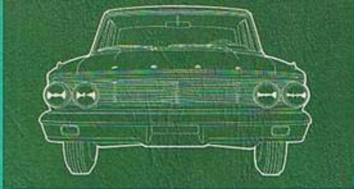
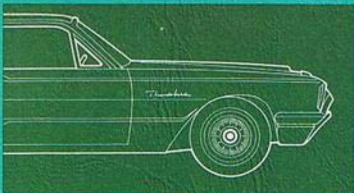
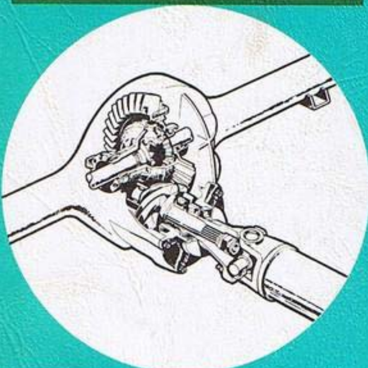
COURSE
4000.1



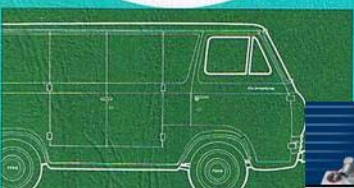
TRAINING HANDBOOK

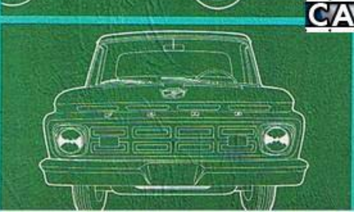


REAR AXLE and DRIVE LINE



PRINCIPLES of OPERATION





SERVICE
FORD MOTOR COMPANY
TRAINING

FORD DIVISION

TABLE OF CONTENTS

SERVICE DEPARTMENT
FORD DIVISION
FORD MOTOR COMPANY
FIRST PRINTING—JANUARY, 1964

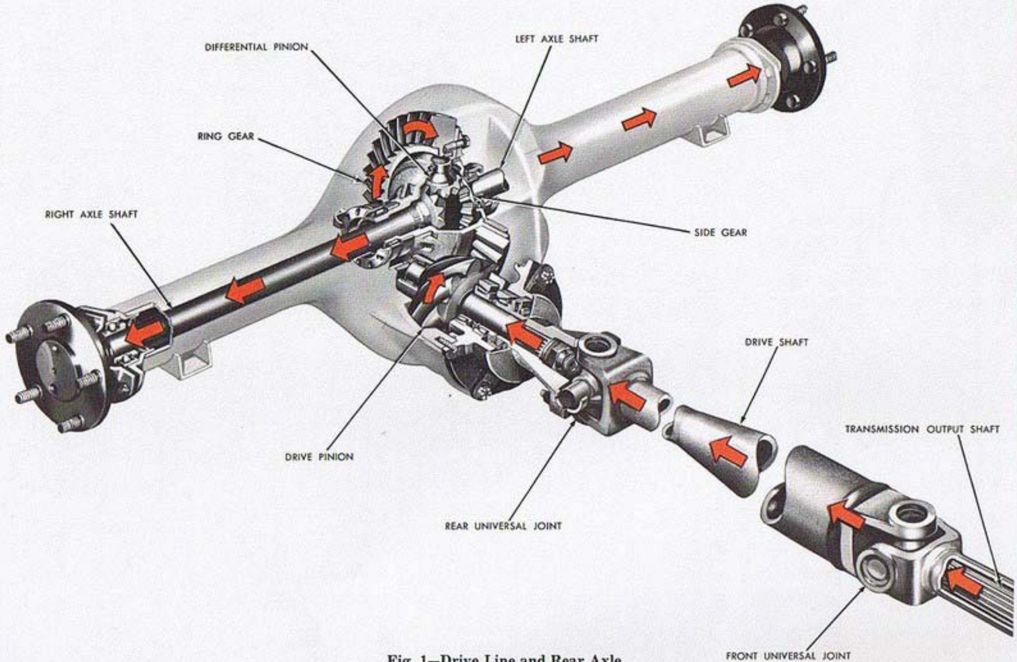
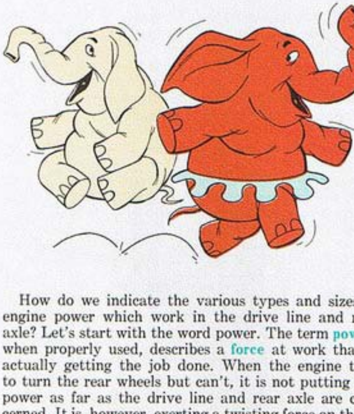


Fig. 1—Drive Line and Rear Axle

INTRODUCTION

The basic function of a car's drive line and rear axle (Fig. 1) is to deliver the engine's driving power from the transmission output shaft to the rear wheels. Since we are dealing with engine power turning shafts, gears and wheels, let's review the meaning of the terms used to describe and measure this power at work in the drive line and rear axle.

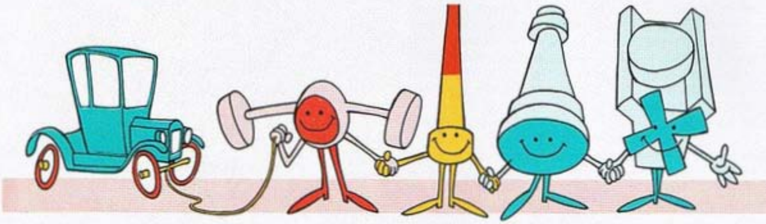
There are times when the engine power tries to turn the rear wheels but cannot do so. There are other times when the engine power turns the rear wheels very slowly against great resistance. At still other times, the engine power drives the rear wheels at a very high speed against comparatively little resistance.



How do we indicate the various types and sizes of engine power which work in the drive line and rear axle? Let's start with the word power. The term power, when properly used, describes a force at work that is actually getting the job done. When the engine tries to turn the rear wheels but can't, it is not putting out power as far as the drive line and rear axle are concerned. It is, however, exerting a twisting force on them. This twisting force can be measured and is called torque. When the twisting force in a shaft is said to be 100 foot-pounds of torque, it means that this twisting force is equal to the force which would be exerted by 100 pounds bearing on a lever arm at a point one foot from the center of the shaft. It could, of course, be a force of 50 pounds acting at two feet. Torque, then, is a measure of the twisting force in terms of weight times lever arm length. In drive line and rear axle discussions, twisting forces are nearly always expressed as so many foot-pounds of torque. Properly used, torque refers only to the twisting force acting on a shaft, gear, or wheel. If the twisting force is known, it is expressed as so many foot-pounds. Torque does not tell us whether the shaft is turning or standing still. It merely states that a twisting force is acting on the shaft. The word torque does not tell us as much as the word power. Power tells us that the twisting force is getting a job done. If it is getting a job done that equals the lifting of 33,000 pounds one foot in one minute, the power acting is one horsepower. Horsepower tells us the size of the job being done and the rate at which it is being done.

In this handbook, we will be more concerned with torque than power or horsepower. The drive line can merely transmit power. The rear axle can multiply torque but it cannot multiply power. When power flows through the drive pinion and ring gear, the torque acting on the drive pinion is multiplied in proportion to the gear reduction. Torque is multiplied but the power remains the same, since the torque is multiplied at the expense of rotation.

Now let's see how the rear axle works when the engine and transmission is delivering engine power to drive the rear wheels.



We must remember that for best car performance, the engine, transmission and rear axle must work as a team. Engine horsepower and torque output at any one time depend, among other things, on the load placed on the engine. We know, for example, that a car's engine operating at 4000 rpm with the transmission in neutral, or with the rear wheels spinning on ice, is producing very little horsepower because so little force is required to spin the wheels, thus intake manifold vacuum is high. A load placed on this engine to hold its speed to 4000 rpm will require that the throttle be opened wide to reduce manifold vacuum.

We know that we must get more fuel and air into an engine to increase its output.

It is the job of the transmission and rear axle gear ratio combination to adjust the rear wheel torque load of operating the car to the size of load which the engine can handle efficiently. Fig. 2 shows the maximum torque which a typical V-8 engine can produce under ideal load conditions. This curve was plotted while the engine was operating at full throttle on a test stand.

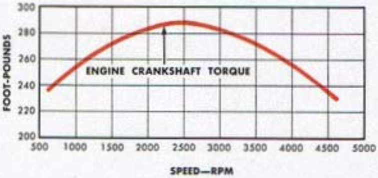


Fig. 2—Typical Engine Crankshaft Torque Curve at Full-Throttle Operation

The ideal transmission and rear axle combination will adjust the engine's load to produce the same curve at full-throttle operation in a car. Let's put a 3-Speed automatic transmission on the same engine and install in a car. Now, let's make a full-throttle acceleration up to 100 mph and measure the torque working on the drive shaft during this run. We will plot a drive shaft torque curve as shown in orange in Fig. 3. During this acceleration, drive shaft torque is greatest at start and decreases sharply up to 20 mph. Most of this torque reduction was accomplished automatically in the torque converter. The two abrupt reductions were due to gear ratio changes.

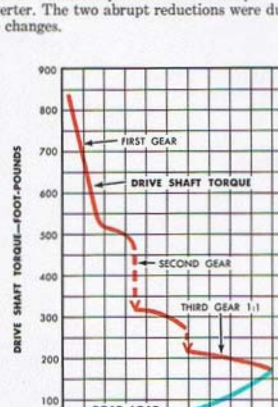


Fig. 3—Typical Drive Shaft Torque Curve During Full-Throttle Acceleration

The orange curve in Fig. 3 shows the drive shaft road load torque. Road load torque in this case, refers only to the drive shaft torque required to keep the car moving at that particular speed. At 5 mph, the drive shaft road load torque was 25 ft-lbs and the drive shaft input torque from the transmission was about 850 ft-lbs. This means that 825 ft-lbs of drive shaft torque was available to accelerate the car. At 100 mph, the road load torque requirements and the drive shaft input torque are equal. There is no left-over torque to accelerate the car. The car has reached maximum speed.

Since we are now rather deep into the subject of drive shaft or transmission output shaft torque, let's see what happens as this torque is transferred to the rear axle.

From the drive shaft torque curve shown in Fig. 3, we can draw another chart which will show drive pinion gear and axle shaft torque for the same car during the same full-throttle acceleration.

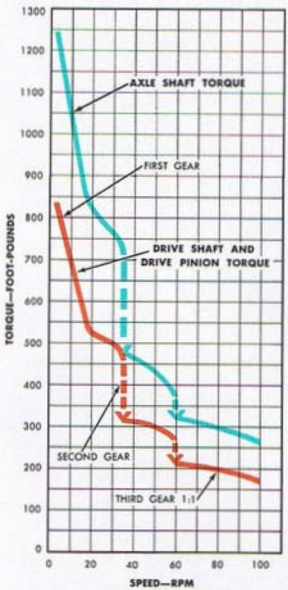


Fig. 4—Typical Drive Pinion and Axle Shaft Torque Curves During Full-Throttle Acceleration

For our purposes, drive shaft torque, transmission output shaft torque and rear axle drive pinion torque are equal. Of course, we are ignoring frictional losses here.

To draw our drive pinion torque curve (Fig. 4), all we need to do is transfer the drive shaft torque curve from the Fig. 3 chart and enter it on the Fig. 4 chart. As we said previously, we are ignoring frictional losses.

The axle shaft torque curve depends on the drive pinion curve. Drive pinion torque is multiplied in proportion to the drive pinion and ring gear ratio, and it is then split equally for the drive shafts by the differential action. Since the car had a 3.00:1 drive pinion and ring gear ratio, the axle shaft torque is 1.5 times the drive pinion torque.

In the introduction, we discussed basically only "what" the car's drive line and rear axle do. They deliver the engine driving power from the transmission output shaft to the rear wheels.

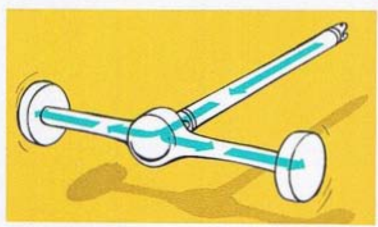
It is now time to get to "how" they deliver this power.

Let's use the drive line and rear axle shown in Fig. 1 as our guide, and trace the power flow through it component by component.

Engine power flows from the transmission output shaft to the front universal joint knuckle, to the universal joint spider, and to the drive shaft.

From the drive shaft, the power flows through the rear universal joint to the drive pinion flange, and to the drive pinion gear. From the drive pinion, the power flows to the ring (drive) gear and differential case. As the power flows from the drive pinion to the ring gear, its torque is multiplied in proportion to the gear ratio of the drive pinion and ring gear.

As the power flows through the differential pinion and side gears, the driving power is split into two equal powers. Therefore, equal power flows into each axle shaft and each rear wheel.

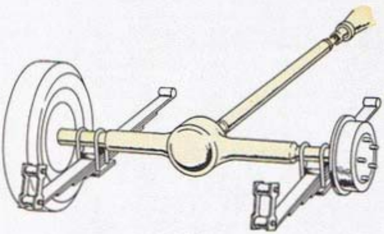


Now, let's take a close look at the individual parts that make up the drive line and rear axle. Occasionally, we will take a look at the corresponding part in drive lines and rear axles of different design.

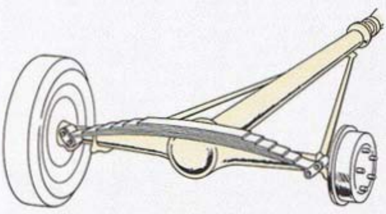
DRIVE LINE CONSTRUCTION

The terms, drive line and drive shaft, are often used as if they meant the same thing. Properly used, the term drive line refers to all the components that transmit engine power from the transmission to the rear axle. The term drive shaft refers only to a shaft between the universal joints.

There are two basic types of drive lines: the torque tube drive line and the Hotchkiss drive line (Fig. 5).



HOTCHKISS-TYPE DRIVE LINE



TORQUE TUBE-TYPE DRIVE LINE

Fig. 5—Drive Line Types

The torque tube drive line is entirely enclosed and has only one universal joint. The Hotchkiss drive line has a minimum of two universal joints, and it is "out in the open."

In the torque tube drive line, the drive shaft is always in perfect alignment with the rear axle drive pinion because the torque tube, which supports the drive shaft, is rigidly attached to the rear axle housing.

In the Hotchkiss drive line, the rear axle housing is usually held in such a position that the drive shaft and drive pinion are not in perfect alignment. In fact, their centerlines are usually at an angle, as we shall see later.

Both types of drive lines have been used on Ford cars. Fig. 6 shows a typical Hotchkiss drive line completely disassembled.

The front yoke of the universal joint is called the universal joint knuckle, or more commonly referred to as the slip yoke. The slip yoke is splined to the external splines of the transmission output shaft.

When going over bumps, the axle is moving up and down on the suspension system. In so doing, the distance between the transmission and the rear axle is continually changing. The slip yoke will move in and out on the transmission shaft to compensate for this change of distance. This is why the drive shaft is not anchored at the front. The spline of the slip yoke fits snugly to the transmission output shaft and is free to move in and out as necessary.

On manual-shift transmissions, the slip yoke spline is lubricated by the transmission's lubricant. This type of lubricant permits the yoke to move in and out under all driving conditions.

Lubrication of the conventional spline slip yoke on automatic transmissions presents a special problem. Automatic transmission fluid does not provide the kind of lubricant needed for yoke slide when the conventional spline yoke is transmitting torque. To overcome this difficulty, a special lubricant is used on the spline teeth. The spline is sealed so that the transmission fluid does not "wash away" the spline lubricant (Fig. 7). Some cars use a yoke that has a recirculating roller bearing spline (Fig. 8). With this yoke, the transmission output shaft is machined with two grooves or keyways in which the two recirculating roller bearing assemblies slide. The roller bearing cages are fitted to machined keys in the yoke. The roller bearings transmit the torque from the yoke to the shaft. As the yoke moves fore and aft, the bearing rollers circulate around the machined keys and reduce the friction between the yoke and output shaft so that a special lubricant is not required.

In our typical Hotchkiss drive line (Fig. 6), the front and rear universal joints are for practical purposes identical in construction and operation. Needle roller bearings support the cross or spider in the yokes. The bearing outer race is cup-shaped. The cup is deep enough to hold a reserve supply of lubricant. A seal is used between the cup and cross to retain the lubricant. Universal joints make it possible for one shaft to drive another when they are at an angle or are not aligned.

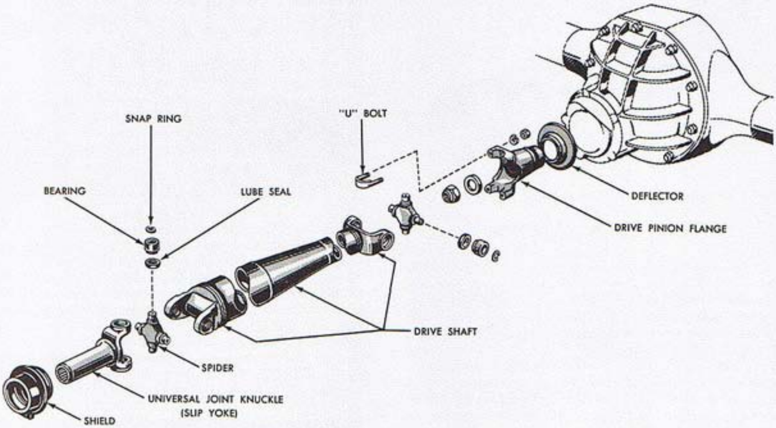


Fig. 6—Typical Hotchkiss Drive Line—Disassembled

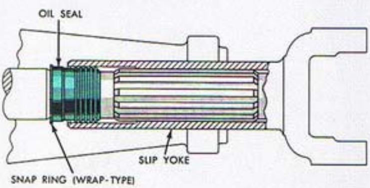


Fig. 7—Output Shaft Spline Seal

In the typical Hotchkiss drive line (Fig. 6), two types of drive shafts are used. They are referred to as the solid-type and the rubber element-type drive shafts.

The solid-type drive shaft is a hollow steel tube which may be "pinched in" at one end for tunnel clearance. Universal joint yokes are welded at each end of the tube to complete the assembly.

The rubber element-type drive shaft (Fig. 9) is of the same construction as the solid-type drive shaft, except for the method of attaching one of the universal joint yokes. One of the universal joint yokes is welded to a separate piece of steel tubing, which is slightly smaller in diameter than the drive shaft tube. Several rubber rings are bonded to the smaller diameter steel tube. The smaller tube and yoke are now pressed into one end of the drive shaft. The rubber rings between the two tubes are now under so much compression that the two tubes are securely locked together. In this drive shaft, there is no metal to metal contact between the drive shaft tube and one of the universal yokes. The purpose of the rubber element is to stop noise from "telegraphing" up and down the drive line.

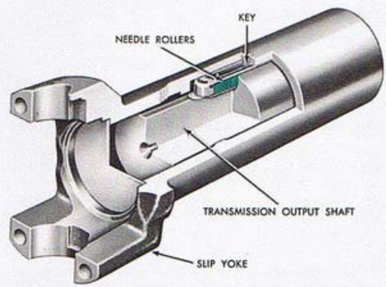


Fig. 8—Recirculating Roller Bearing Spline

OPERATION and CONSTRUCTION

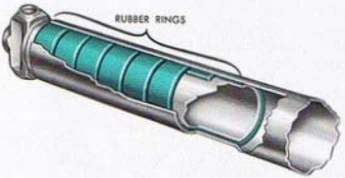


Fig. 9—Rubber Element Drive Shaft

DRIVE LINE OPERATION

Two universal joints are used in our typical Hotchkiss drive line (Fig. 6). Two universal joints are required because the rear axle housing in normal driving not only moves up and down in relation to the car's frame, but it also rotates on its own center in relation to the car's frame (Fig. 15). This means that power flow through the drive line may change direction twice. For example, engine power flowing from the transmission output shaft to the drive shaft may change direction as it flows through the front universal joint. As the same engine

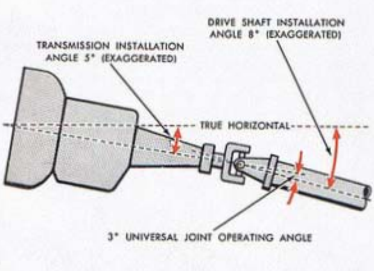


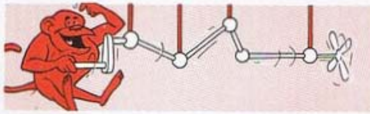
Fig. 10—Transmission and Drive Shaft

power flows from the drive shaft to the drive pinion, it may again change direction, because the axle has moved up or down or it may have rotated on its own center. The power flow may have changed directions, because the design of the car may have called for the transmission to be installed higher or lower than the rear axle.

Before we get deeper into drive line operation, let's define some of the common terms used in drive line service operations.

INSTALLATION ANGLES

The transmission and the rear axle housing are installed in the car at a definite angle in relation to the car's frame or underbody structure (Fig. 15). The transmission is rigidly attached to the car's frame and its



installation angle changes only to the extent of the engine-transmission mount deflect. For our purposes, the transmission installation angle does not change during car operation. The rear axle housing is attached to the rear springs, which in turn are attached to the frame. The rear axle housing installation angle is, therefore, constantly changing with axle housing up and down movement and with axle housing rotation during braking and acceleration. The installation angle for the rear axle housing is, therefore, specified when the car is standing still and at curb weight.

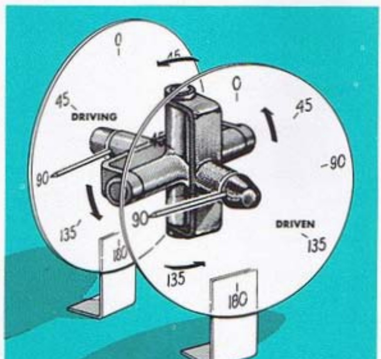


Fig. 11—Non-Constant Velocity-Type Universal Joint—Demonstration

When the transmission and rear axle housing installation angles and relative height with reference to the car's frame have been established, the drive shaft angles are also established.

The transmission's installation angle is the angle formed by the transmission's output shaft centerline crossing the frame line (Fig. 15). This angle can be measured on the car with a spirit-level protractor. Usually, the protractor is applied to a large machined surface on the transmission case. These machined surfaces are either parallel to or at exactly 90 degrees to the output shaft centerline. If, therefore, the machined surface at the rear of the transmission case is 5 degrees from the vertical, the output shaft centerline is 5 degrees from the horizontal.

The rear axle installation angle is the angle formed by the drive pinion centerline intersecting the frame line (Fig. 15). This angle can be measured on machined surfaces on the differential carrier housing or on horizontal machined surfaces on the drive pinion flange.

The drive shaft installation angle is measured by placing a protractor on the tube portion of the drive shaft.

UNIVERSAL JOINT OPERATING ANGLES

Universal joint operating angle is another common term in drive line discussion. It is the angle formed by the crossing of the centerlines of two drive line components which are coupled by a universal joint (Fig. 10). This angle is referred to as the included angle. This angle cannot be measured directly. It must be calculated from the installation angles of the components which are coupled by the universal joint. If the components are tilted in the same direction, the universal joint operating angle is the difference between the installation angles. If the components are tilted in opposite directions, the universal joint operating angle is the sum of the installation angles (Fig. 10).

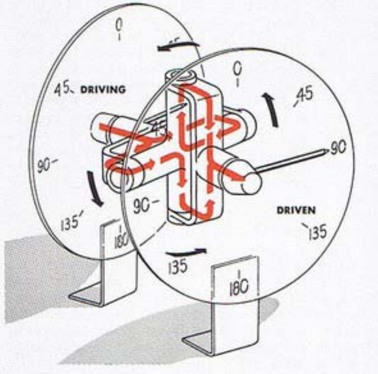


Fig. 12—Universal Joint Power Flow

The size of the universal joint operating angles is important because the universal joints in our typical drive line (Fig. 6) are the non-constant velocity-type.

The velocity which is referred to in the non-constant velocity-type universal joint, is angular velocity. Usually a shaft's velocity (speed of rotation) is measured in terms of complete turns (revolutions) per time unit (minute). For example, 1000 rpm means that the shaft

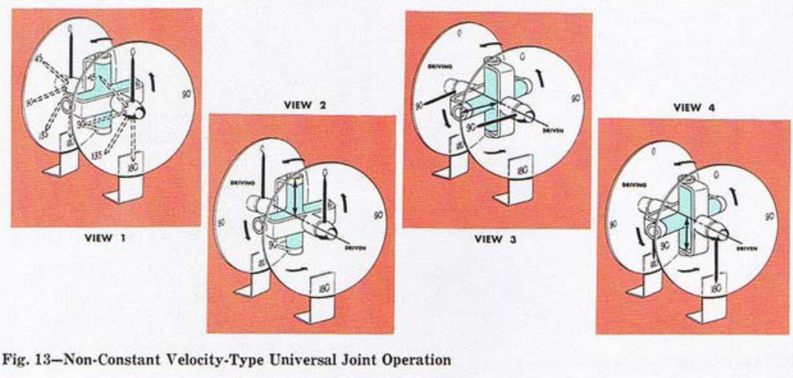


Fig. 13—Non-Constant Velocity-Type Universal Joint Operation

completed 1000 complete turns in one minute. When we come to the rotation of a shaft which is driven by a universal joint and the joint has an operating angle, we need to measure shaft velocity or motion from point to point within one revolution. Point to point around a circle is indicated by the number of degrees that separate the points or the angle between the points. From this, we get the term angular velocity. A non-constant velocity-type universal joint is one in which the driving shaft does not transmit uniform angular motion from one shaft to another. This occurs only when the shafts are at an angle.

Let's operate the universal joint model shown in Fig. 11, and see why it is a non-constant velocity-type. In its principles of operation, the model is exactly like the universal joints shown in Fig. 6.

The model has all the basic parts required for an operating universal joint. For convenience, let's call one shaft "driving" and the other "driven." In a car, power flow through the universal joints reverses direction often. The driving and driven shafts have yokes. The cross has four arms which are 90 degrees apart. Two cross arms, 180 degrees apart, are connected to the driving yoke and are free to rotate in the yoke on their own centers. The other two arms, 180 degrees apart, are connected to the driven yoke and are also

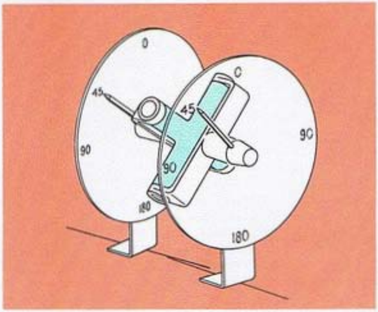


Fig. 14—Universal Joint Operating Angles

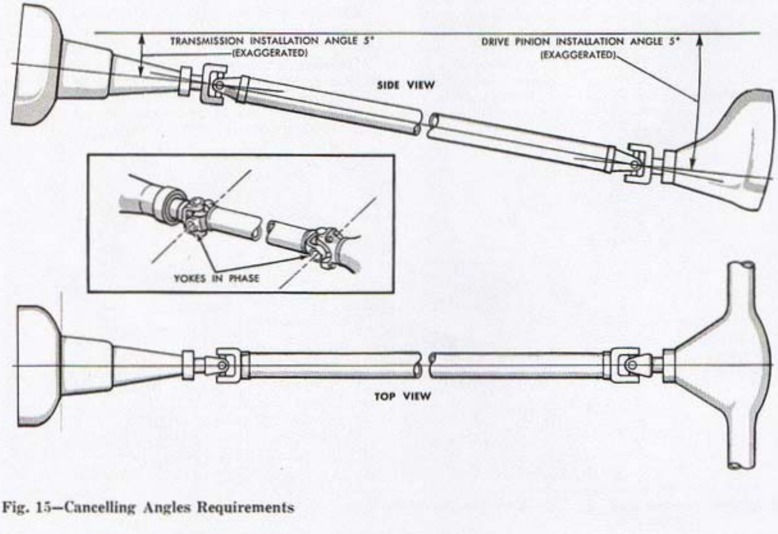


Fig. 15—Cancelling Angles Requirements

free to rotate in the yoke on their own centers.

The model has pointers and divided circles on the driving and driven shafts. This makes it possible to compare driving and driven shaft rotation at 45 degree intervals.

Let's look at the power flow through this type of universal joint (Fig. 12). As power flows from the driving shaft to the driving yoke, it splits into two equal flows. The two flows combine in the cross and then split again as the power flows into the driven yoke. As the power flows from the yoke into the driven shaft, the flows combine once more. As the universal joint operating angle increases, the speed variation in the output shaft increases. Since our model is not made for precise measurement, let's operate it with a 25 degree universal joint operating angle, so that the readings will be sizeable and easily compared. Our purpose is to demonstrate a principle rather than take precise measurements. A universal joint operating in a car will seldom operate at an angle greater than 7 degrees.

View 1 in Fig. 13 shows the relative positions of the drive and driven pointers for one-half turn or 180 degrees. At 0 degrees.the pointers are aligned. At 45 degrees,the driven pointer is at less than 45 degrees. The driven shaft has fallen behind the drive shaft about 3 degrees. At 90 degrees,the driven shaft has caught up with the driving shaft. At 135 degrees,the driven shaft is leading the driving shaft by about 3 degrees. At 180 degrees,the pointers are aligned. **This is what is meant by non-constant velocity.**

Assume that the driving shaft is turning at a constant speed during the one-half turn from 0 to 180 degrees. The driven shaft.during this one-half turn,lost speed as it turned from 0 to 45 degrees, and gained speed as it turned from 45 to 90 degrees. From 90 to 135 degrees it gained speed and from 135 to 180 degrees the driven shaft lost speed.

The reason for these changes in speed is shown in Views 2, 3 and 4 in Fig. 13. The universal joint yokes and cross are a lever system which transfers rotation from the driving to the driven shaft. Since the drive and driven shafts yokes are not rotating in the same plane, the effective lever arm lengths are constantly changing. Views 2, 3 and 4 show the effective arm lengths at 0, 90 and 180 degrees.

The effective arm length is shown for only one of the driving cross arms, since the other driving cross-arm length is identical. As the driving yoke rotates from 0 to 90 degrees,the effective cross-arm length goes from maximum to minimum. From 90 to 180 degrees ,the effective arm length goes from minimum to maximum. If the model is rotated another one-half turn, the first one-half cycle will be repeated as far as drive and driven shaft speed fluctuations are concerned.

View 1 in Fig. 13 shows the driving shaft pointer at 45 degrees and the driven shaft pointer at less than 45 degrees. The pointers started from zero. This is what is meant by non-constant velocity. During the same period of time, the driven shaft rotated exactly ⅛ turn, and the driven shaft rotated less than ⅛ turn.

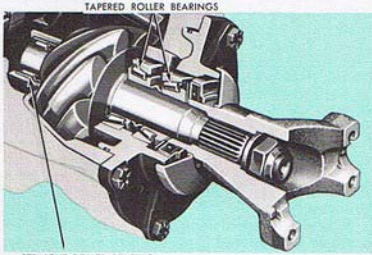


Fig. 16—Straddle-Mounted Drive Pinion

The driven shaft turned slower than the driving shaft. The reason for this difference in speed is shown in Views 2, 3 and 4 in Fig. 13. The universal joint cross is a lever system that transfers motion from the driving yoke to the driven yoke. Since the yokes are not traveling in the same plane, the effective lever arm lengths are constantly changing. Views 3 and 4 (Fig. 13) show the effective arm lengths at 0 degrees, 45 degrees and 90 degrees.

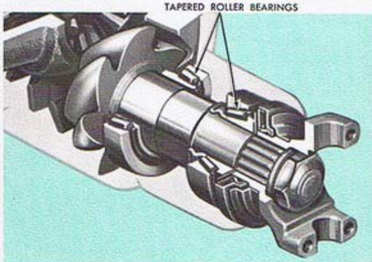


Fig. 17—Overhung-Mounted Drive Pinion

The effective arm length, in our case, is the shortest distance between the driving yokes and the centerline of the driven shaft. As the driving yoke rotates from 0 degree to 45 degrees, the yoke arms move closer to the centerline of the driven shaft and thereby shorten the effective arm lengths. As the effective arms become shorter, they will cause greater rotation in the driven shaft, although they are receiving uniform motion from the driving shaft.

As the driving yoke rotates from 45 degrees to 90 degrees, the effective lever arms become progressively longer, and transmit less rotation as they become longer (Fig. 13).

As the driving yoke rotates from 180 degrees to 225 degrees, the 0 degree to 45 degree action recurs. It is the beginning of a new cycle that will be completed, when the yoke rotates back to 0 degree.

Now, let's observe how the variations in rotation decrease in size as the size of the universal joint operating angle is reduced (Fig. 14). With a 10 degree universal joint operating angle, the driven shaft has fallen behind the driving shaft less than 1 degree at 45 degrees of rotation.

Along with the speed of rotation variations, which are caused by the universal joint operating at an angle, go driving torque variations. As the driven shaft rotation is increased by the universal joint, its torque is reduced. The power flow, of course, remains the same. The gain in rotation is made at the expense of torque. The opposite holds true for rotation loss between the driving and driven shafts. With a loss of rotation, there is a gain in torque.

The rear universal joint can change the drive shaft's non-uniform motion into a uniform drive pinion shaft motion, provided that:

1. The operating angles of the rear and front universal joints are equal (Fig. 15). This will be so, if the transmission output shaft and drive pinion shaft are parallel, and if they lie in the same vertical plane.
2. The driving yoke of the rear universal joint operates at 90 degrees to the driving yoke of the front universal joint. In our typical drive line, this condition is met since the drive shaft yokes are in the same plane. They are said to be "in phase."

When the universal joints are arranged as described above, the non-uniform motion introduced into the drive shaft by the front joint is cancelled by the rear joint.

Of concern in drive line service are the installation angles, which govern the size of the universal joint operating angles.

A cancelling angle situation is not present in the drive line at all times. Axle housing rotation during full-throttle starts and panic-stop braking cause the rear universal joint operating angle to increase faster than the front joint angle increases. In this booklet, only the basic problem of non-constant velocity-type universal joints is discussed. The actual universal joint operating angles, which are acceptable in a specific car, are determined by the manufacturer. As the type of rear suspension, type of engine and transmission mounting, length of drive shaft, etc. change, the drive line operating characteristics also change. Occasionally, the installation angles have to be restored to "new car" specifications to provide acceptable universal joint operating angles.

DRIVE PINION MOUNTING

In our typical rear axle, the drive pinion is **straddle mounted** as shown in Fig. 16. In the Falcon rear axle, the drive pinion is **overhung**, or has an overhung mounting (Fig. 17). These two types of pinion mountings refer to the location of the pinion shaft bearings in relation to the pinion gear. The problem in mounting the drive pinion is to keep it in proper mesh with the ring gear. When the drive pinion is driving the ring gear, two resultant forces are acting. One is the end thrust and the other is radial load. **Thrust load** is a

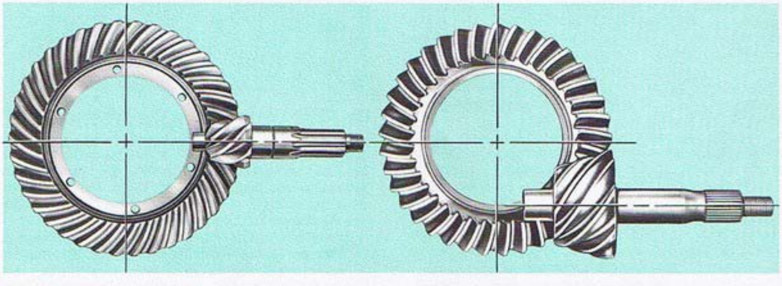


Fig. 18—Spiral Bevel and Hypoid Gears

force acting parallel to the axis of the shaft, while radial load is a force acting at right angles to the shaft.

If bearings are installed on both sides of the pinion gear, the problem has been straddled. The tendency of the pinion gear to change its radial relationship with the ring gear is held back on both sides of the gear.

In the overhung-type mounting, the tendency of the pinion gear to change this relationship with the ring gear is held back on only one side of the gear.

When the drive pinion is straddle mounted, the tapered roller bearings can be mounted close together (Fig. 16), since they do not have to hold back against the pinion gear's tendency to change relationship with the drive gear and get out of mesh. The pilot bearing resists this movement.

In the overhung-mounted drive pinion (Fig. 17), the tapered roller bearings are spread farther apart, so that the front bearing has a longer lever arm against the rear bearing (pivot) to hold the pinion gear in proper mesh.

The terms drive, coast and float are often used in rear axle discussions. The term drive indicates that engine power is driving the car. In the rear axle, it means that the pinion gear is driving the ring gear, and that the ring gear and differential case are driving the rear wheels. The term coast indicates that the car's momentum is driving the engine. In the rear axle, this means that the rear wheels are driving the differential case and ring gear, and that the ring gear is driving the pinion.

The term float indicates that the engine drive and rear wheel drive are equal.

During a drive condition, the drive pinion shaft end thrust is forward and is contained by the rear bearing. During a coast condition or on coast, the drive pinion shaft end thrust is rearward and is contained by the front bearing. On a float condition, there is of course, no end thrust in the pinion.

Usually, the pinion rear bearing is larger than the front bearing, because pinion end thrust forces on drive are generally greater than on coast (Fig. 17). On the Ford straddle-mounted pinion, the bearings are the same size to facilitate manufacture and service.

DRIVE PINION BEARING PRELOAD

For quiet pinion and ring gear operation, the gears must be held in exactly the proper mesh. This means that the pinion gear must be held to zero end play. Zero end play, in a shaft mounted on two opposed tapered roller bearings, means that there must be zero clearance between the cone and rollers, and between the rollers and cups in both bearings. As we noted previously, pinion end thrust reverses direction as it goes from drive to coast. If there is any clearance at the rollers, the pinion shaft will walk back and forth as the direction of thrust changes. A walking pinion shaft means that the pinion and ring gear are walking in and out of proper mesh.

To ensure zero end play at all times, the bearing cones are actually forced against the rollers, and the rollers against their cups, by tightening the pinion shaft nut. As the pinion shaft nut is tightened, the pinion shaft flange, the oil slinger, the front bearing spacer, and the rear bearing cone are forced closer together.

In the Ford rear axles, the bearing spacer is collapsible so that at a specified torque on the pinion nut, the spacer is squeezed to a shorter length. As the spacer gets shorter, the bearing cones are pulled closer together and press the bearing rollers against their cups. When they are pressed to the point where about a 15 inch-pound torque is required to keep the shaft rotating, the bearings are properly preloaded. As the pinion shaft nut is tightened beyond the point of zero clearance at the roller bearings, the pinion shaft is stretched. This stretch remains in the pinion shaft and it tends to keep the bearing rollers seated under all operating conditions.

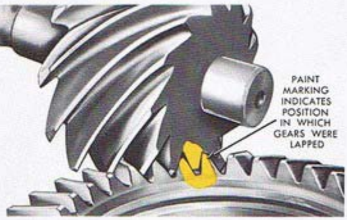


Fig. 19—Non-Hunting Gear Set Timing Mark

DRIVE PINION BEARING SPACER

Why have a spacer between the tapered roller bearing cones? The spacer is placed between the bearing cones so that they are pinched between the pinion input shaft flange and the pinion gear. This will cause the bearing cones to rotate along with the shaft. If a cone stands still, while the components next to it rotate, it will be "chewed" into a shorter length by the moving components. If the cone becomes shorter, both preload and pinch will be lost.

DRIVE PINION AND RING GEAR

In hypoid gears, the teeth are not straight. They are curved or tend to follow the form of a spiral. There are various advantages in using a hypoid ring and pinion gear.

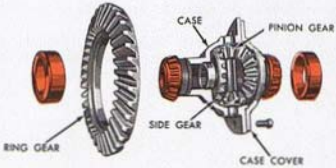


Fig. 20—Differential Case Assembly

An important feature is that we are able to use an offset pattern. It is not necessary to match the centerlines as is the case with spiral bevel gears (Fig. 18). The pinion gear is actually set below the centerline of the ring gear. This is what enables us to lower the drive shaft, and in turn lower the tunnel of the car, which makes the entire automobile lower. Also, by using hypoid gears, we have an end-wise sliding action between the teeth along with the rolling action. Because of this sliding action, we are able to lap the ring and pinion gears, which in turn gives us a more perfect match, smoother action and a quieter running ring and pinion gear set.

Pinion and ring gear sets may be classified as hunting, non-hunting and partial non-hunting. Each classification has its own requirements for a satisfactory gear tooth contact pattern.

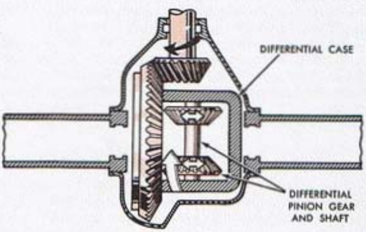


Fig. 21—Differential Pinion Gear Operation

A **hunting gear set** is one in which any one pinion gear tooth comes into contact with all the ring gear teeth. The 3.56 ratio, with 9 teeth on the pinion and 32 teeth on the ring gear, is a hunting gear set. If tooth 1 on the pinion is meshed with tooth 1 on the ring gear, as the gears roll, pinion tooth 1 will contact ring gear teeth numbers 1, 10, 19, 28 — 5, 14, 23, 32 — 9, 18, 27 — 4, 13, 22, 31 — 8, 17, 26 — 3, 12, 21, 30 — 7, 16, 25 — 2, 11, 20, 29 — 6, 15, 24, and back to 1. In the sentence above, the dashes indicate the end of one revolution of the ring gear and the start of a new revolution.

A **non-hunting gear set** is one in which any one pinion tooth will contact only a few ring gear teeth, and in which all possible tooth contact combinations will come out in one revolution of the ring gear. The 3.00:1 ratio, with either a 10-and 30-or 13-and 39-tooth combination on the pinion and ring gears, is a non-hunting gear set.

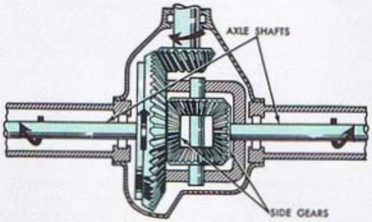


Fig. 22—Differential Pinion and Side Gear Operation

A **partial non-hunting gear set** is one in which any one pinion tooth comes into contact with only part of the ring gear teeth, but more than one revolution of the ring gear is required to bring out all possible gear tooth contact combinations. The 3.50:1 ratio with a 10 - and 35-gear tooth combination is a partial non-hunting gear set.

Non-hunting and partial non-hunting gear sets have a painted "timing" mark on the pinion and drive gear teeth (Fig. 19). This marking is made at the final gear tooth lapping operation. **If the pinion and ring gears**

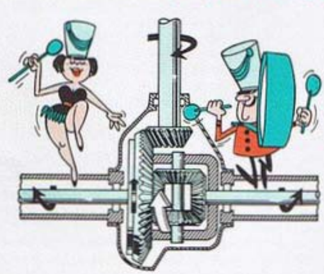


Fig. 23—Differential Power Flow during Straight-Ahead Travel

are assembled out of time, gear teeth will be working together which have not been lapped together.

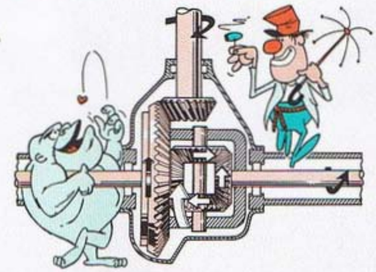


Fig. 24—Differential Power Flow with One Wheel Stationary

DIFFERENTIAL CASE

The differential case is mounted in the carrier casting between two tapered roller bearings (Fig. 20). It supports the ring gear, which is attached to it by bolts. Power flows from the drive pinion to the ring gear, and the ring gear drives the differential case. Inside the differential case are four gears. The two differential pinion gears are mounted on the differential pinion shaft. The pinion gears are free to turn on their own centers, but they have to travel in a circle as the differential case and pinion shaft rotate (Fig. 21). Two side gears are meshed with the pinion gears. The side gears are free to turn on their own center. Since they are mounted on the differential case centerline, they

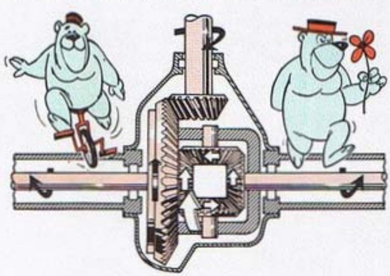


Fig. 25—Differential Power Flow while Cornering

do not travel in a circle like the pinion gears. The axle shafts are splined to the side gears (Fig. 22).

During straight-ahead travel, the differential case assembly revolves as a unit. The differential pinions rotate in a circle but do not turn on their own centers (Fig. 23). Both side gears are driven at the same speed and both rear wheels are turning at the same speed.

If one wheel cannot turn, one side gear cannot turn (Fig. 24). With this condition, the differential case turns the pinion gears in their usual circle. Since one side gear is stationary, they now have to turn on their own centers as they "walk" around the stationary side gear. As they "walk" around the stationary side gear, they drive the other side gear at twice their own speed of traveling their circle. The pinion gears are not only traveling their circle, they are also rotating on their own center. These two motions are combined in driving the one side gear at twice the speed of case rotation. The moving wheel is now turning at twice the speed of the differential case, but the torque applied to it is only one-half of the torque applied to the differential case. The turning wheel gets all the drive power. The torque or twisting force is reduced by one-half, because the turning wheel is running at twice the speed of the differential case. Here we have an overdrive condition, which is directly opposite to reduction. As power flowed from the drive pinion to the ring gear, torque was

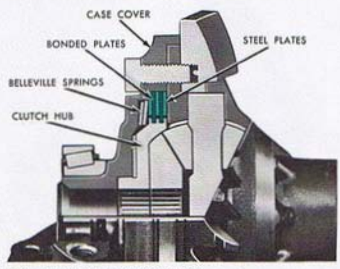


Fig. 26—Equa-Lock Differential

multiplied in direct proportion to the reduction. What was gained in torque or twisting force was paid for by loss in rotation. In the differential drive with one wheel stationary, rotation is gained and it is paid for in loss of torque.

When the car goes around a corner, the inside wheel travels a shorter distance than the outside wheel (Fig. 25). The inside wheel must, therefore, rotate more slowly than the outside wheel. In this situation, the differential pinion will "walk" forward on the slower turning inside side gear and thereby increase the speed of the faster turning outside side gear.

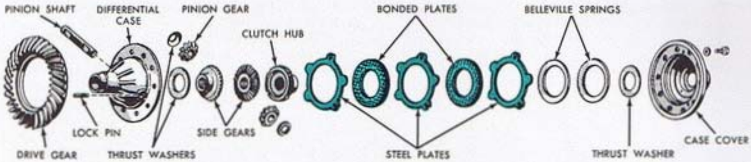


Fig. 27—Equa-Lock Differential Disassembly

LIMITED-SLIP DIFFERENTIALS

Two types of limited-slip differentials are used on Ford cars and light trucks. They are the Ford Equa-Lock and the Thornton-Spicer Power-Lok.

Power flow through the Equa-Lock differential is the same as that in the conventional differential except that the differential action is partially controlled by a constant friction clutch (Fig. 26).

Three dog-eared steel clutch plates are locked into the differential cover (Fig. 27). Two bronze bonded clutch plates are splined to a clutch hub which, in turn, is splined to the left axle shaft.

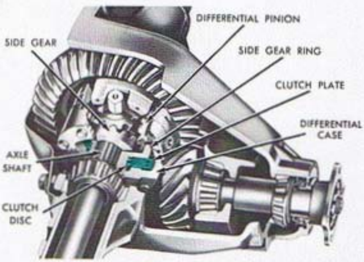


Fig. 28—Power-Lok Differential

Fig. 28 shows the clutch that connects the differential case to the right axle shaft; an identical clutch on the opposite side of the differential connects the differential case to the left axle shaft.

Each clutch pack consists of 5 steel plates, set between the case and the side gear ring. (Fig. 29). The two outer plates and the center plate are locked to the differential case by external lugs. The external lug plate that is installed next to the case is a Belleville spring plate. This spring plate is installed with the convex (bowed) side against the case. The remaining two plates (discs) have internal spline teeth which lock to the splined hub on the side gear ring. The side gear ring is, in turn, splined to the axle shaft and acts as a pressure plate against the clutch pack. Since the side gear ring fits against the pinions on the cross shaft (mate shaft), any outward force exerted by the mate shaft and its pinions will press the ring against the clutch back and thus connect the differential case directly to the axle shaft.

The limited-slip differential mate shafts are not rigidly attached to the differential case, nor are they attached to each other. At both ends of the mate shafts there are two flat surfaces so arranged that they form a "V" which mates with the corresponding "V" shaped surfaces (ramps) cut in the shaft openings of the differential case.

When the differential case rotates in either direction, the mate shafts will be forced to bear against one side of their "V" ramps and will apply pressure against the clutch packs. The clutches will apply whether the power flow is from the differential case to the axle shafts, or from the axle shaft to the differential case.

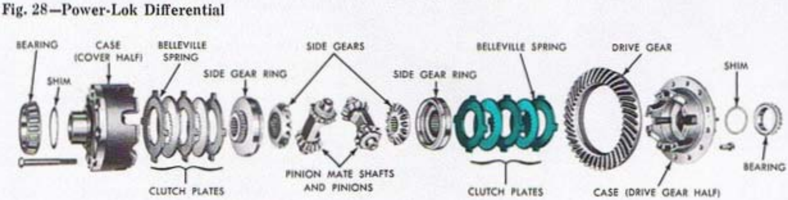


Fig. 29—Power-Lok Differential—Disassembled