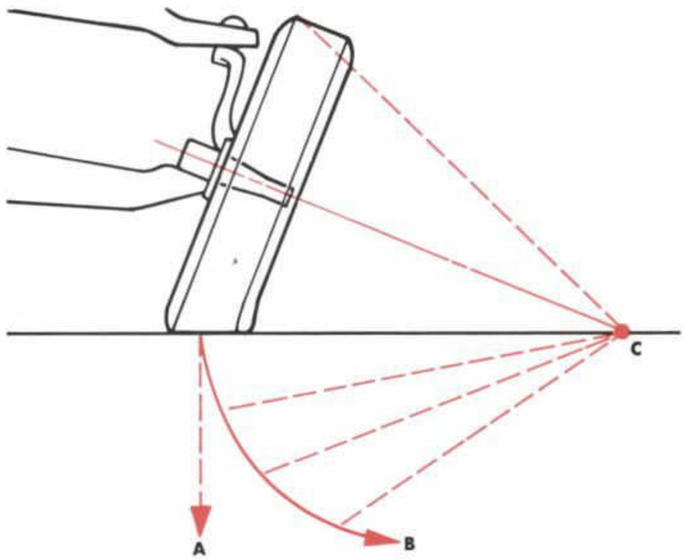


Fig. 54—Cambered Wheel Rolls Like a Cone

and the vehicle will pull or lead to the side having the greatest amount of positive camber, another factor, toe-in, is used to overcome this tendency. If a vehicle is operated on high-crown roads, the road crown will add to the camber effect of the right wheel. This will cause the vehicle to lead to the right, although the camber settings may be within specifications.

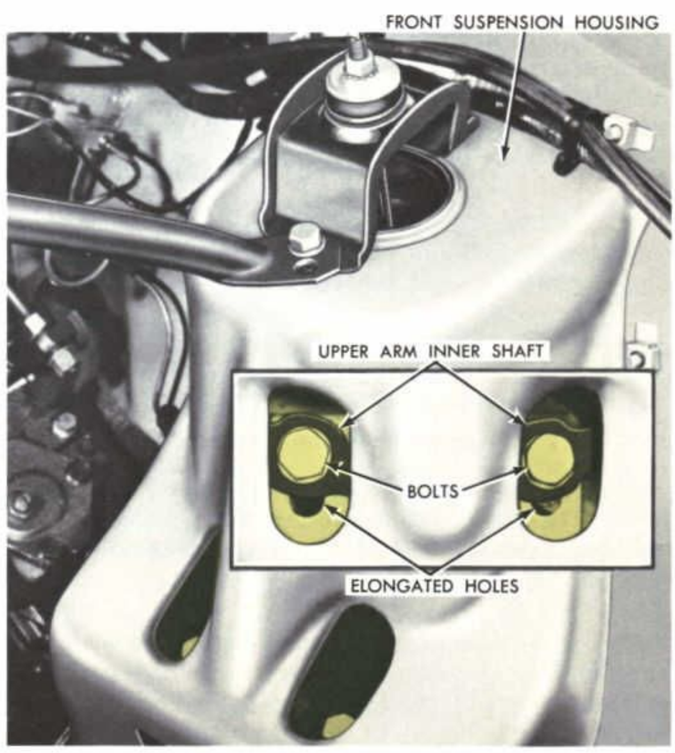


Fig. 55—Slotted Holes for Camber Adjustment

Adjusting Camber

The camber angle on beam-axle vehicles can be adjusted only by bending the axle. On Ford vehicles up to 1965, with independent suspension, two provisions are made for camber adjustment. One method is to add or subtract shims between the inner end of the upper control arm and its attaching point. Shims are added to increase the camber angle or removed to decrease camber. A second method of camber adjustment is to have slotted holes at the attachment point for the upper control arm (Fig. 55).

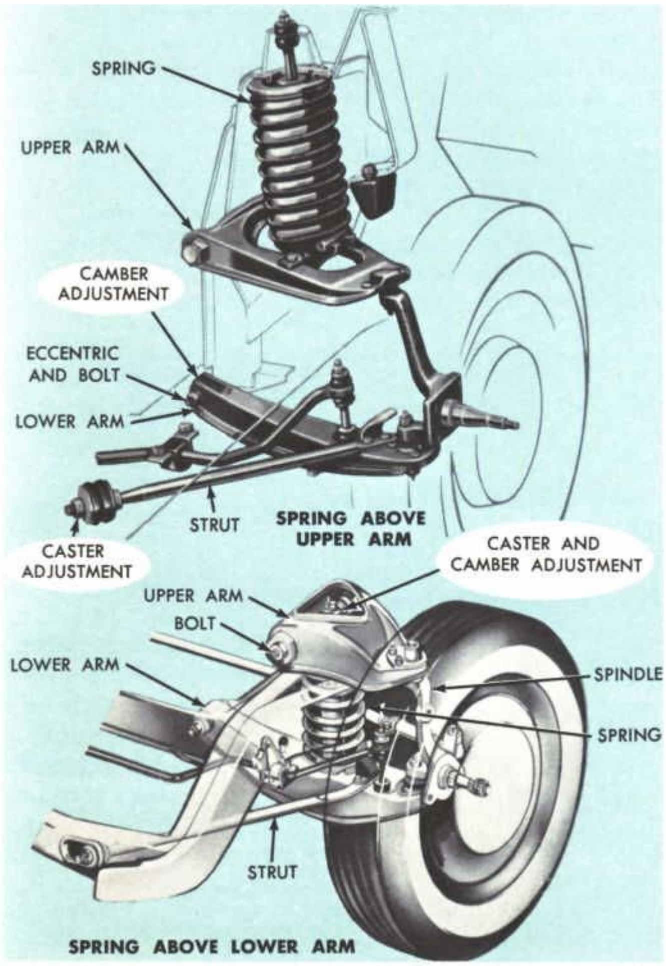


Fig. 56—Camber and Caster Adjustment Points

In the slotted hole method, camber is adjusted by loosening the attaching bolts and sliding the arm in or out to obtain the desired setting. When the adjustment has been made, the bolts are tightened, and serrations in the parts "bite" into the metal around the holes to prevent further movement.

To adjust camber on current Ford cars, (Fig. 56) there are two new methods. If the front spring is mounted on the top arm, loosen the nut and bolt and turn eccentric bolt located on the lower arm. If the front spring is mounted on the lower arm, adjust caster and camber by loosening bolts and nuts located on the upper arm and moving spindle in or out as desired.

CASTER

Caster is the backward or forward tilt of the kingpin from the vertical (Fig. 57). With the Ford ball

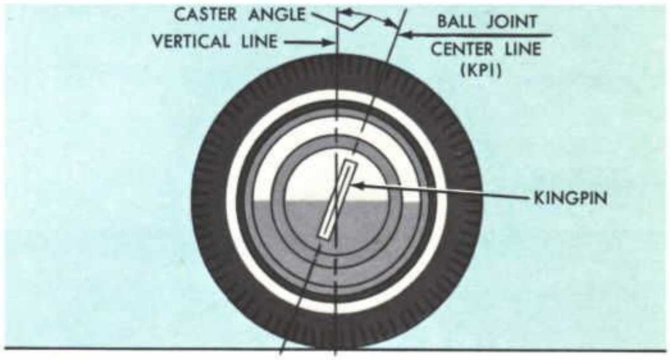


Fig. 57—Caster Angle

joint suspension, caster is the backward or forward tilt of the ball joint center line from the vertical. The effect of caster can be more easily understood if the action of commonplace examples of caster are studied. Two such examples are the bicycle front wheel and the ordinary household furniture caster (Figs. 58 and 59). When a piece of furniture mounted on casters is pushed, the casters turn in their pivots so as to bring the wheels in line with the direction of the force applied to the furniture. The wheels will

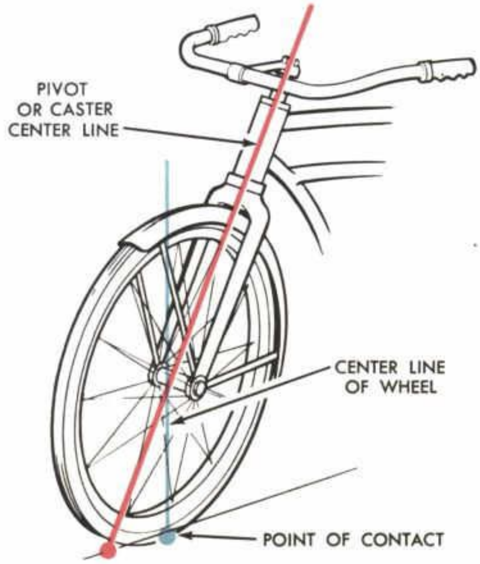


Fig. 58—Example of Caster

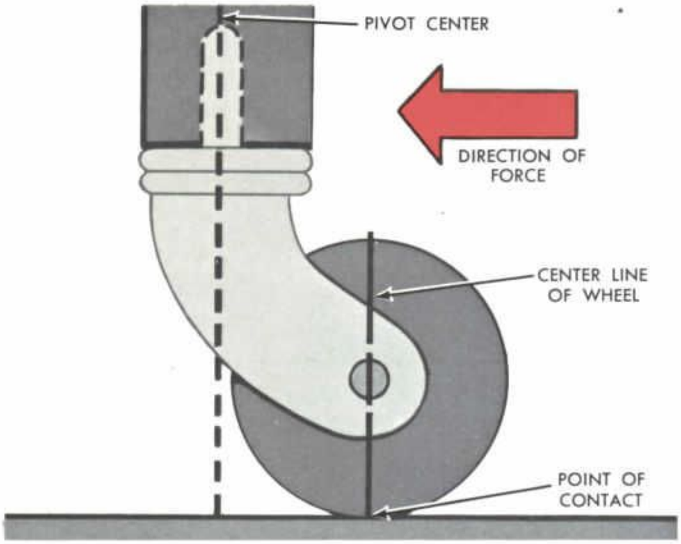


Fig. 59—Action of a Castered Wheel

then trail behind the pivot and the furniture will roll easily in a straight line.

Directional Stability

Figure 59 shows the relative positions of the center line of the caster pivot and the point of wheel contact. Because the weight on the wheel results in a resistance to wheel movement, any force exerted on the pivot will cause the wheel to turn until it is lined up with the force on the pivot (Fig. 60). The

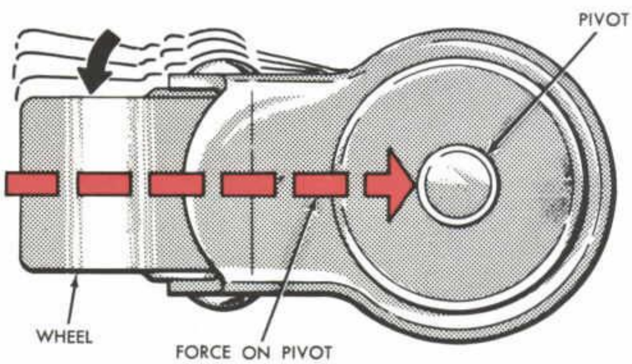


Fig. 60—Top View of Castered Wheel

bicycle front wheel in Fig. 58 acts in exactly the same way. It is interesting to note that "trick" bicycles used in the entertainment field are designed without caster. The lack of caster makes it possible for these entertainers to "spin" the bicycle handlebars while riding the bicycle. Conversely, the standard bicycle will move in a straight line without being steered by the rider as long as the wheel is perpendicular to the road. Of course, if the rider causes the bicycle to "lean" to one side or the other, camber effect takes over and the bicycle will turn in the direction in which the bicycle is leaning.

Positive caster angle in automotive vehicles has the same effect as in the examples just discussed. It is one of the angles that provides directional stability. In other words, the wheels will always try to assume a straight-ahead position.

Zero Caster

In Fig. 61, the center line of the pivot point is perpendicular to the road surface. If this line is extended, it will contact the road in line with the pivot point of the tire. This means that the tire contact at the road is split evenly by the center line, therefore, there is no tendency for the wheel to turn in either direction. Thus, no contribution is made to directional stability. We term this condition "zero caster".

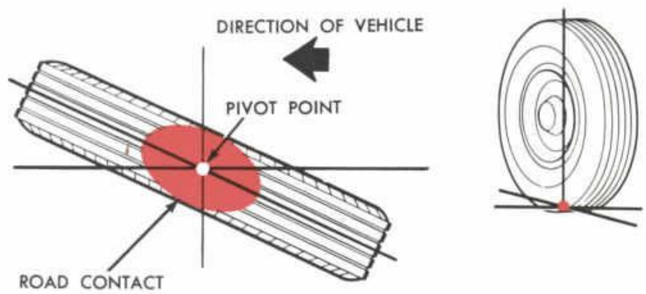


Fig. 61—Zero Caster

Positive and Negative Caster

With positive caster (Fig. 62), the extended center line of the pivot contacts the road ahead of the point of tire contact. The area, shown in red in Fig. 62, is off-center with regard to the "direction of vehicle travel" when the wheel is turned from the straight-ahead position. The "drag" or friction caused by this area (blue) of tire contact produces the force which tends to hold or return the wheel to the straight-ahead position. The red area shown in Fig. 63 is behind the pivot point of the tire and off-center with respect to the "direction of travel" of the vehicle

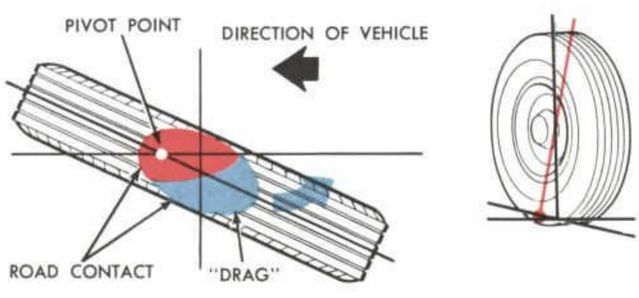


Fig. 62—Positive Caster

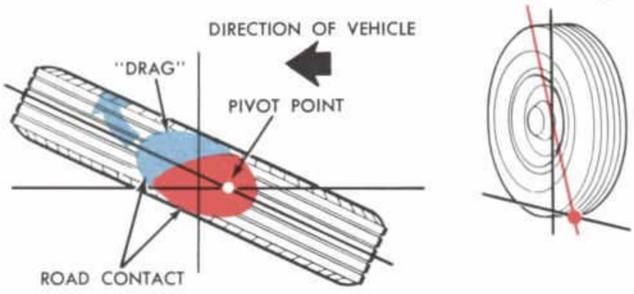


Fig. 63—Negative Caster

when the wheel is turned. Thus, the force (blue area) exerted tends to turn the wheel farther away from the straight-ahead position when caster is negative.

In the early automobiles with their high-pressure, small cross-section tires, the area of tire road contact was small (Fig. 64) and relatively large caster angles were required to give the car the needed directional stability. With the advent of large cross-section, low-pressure tires, this area increased considerably, so that a lesser caster angle now produces the desired directional stability.

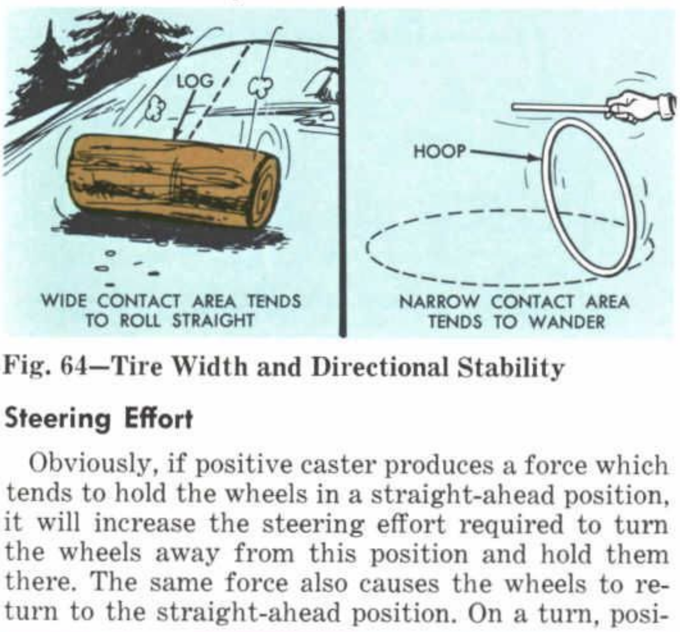


Fig. 64—Tire Width and Directional Stability

Steering Effort

Obviously, if positive caster produces a force which tends to hold the wheels in a straight-ahead position, it will increase the steering effort required to turn the wheels away from this position and hold them there. The same force also causes the wheels to return to the straight-ahead position. On a turn, positive caster tends to raise the inside spindle and lower the outside spindle (Fig. 65).

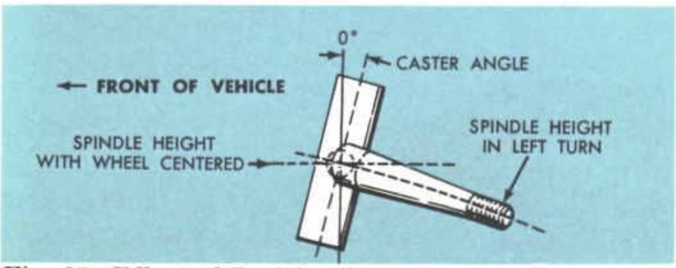


Fig. 65—Effect of Positive Caster on Spindle Height in a Turn

Excessive positive caster is undesirable for several reasons. It can result in too high a steering effort, too rapid a wheel return, high-speed wander, low-speed shimmy and road shock. Road shock is caused by the spindle pivot center line actually being pointed at the irregularities in the road, so that less shock is absorbed by the suspension (Fig. 66). Since caster

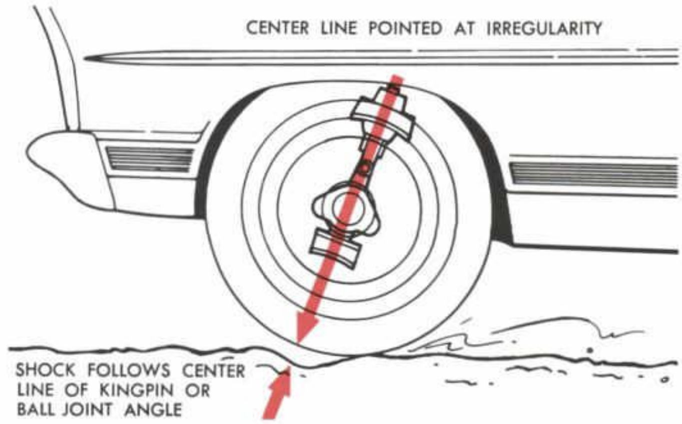


Fig. 66—Road Shock as a Result of Excessive Caster

angle is influenced by the horizontal plane of the car, any sagging of the front springs will decrease the positive caster, while rear spring sag will increase the positive caster (Fig. 67). Large, heavy vehicles

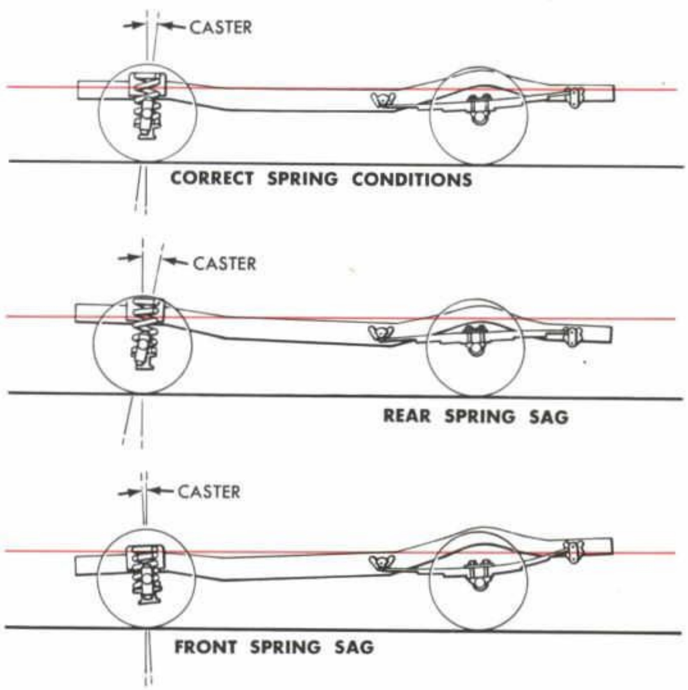


Fig. 67—Caster Changes With Spring Sag

with wide cross-section tires have more directional stability than smaller vehicles. Since a positive caster angle on heavier vehicles is not necessary for stability and only increases steering effort, many of these vehicles have negative caster. This reduces steering effort and the tendency of the wheels to "snap-back", since the action with negative caster is opposite to that with positive caster.

Adjusting Caster

On solid-beam-axle suspensions (Fig. 68), caster angle is adjusted by tilting the axle. This is usually accomplished by loosening the spring U-bolts and sliding tapered shims between the axle and the spring to produce the desired angle. On Ford independent suspension front ends up to 1965, the upper end of the pivot is tilted by removing shims from the front and adding shims to the rear. To decrease

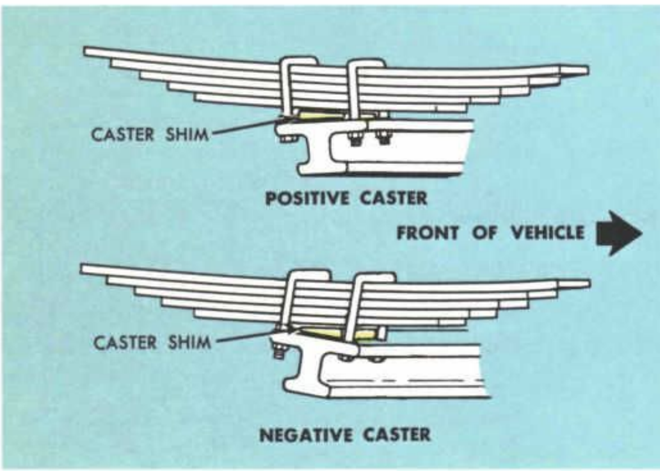


Fig. 68—Adjusting Caster Angle With Tapered Shims on Solid Beam Axles

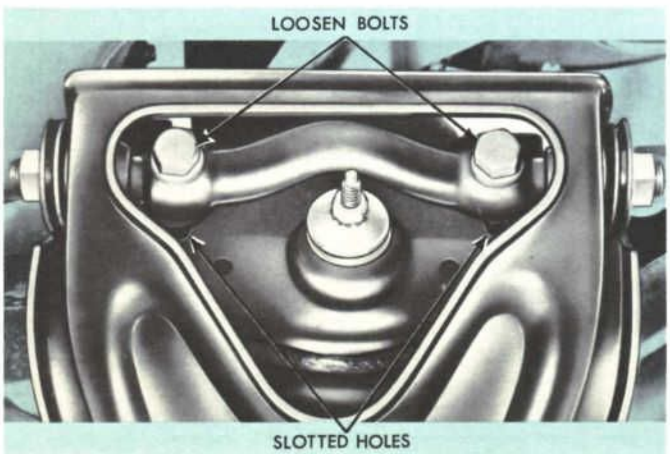


Fig. 69—Caster Angle Adjustment With Independent Suspension

positive caster, remove shims from the rear. To increase positive caster, add shims to the front.

To adjust the caster on current Ford cars with the spring mounted on the top arm, loosen and adjust the strut the desired amount. To adjust caster on current Ford cars with the spring mounted on the lower arm, loosen the bolts on the upper arm inner shaft and move the spindle assembly as desired (Fig. 69).

It is extremely important that the caster angle be equal for both wheels. If it is not equal, the vehicle will lead to the side with the lesser positive caster. On cars having a negative setting, the car will lead to the side having the greater negative caster angle.

KINGPIN OR BALL JOINT INCLINATION

This front end factor is also known as steering axis inclination. It is the second factor influencing directional stability. It may be defined as the tilt of the kingpin or ball joint steering axis in toward the center of the car (Fig. 70). It is measured in degrees.

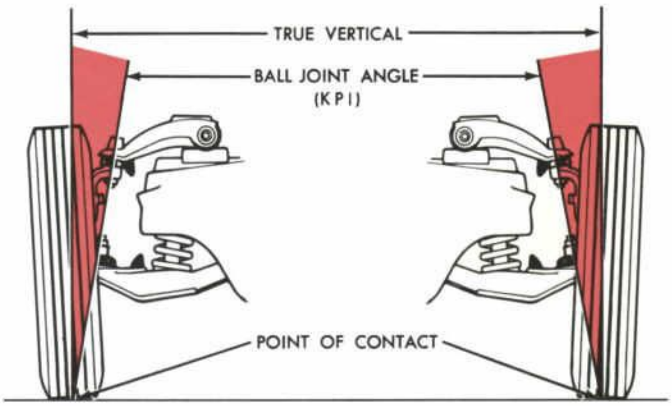


Fig. 70—Kingpin or Ball Joint Inclination

As mentioned previously, when tire cross-section is increased, it is necessary to decrease camber angle and increase the scrub radius a corresponding amount. This means an increase in steering effort and a rather violent reaction to the small differences in front brake equalization. Figure 70 illustrates how slanting the kingpin or ball joint in at the top brings the extended center line of the pivot more nearly to the center of tire road contact and reduces this scrub radius.

Front End Raise In Turns

The tilting of the ball joint pivot center line or kingpin also makes a significant contribution to directional stability. When the front wheels are turned to the right or left, the spindle revolves around the pivot. Because of the angle of the pivot, the end of

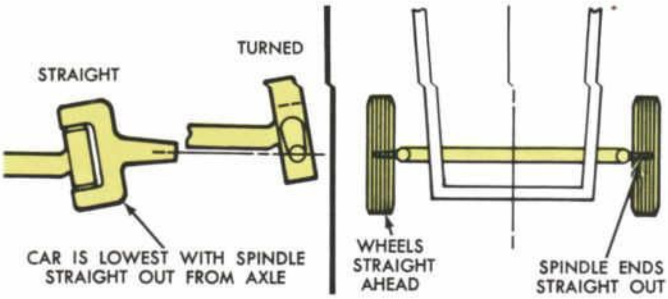


Fig. 71—Spindle Arc With Kingpin Inclination

the spindle describes an arc. The ends of the arc are closer to the road surface (Fig. 71). Since it is impossible for the end of the spindle to get closer to the road surface because of the wheel and tire, it follows that the front of the vehicle must be raised when the wheels are turned from the straight-ahead position (Fig. 72).

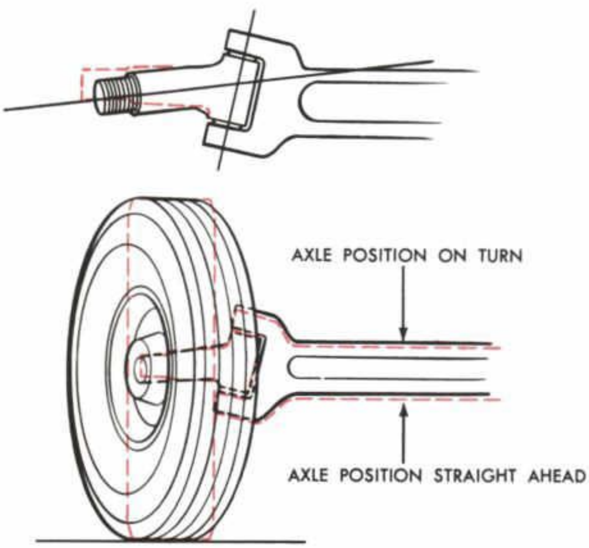


Fig. 72—Front Axle Raising

The weight of the vehicle causes it to seek its lowest possible position with respect to the road (Fig. 73). Therefore, the vehicle will be at its lowest position when the spindle ends are straight out and the wheels are in the straight-ahead position.

The inclination of the pivot allows the wheels of the vehicle to resist turning to begin with and gives the wheels a tendency to return to the straight-ahead position after a turn has been made. However, this force is not great enough to cause hard steering, but it does provide good directional stability. For this reason, it is a more important stability factor than caster.

Since the caster angle and the kingpin inclination are both obtained by tilting the kingpin or pivot

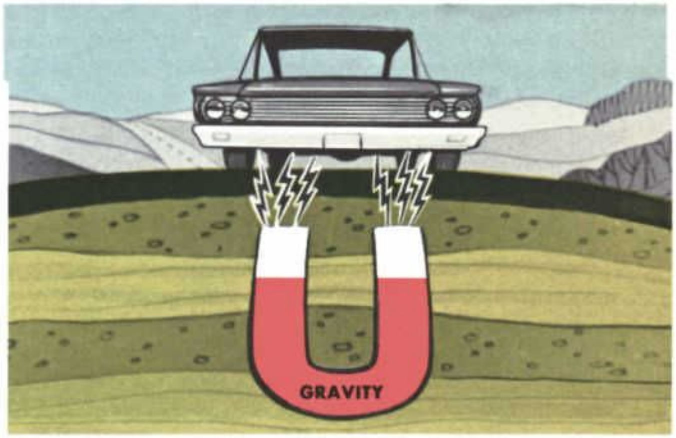


Fig. 73—Car Tries to Get As Low As Possible

axis, caster has an effect on kingpin inclination. However, the practical effect of this relationship is not very important since caster angle is generally small.

TOE-IN OR TOE-OUT

Toe-in or toe-out is the difference in the distance between the extreme front and the extreme rear of the tires, measured about nine inches from the floor. As a general rule, the front wheels toe-in, meaning the dimension taken at the front of the front tires is less than that taken at the rear of the front tires (Fig. 74). Since improperly adjusted toe-in is the

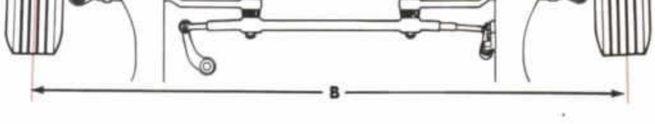


Fig. 74—Toe-In

most prevalent cause of excessive tire wear, it is extremely important that this factor be carefully checked. The purpose of toe-in is to offset the small deflections in the front suspension and steering linkage when the car is rolling forward. It ensures parallel rolling of the front wheels and tires, and minimizes tire wear from scuffing. A toe-in error of 1/8 of an inch is equivalent to dragging the tire crossways 11 feet for each mile the vehicle is driven. To obtain maximum tire mileage, the **running** toe-in

should be zero. The stationary toe-in of a vehicle should be just enough to offset the looseness and spreading action in the linkage, caused by camber (Fig. 54), when the vehicle is being driven forward.

TURNING ANGLE

The final factor in wheel alignment factors is the **turning angle** or **toe-out on turns.** The toe-out factor is necessary because of the design of the front end used in motor vehicles. When rounding corners, the front and rear wheels must turn about a common center with respect to the radius of the turn (Fig. 75). The front end design of most motor vehicles is

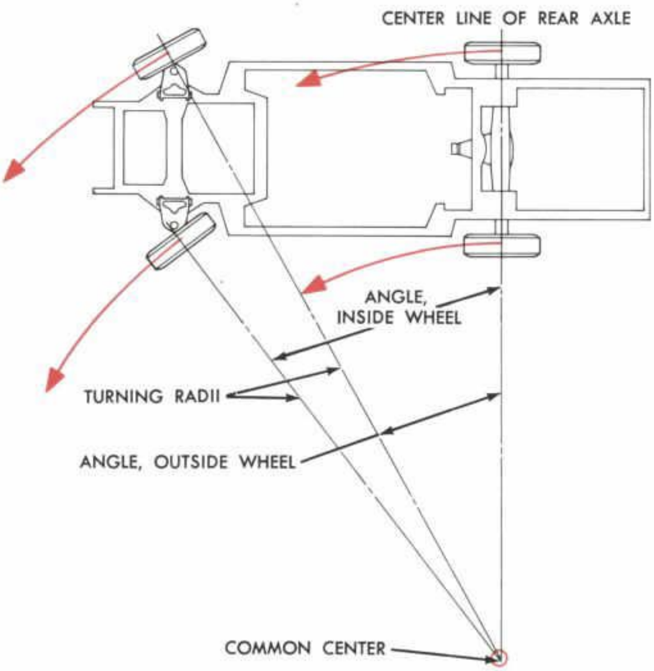


Fig. 75—Turning About a Common Center

such that the front wheels pivot independently and at different distances from the center of the turn. This makes it necessary to have the wheels turn at different angles. The inside wheel, being ahead of the outside wheel, must turn at a sharper angle than the outside wheel in order to remain perpendicular to the radius and avoid scrubbing the tires. However, the front wheels must return to their original parallel position when the vehicle is being operated in the straight-ahead position. This toe-out of the wheels is accomplished by making use of an interesting geometrical fact; the action of a lever moving in a circle (Fig. 76). When the lever is moved from point "A" to point "B", it pivots about point "0" and moves a horizontal distance "a-b". When the same lever is moved a much greater distance from point "B" to point "C", the horizon-

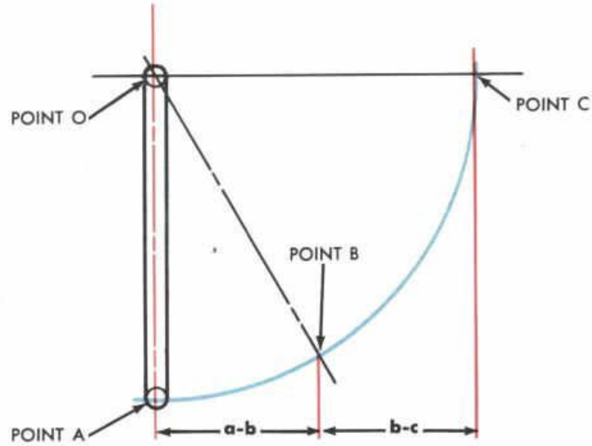


Fig. 76—Lever Acting in a Circle

tal movement "b-c" is exactly the same for this greater arc.

This same principle applies to a typical front end (Fig. 77). Let's assume that the steering linkage is attached to the lever or steering arm at point "A", and that the spindle pivot is also the pivot for the lever at point "O". When the steering linkage moves through the distance "a-b", the spindle will pivot through angle "AOB". However, when the linkage moves through the equal distance "b-c", the spindle will pivot through the larger angle "BOC". Note that in a turn in either direction, the linkage on the inside of the turn will always move through the "b-c" projection of the steering arm arc, while the outer wheel will always move through the "a-b" projection. Thus, the inner wheel will always turn at a sharper angle than the outer.

This feature is not adjustable, and any deviation from specifications would indicate bent steering arms or bent, worn, or otherwise damaged linkage. Improper toe-out on turns will result in tire wear similar to that caused by improper toe-in adjustment.

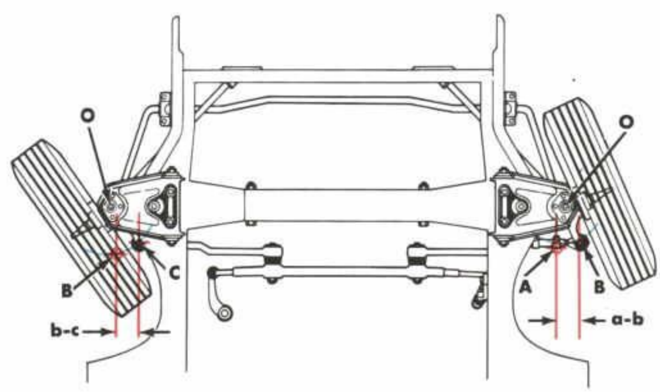


Fig. 77—Turning Angle

Nonparallel Steering Arms

In order to better understand this action, let us examine the construction of the linkage. The steering arms pivot about the kingpins or ball joints at one end. While at the other end, they are attached to tie rods which maintain the wheels in a parallel attitude when the vehicle is moving in the straight-ahead position. These steering arms are not parallel. However, they are closer together at the point where the tie rods connect than at their pivot point. When the tie rod is located ahead of the front suspension, the reverse is true. Thus, the angle formed by the steering arm and the tie rod is greater than 90 degrees, or a right angle. As the wheels are turned, the angle formed by the inside tie rod and steering arm increases, while the angle formed by the tie rod and steering arm on the outside wheel decreases. Since the amount of linear tie rod movement increases as the angle decreases, the lateral movement of the tie rod transmitted to the steering arms will result in a larger radial movement of the inside arm for any given tie rod movement and a corresponding sharper wheel angle for the inside wheel on a turn. Since both steering arms are designed to have the same angle, the same thing is true of a turn in either direction. Furthermore, the sharper the wheels are turned, the greater the need for toe-out. This arrangement increases or decreases the amount of toe-out with increased or decreased wheel angle. Theoretically, the front wheels should turn in a circle whose center is in line with the rear axle (Fig. 78).

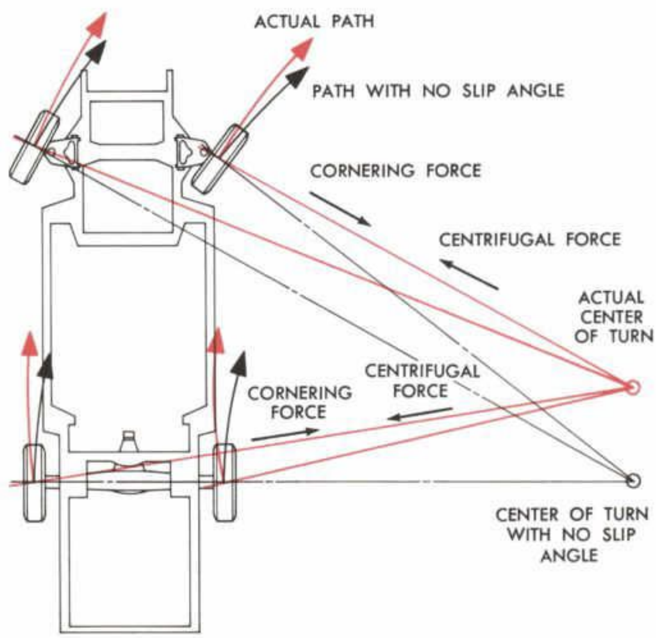


Fig. 78—Slip Angles

Slip Angle

A slip angle condition can occur at just about any speed. Centrifugal force causes all the tires to slip somewhat. The result is that the actual turning center is considerably ahead of the theoretical center (Fig. 78).

Different vehicles have different slip angles. As a result, vehicles of the same wheelbase may not have the same steering arm angles.

The turning angle is not adjustable. Any deviation from specifications would indicate bent steering arms, bent or worn linkage, or otherwise damaged linkage. Improper toe-out on turns will result in tire wear similar to that caused by improper toe-in adjustment.

QUICK REFERENCE

Axle—A vehicle cross support which is designed to carry the weight of the car.

Balance—State of equipoise, as between weights, different elements or opposing forces.

Ball Joint Inclination (K.P.I.)—The tilt of the center line of the steering ball joints or of the kingpin on solid axle suspensions, as viewed from the front or rear.

Camber—The inward or outward tilt of a wheel. The angle made by the center line of the wheel and the true vertical.

Camber Roll—An inherent characteristic of independent suspension vehicles to change camber angle when cornering.

Camber Wear—Wear on one side of a tire tread caused by the angle of the tire tread to the road surface.

Caster—The forward or backward tilt of the kingpin or steering axis center line.

Center of Gravity—The point about which the car weight is evenly distributed or balanced.

Curb Weight—The weight of the vehicle with a full supply of oil, water and fuel (no driver or passengers).

Distortion (Deflection)—A twisting, twisted, or bending condition.

Drag Link (Steering Connecting Rod)—The tube or rod connecting the steering gear Pitman arm to the tie rods or steering knuckle arms.

Dynamic Balance—Balance in motion, such as the balance of a wheel while rotating. The total weight distributed evenly in reference to both the axis of rotation and center line of the wheel.

QUICK REFERENCE

Front Suspension—The linkage which is used to attach the front wheels to the vehicle, support the weight and keep the front wheels in proper alignment.

Idler Lever (Arm)—A lever or arm which can rotate about its support and is used to support one end of a tube or rod.

Kingpin—See Spindle Bolt.

Kingpin Inclination (Steering Axis Inclination)—The tilt of the upper end of the kingpin or steering axis center line toward the center of the car.

Linkage—A system of rods and levers used to transmit motion or force.

Pitman Arm (Steering Gear Arm)—The arm connected to the steering gear cross shaft to transfer the rotating motion of the cross shaft to lateral motion of the drag link.

Pull (Lead)—The tendency of a vehicle to pull or lead to the right or left of the roadway.

Rate—The softness or stiffness of a spring. The load required to cause the spring to deflect one inch.

Ride Height—The distance from a specified point on the car to the road surface when the car is at a curb weight condition.

Road Shock—A shock or movement transmitted from the road surface to the steering wheel through the steering gear and linkage.

Scrub Radius—The distance between the extended center line of the steering axis and the center line of the tire at the point where the tire contacts the road.

Shim—A spacer used to adjust the distance between two parts.

Shimmy—A rapid oscillation or wobble of the wheel and tire assembly about the steering axis.

Shock Absorber—A device used to damp out spring oscillations.

Slip Angle—The angle between the true center line of the tire and the actual path followed by the tire when rounding a turn.

Spindle—A shaft or pin about which another part rotates.

Spindle Bolt (Kingpin)—A pin or bolt on which the steering spindle assembly pivots.

Stability—The property of a body which causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or tendencies to restore the body to its original condition.

Stabilizer—A device employing the torsional resistance of a steel bar to reduce car side roll and to prevent too great a difference in the spring action at the two front wheels.

Static Balance—Balance at rest. A distribution of weight around the axis of rotation so that the wheel has no tendency to rotate by itself, regardless of its position.

Steering Gear—A device made up of gears and rollers to transmit driver steering effort to the steering linkage for the purpose of guiding the car. A fairly high mechanical advantage is usually designed into the steering gear.

Steering Linkage—A system of links, rods, tubes and levers used to transmit motion from the steering gear to the front wheel steering spindles.

Steering System—The combination of steering gear, steering wheel, and steering linkage which is designed to make it possible for the driver to turn the front wheels and guide the car.

Support Arms—The front suspension horizontal arms which connect the front wheels to the car and support the front end weight.

Tire Print—The pattern made by the tire at the point of road contact.

Toe-In or Toe-Out—The difference between the front wheel measurement at the front of the wheels and the rear of the wheels. These measurements must be taken at a specified height from the road surface.

Toe-Out-On-Turns (Turning Angle)—The difference between the turning angle of the inside wheel and outside wheel on a turn to the right or left. This angle is usually measured with the outside wheel turned 20 degrees.

Torque—Any force tending to produce a twisting or turning motion.

Tramp—The up-and-down "hopping" action of a wheel. This condition is usually caused by static unbalance.

Unsprung Weight—Weight of parts of the suspension that are not supported on the springs. In general, increasing unsprung weight increases roughness of the ride. Conversely, low unsprung weight makes the ride smoother.

Wander (Weave)—The tendency of a car to veer from a straight path without driver control.

Wheel Spindle—That part of the front suspension about which the front wheel rotates.

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