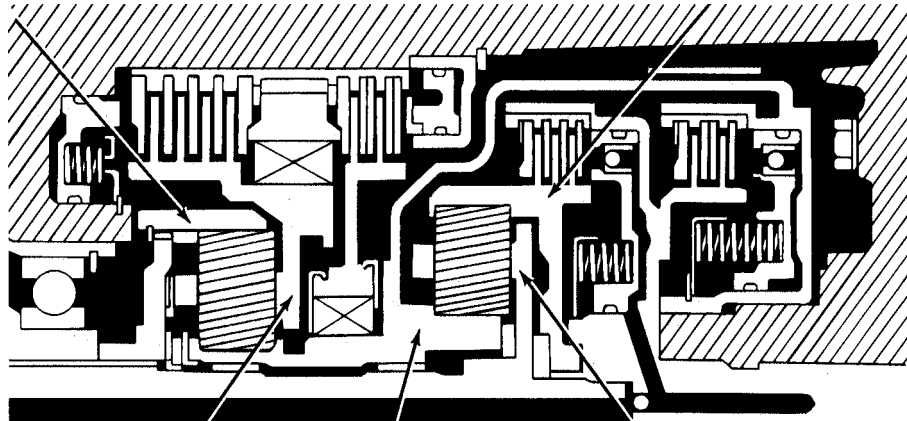# Section 3

SIMPSON PLANETARY GEAR UNIT

Lesson Objectives

1. Manipulate transmission components to demonstrate power flow through a simple planetary gear set for:
   - Gear reduction
   - Gear increase (overdrive)
   - Reverse
2. Identify the three major components of the simple planetary gear set.
3. Describe the function of the simple planetary gear set to provide:
   - Rotational speed change
   - Rotational torque change
   - Change in rotational direction
4. Demonstrate the measurement for wear on planetary carrier assembly and determine serviceability.
5. Describe the operation of the following holding devices:
   - Multiplate clutch
   - Brake band
   - One-way clutch

Toyota automatic transmissions use the Simpson-type planetary gear unit. This unit is made up of two simple planetary gear sets arranged on the same axis with a common sun gear. These gear sets are called the front planetary gear set and the rear planetary gear set, based on their position in the transmission. These two planetary gear sets result in a three-speed automatic transmission having three forward gears and one reverse gear.

Simpson Planetary Gear Set

Made up of two simple planetary gear sets arranged on the same axis with a common sun gear.
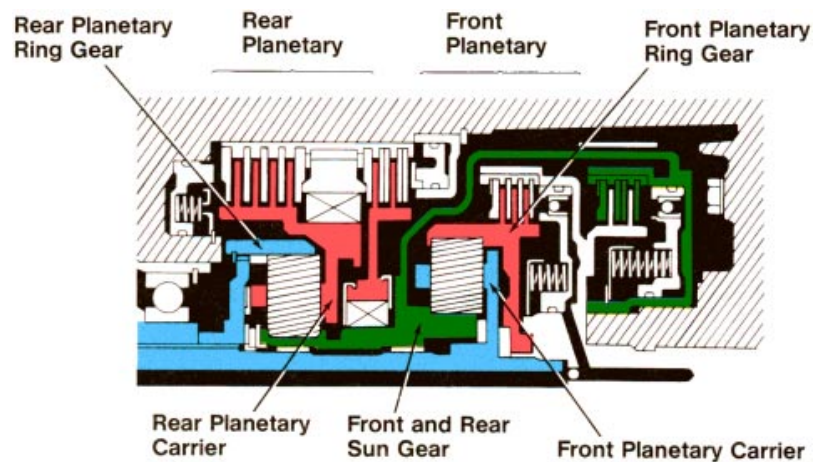
These planetary gear sets, the brakes and clutches that control their rotation, and the bearings and shafts for torque transmission are called the planetary gear unit.

The planetary gear unit is used to increase or decrease engine torque, increase or decrease vehicle speed, reverse direction of rotation or provide direct drive. It is basically a lever that allows the engine to move heavy loads with less effort.

There is an inverse relationship which exists between torque and speed. For example: when a vehicle is stopped it requires a great deal of torque to get it to move. A low gear is selected which provides high torque at low vehicle speed. As the heavy load begins to move, less leverage is required to keep it in motion. As the load remains in motion and speed increases, torque requirements are low. With a suitable number of levers or torque ratios, improved performance and economy are possible.

Gear Rotational Direction and Gear Ratio

Before getting into simple planetary gears, it is necessary to understand gear rotation and gear ratios or leverage. When two

external gears are in mesh as illustrated below, they will rotate in opposite directions. That is, when the small gear is rotated in a clockwise direction, it will cause the larger gear to rotate in a counter-clockwise direction. This is important to obtain a change in output direction, such as in reverse.

Gear Rotational Direction

When two external gears are in mesh, they will rotate in opposite directions.

Counter Clockwise

Clockwise
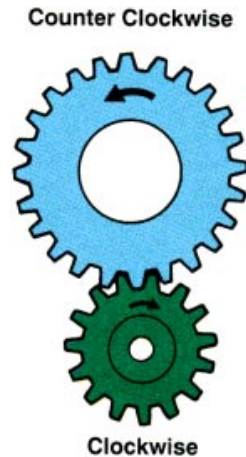
The gear ratio that these two gears provide will be a lever advantage. The rotating speed of an output gear is determined by the number of teeth of each gear. The gear ratio, and thus the rotational speed of the output gear, can be found by dividing the number of output gear teeth by the number of input gear teeth. These gear ratios are determined by the engineers and fixed in the manufacture of the transmission.

$$\text{Gear ratio} = \frac{\text{Number of output gear teeth}}{\text{Number of input gear teeth}}$$

$$\text{Gear ratio} = \frac{24}{15} = 1.6{:}1$$

In the illustration above, if the input gear has 15 teeth and the output gear has 24 teeth, the gear ratio is 1.6 to 1 (1.6:1). In other words, the input gear has to turn slightly more than one and one-half turns to have the output gear turn once. The output gear would turn slower than the input gear which would be a speed decrease. The advantage in this example is an increase in torque capability.

To contrast this illustration, let's assume that a set of gears have the same diameter with the same number of teeth. If we determine the gear ratio using the formula above, the ratio is 1 to 1 (1:1). In this example there is no leverage or speed increase. One rotation of the input gear results in one rotation of the output gear and there is no lever advantage.

When an external gear is in mesh with an internal gear as illustrated below, they will rotate in the same direction. This is necessary to get a change in output gear ratio. The gear ratio here can be determined in the same manner as was just discussed. Since the ratio is only accomplished when all members of the planetary gear set function together, we'll examine gear ratios of the planetary gear set under the Simple Planetary Gear Set.

Gear Rotational Direction

When an external gear is in mesh with an internal gear, they will rotate in the same direction.

Clockwise

Clockwise
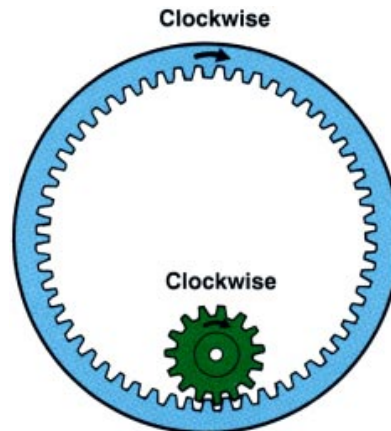
Simple Planetary Gear Set

Our introduction to Toyota automatic transmissions will begin with a simple planetary gear set. A planetary gear set is a series of three interconnecting gears consisting of a sun gear, several pinion gears, and a ring gear. Each pinion gear is mounted to a carrier assembly by a pinion shaft. The sun gear is located in the center of the assembly; several pinion gears rotate around the sun gear; and a ring gear surrounds the pinion gears. This gear assembly is called the "planetary" gears because the pinion gears resemble planets revolving around the sun.

In a planetary gear design, we are able to get different gear ratios forward and reverse, even though the gear shafts are located on the same axis.

Simple Planetary Gear Operation

HELD	POWER INPUT	POWER OUTPUT	ROTATIONAL		ROTATIONAL DIRECTION
			SPEED	TORQUE	
Ring gear	Sun gear	Carrier			
	Carrier	Sun gear			
Sun gear	Ring gear	Carrier			
	Carrier	Ring gear			
Carrier	Sun gear	Ring gear			
	Ring gear	Sun gear			

Planetary Gear Ratios

Gear ratios can also be determined in a planetary gear set although it is not something that can easily be changed. The gear ratio of the planetary gear set is determined by the number of teeth of the carrier, ring gear, and sun gear. Since the carrier assembly has no teeth and the pinion gears always operate as idle gears, their number of teeth is not related to the gear ratio of the planetary gear set. However, an arbitrary number needs to be assigned to the carrier in order to calculate the ratio. Simply count the number of teeth on the sun gear and the ring gear. Add these two numbers together and you have the carrier gear number for calculation purposes.

The number of carrier teeth (Zc) can be obtained by the following equation:

Zc = Zr + Zs
where
Zc = Number of carrier teeth
Zr = Number of ring gear teeth
Zs = Number of sun gear teeth

For example, assume the number of ring gear teeth (Zr) to be 56 and that of sun gear (Zs) to be 24. When the sun gear is fixed and the ring gear operates as the input member, the gear ratio of the planetary gear set is calculated as follows:

$$\text{Gear ratio} = \frac{\text{Number of output gear teeth}}{\text{Number of input gear teeth}}$$

$$= \frac{\text{Number of carrier teeth (Zc)}}{\text{Number of ring gear teeth (Zr)}}$$

$$= \frac{56 + 24}{56} \qquad = \qquad \frac{80}{56}$$

$$= 1.429$$

In other words, the input member would have to turn almost one and a half times to one turn of the output member.

Now let's assume that the carrier is the input member and the ring gear is the output member. We would use the same equation in determining the gear ratio.

$$\text{Gear Ratio} = \frac{56}{56 + 24} \qquad = \qquad \frac{56}{80}$$

$$= 0.7$$

In this case, the input member would only turn a little more than a half turn for the output member to turn once.

Operation   The operation of a simple planetary gear set is summarized in the chart below: different speeds and rotational directions can be obtained by holding one of the planetary members in a fixed position providing input torque to another member, with the third member used as an output member.
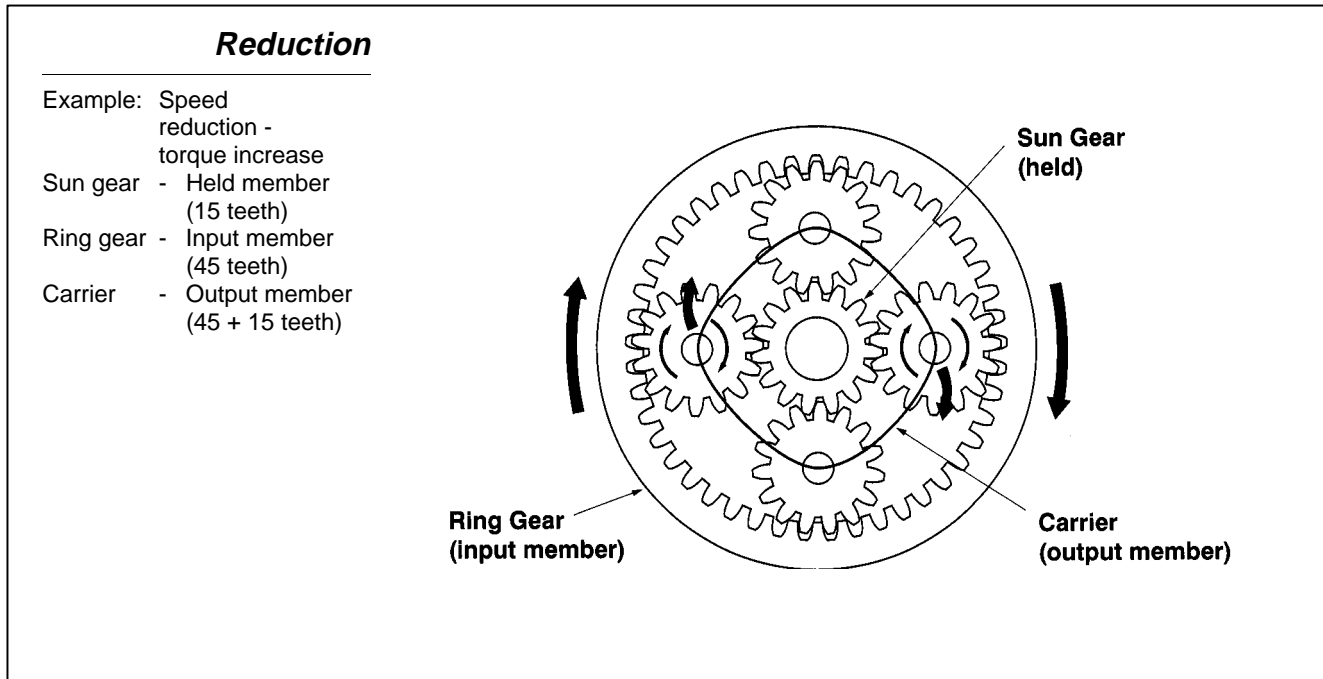
This chart represents more ratios and combinations than are used in Toyota automatics, but are represented here to show the scope of its design. The shaded areas represent the combinations used in Toyota transmissions and are, therefore, the only combinations we will discuss.

Simple Planetary Gear Operation

HELD	POWER INPUT	POWER OUTPUT	ROTATIONAL		ROTATIONAL DIRECTION
			SPEED	TORQUE	
Ring gear	Sun gear	Carrier	Reduced	Increased	Same direction as drive member
	Carrier	Sun gear	Increased	Reduced	
Sun gear	Ring gear	Carrier	Reduced	Increased	Same direction as drive member
	Carrier	Ring gear	Increased	Reduced	
Carrier	Sun gear	Ring gear	Reduced	Increased	Opposite direction as drive member
	Ring gear	Sun gear	Increased	Reduced	

Forward Direction   When the ring gear or sun gear is held in a fixed position, and either of the other members is an input member, the output gear rotational direction is always the same as the input gear rotational direction.

When the internal teeth of the ring gear turns clockwise, the external teeth of the pinion gears walk around the fixed sun gear while rotating clockwise. This causes the carrier to rotate at a reduced speed.

Reduction

Example: Speed
             reduction -
             torque increase
Sun gear   - Held member
                 (15 teeth)
Ring gear - Input member
                 (45 teeth)
Carrier   - Output member
                 (45 + 15 teeth)

Sun Gear
(held)

Ring Gear
(input member)
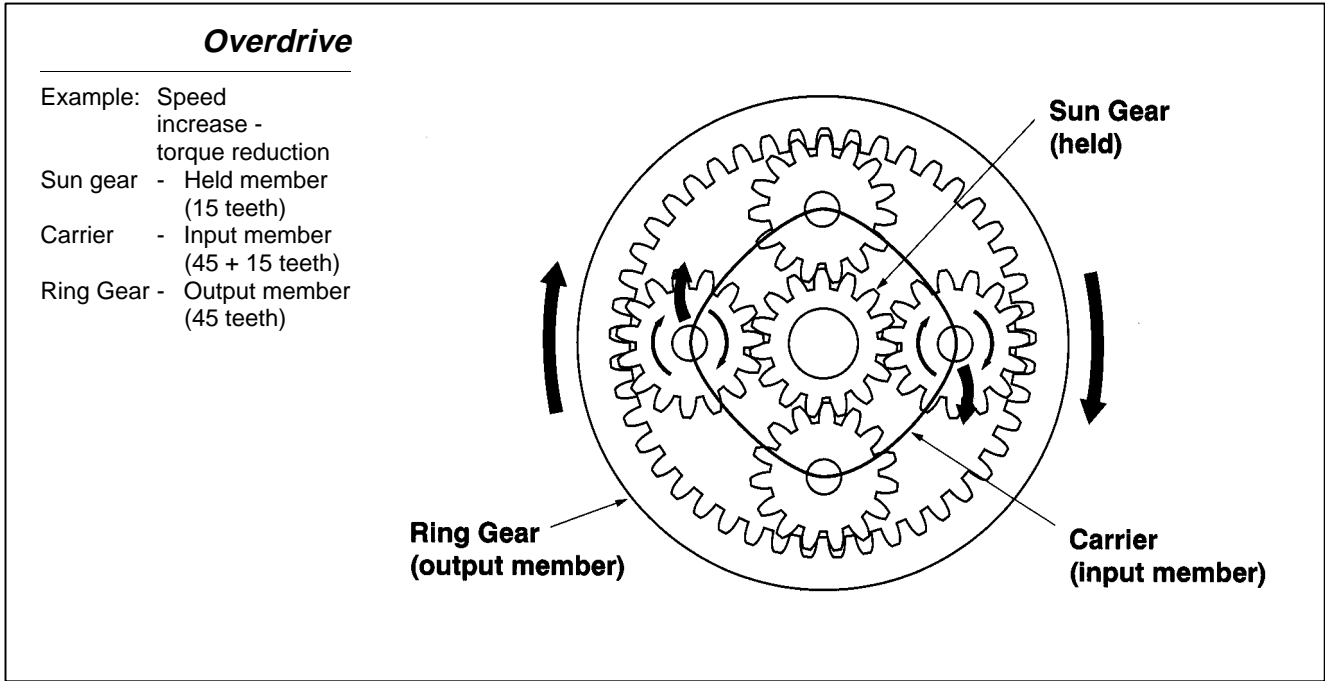
Carrier
(output member)

The gear ratio is computed as follows:

$$\text{Gear ratio} = \frac{\text{Number of output gear teeth}}{\text{Number of input gear teeth}}$$

$$\text{Gear ratio} = \frac{45 + 15}{45} \quad = \quad 1.3{:}1$$

In this example, the input gear (ring gear) must turn 1.3 times to 1 rotation of the output gear (carrier). This example is used in second gear.

When the carrier turns clockwise, the external toothed pinion gears walk around the external toothed sun gear while rotating clockwise. The pinion gears cause the internal toothed ring gear to accelerate to a speed greater than the carrier speed in a clockwise direction.
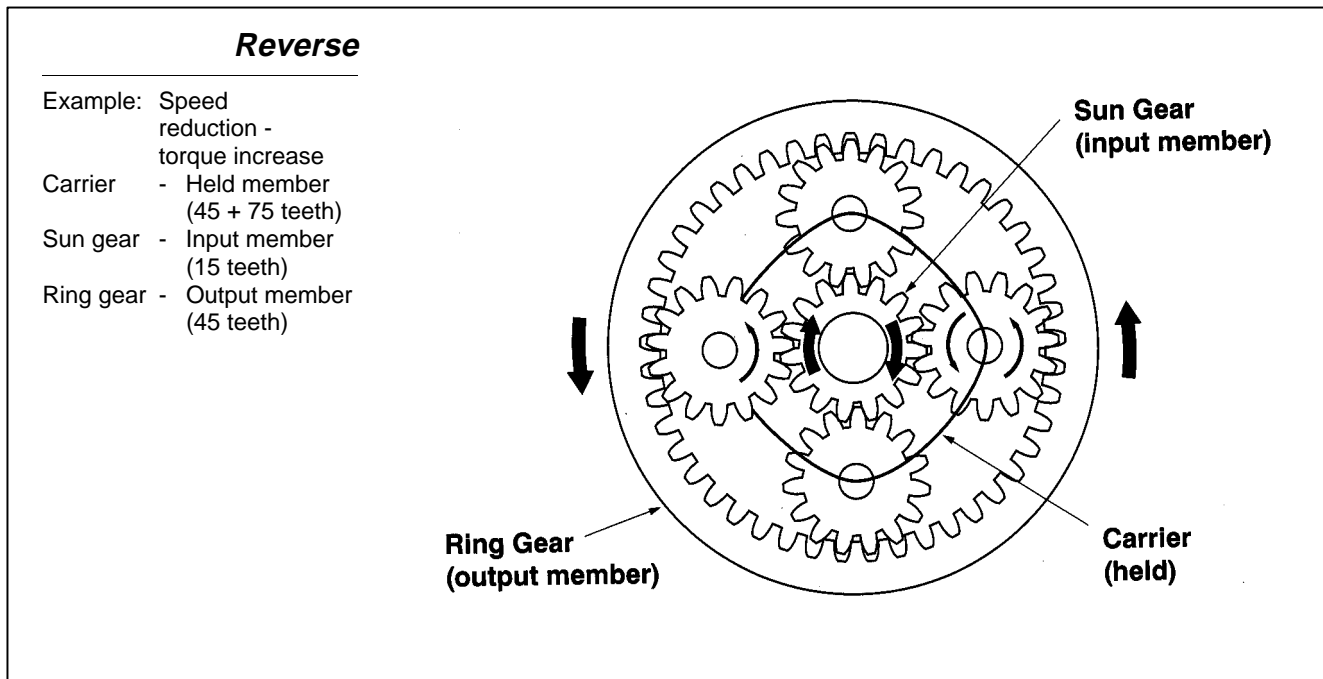
Overdrive

Example: Speed increase - torque reduction

Sun gear - Held member (15 teeth)

Carrier - Input member (45 + 15 teeth)

Ring Gear - Output member (45 teeth)

Sun Gear (held)

Ring Gear (output member)

Carrier (input member)

The gear ratio is computed as follows:

$$\text{Gear ratio} = \frac{45}{45 + 15} = .75:1$$

In this example, the input gear (carrier) must turn three-quarters of a turn (.75) to 1 rotation of the output gear (ring gear). This example is used in overdrive.

Reverse Direction   Whenever the carrier is held and either of the other gears are input members, the output gear will rotate in the opposite direction.

With the carrier held, when the external toothed sun gear turns clockwise, the external toothed pinion gears on the carrier idle in place and drive the internal toothed ring gear in the opposite direction.

Reverse

Example: Speed
reduction -
torque increase
Carrier   - Held member
(45 + 75 teeth)
Sun gear - Input member
(15 teeth)
Ring gear - Output member
(45 teeth)

**Sun Gear
(input member)**

**Ring Gear
(output member)**

**Carrier
(held)**

The gear ratio is computed as follows:

$$\text{Gear ratio} = \frac{45}{15} = 3:1$$

In this example, the input gear (sun) must turn three (3) times to 1 rotation of the output gear (ring gear). This example is used in first gear and reverse gear.

**Direct Drive -
(One-To-One Ratio)**   When any two members are held together and another member provides the input turning force, the entire assembly turns at the same speed as the input member.

Now the gear ratios from a single planetary set do not give us the desired ratios which take advantage of the optimum torque curve of the engine. So it is necessary to use two single planetary gear sets which share a common sun gear. This design is basic to most all automatic transmissions in production today.

Inspection and Measurement

Planetary Gear Assembly

The planetary gear assembly is a very strong gear unit. Input torque is transmitted to both front and rear planetary gear assemblies, which makes this unit very durable. However, since there are no seals and 0 rings to replace, this unit can be easily overlooked during inspection. It is very critical that it be inspected and measured for excessive wear during the overhaul process. Excessive wear may be the source for future failure or noise.

Begin with a visual inspection of the gear teeth. Any chips of the gears would warrant replacement. Also check thrust surfaces to ensure that the bushing or bearing has a smooth surface to mate to. With the visual inspection complete, measure the bushing inside diameter and compare it to the repair manual specifications. If it is outside the wear tolerance, replace the assembly.

Bushing Inside Diameter

Measure the diameter in three positions. If any is outside the wear tolerance, replace the assembly.
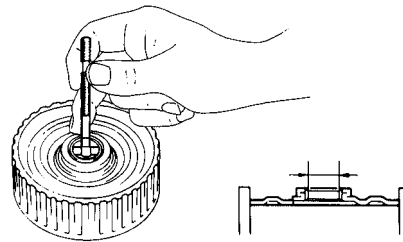
Use a feeler gauge to measure the clearance of the pinion gear to carrier housing and compare to the specifications. Standard clearance is 0.0079" to 0.0197". Clearance in excess of the standard on any planetary gear would require the replacement of the carrier assembly.

Pinion Gear Clearance

Excess clearance at any planetary gear requires replacement of the assembly.
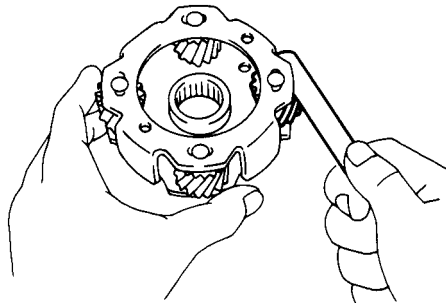
Holding Devices For Planetary Gear Set

There are three types of holding devices used in the planetary gear set. Each type has its specific design advantage. The three include multiplate clutches/brakes, brake bands and one-way clutches.

- Multiplate Clutch — holds two rotating planetary components

- Brake — holds planetary components to the housing
  - multiplate brake
  - brake band
- Roller or Sprag One-Way Clutch — holds planetary components in one rotational direction

The multiplate clutch and multiplate brake are the most common of the three types of holding devices; they are versatile and can be modified easily by removing or including more friction discs. The brake band takes very little space in the cavity of the transmission housing and has a large surface area to create strong holding force. One-way clutches are small in size and release and apply quickly, giving good response for upshifts and downshifts.
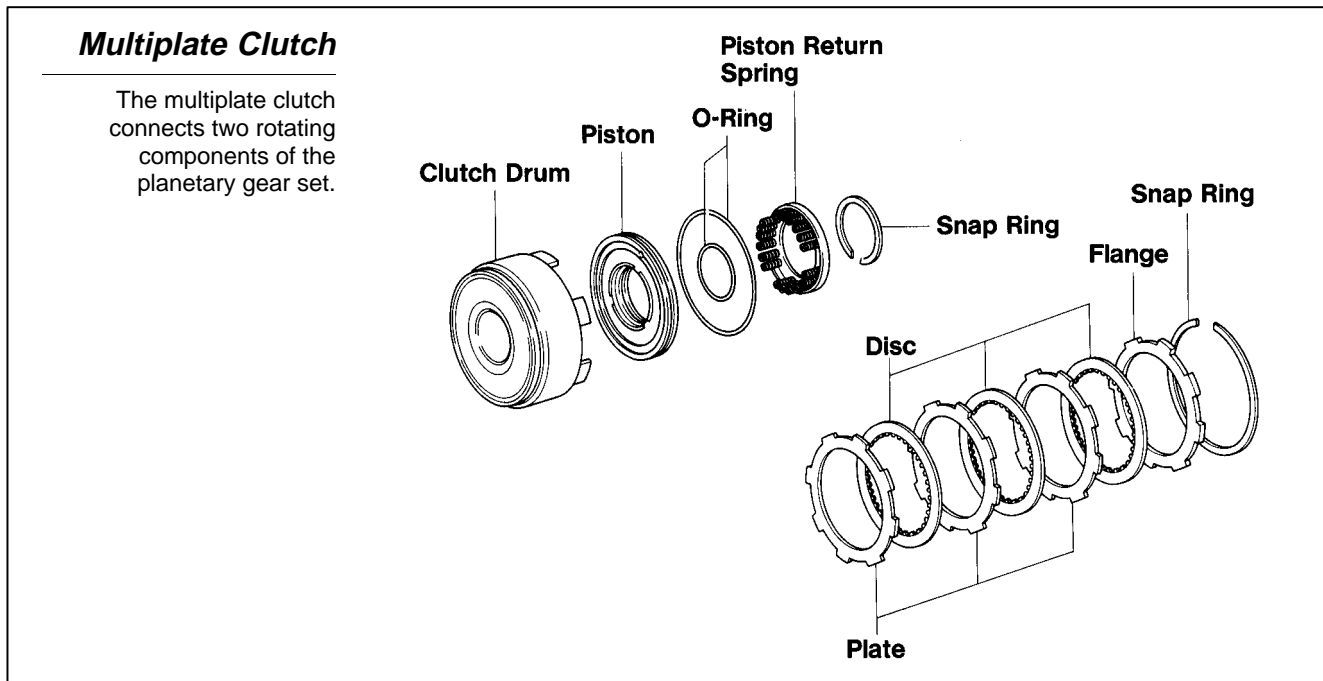
Multiplate Clutch

The multiplate clutch connects two rotating components of the planetary gear set.

Labels: Piston Return Spring, O-Ring, Piston, Clutch Drum, Snap Ring, Snap Ring, Flange, Disc, Plate

Multiplate Clutch

The multiplate clutch connects two rotating components of the planetary gear set. The Simpson planetary gear unit uses two multiplate clutches, the forward clutch (C1) and the direct and reverse clutch (C2). Each is made up of a clutch drum which is splined to accept the input shaft and turning torque from the engine. The drum also provides the bore for the clutch piston. Because this assembly rotates while the vehicle is in motion, it presents a unique challenge to ensure fluid under pressure reaches the clutch and holds the clutch engaged for thousands of miles of service.

The piston houses a seal on its inner diameter and on its outer diameter which seals the fluid which actuates the piston. A relief ball valve is housed in the piston body of the multiplate clutch. This valve has an important function in releasing hydraulic fluid pressure. When the clutch is released, some fluid still remains behind the piston. As the drum rotates, centrifugal force will force the fluid to the outside of the drum, which will try to apply the clutch. This pressure may not fully engage the clutch; however, it may reduce the clearance between the discs and metal plates, promoting heat and wear. The relief ball valve is designed to release the fluid after pressure is released. Centrifugal force causes the ball to move away from the valve seat, and fluid escapes.

Since the multiplate brake does not rotate, this phenomenon does not occur. The return springs force the fluid out of the cylinder, and the brake is released.
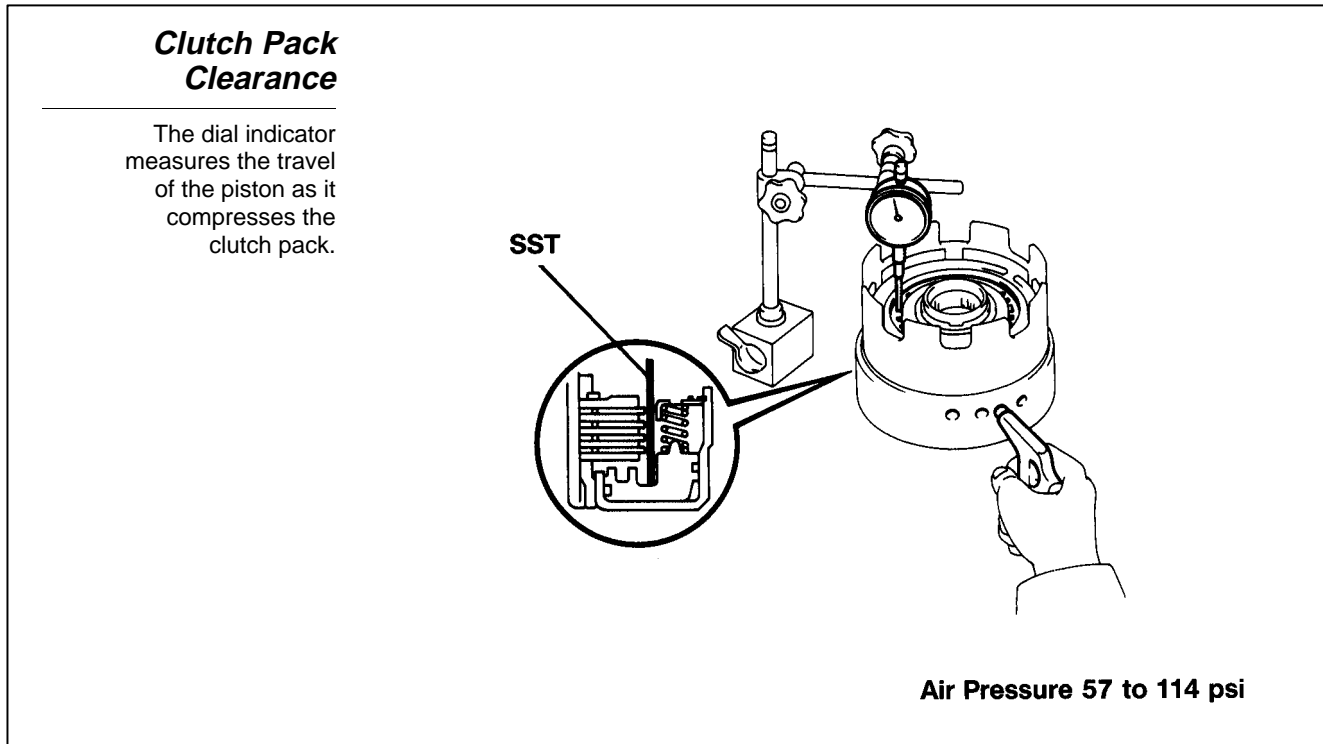
Multiplate Clutch Operation

Hydraulic pressure applies the clutch, and the return springs release it.
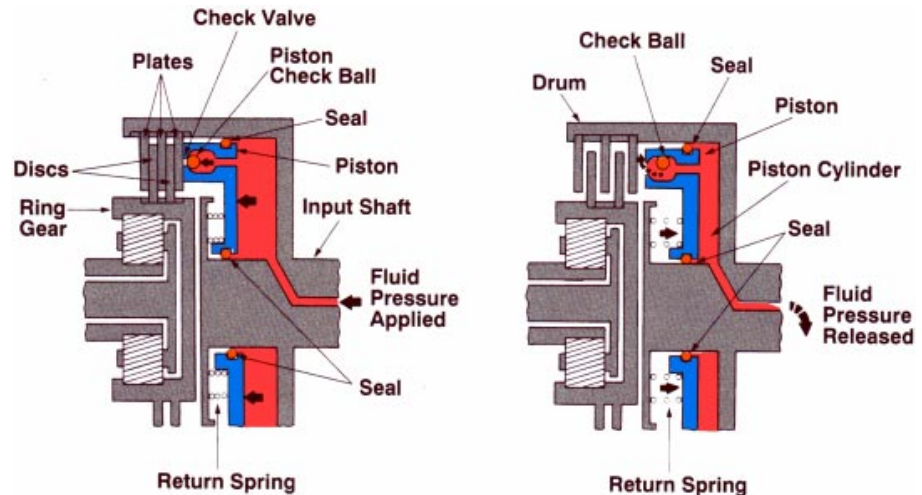
Hydraulic pressure actuates the piston and return springs return the piston to the rest position in the clutch drum when pressure is released. Friction discs are steel plates to which friction material is bonded. They are always located between two steel plates. The friction disc inner diameter is slotted to fit over the splines of the clutch hub.

Adjustments and Clearances   Clearance for the clutch pack can be checked using a feeler gauge or dial indicator as shown in the illustration below. Apply air pressure in the range of 57 to 114 psi to ensure that the clutch is fully compressed. Proper clearance ensures that disc and steel plates do not wear prematurely and ensures proper shift timing. To obtain the desired clearance, steel flange plates are available in varying thicknesses.

Clutch Pack Clearance

The dial indicator measures the travel of the piston as it compresses the clutch pack.

SST

Air Pressure 57 to 114 psi

Assembly Inspection   Verify the proper assembly of holding devices by air testing each multiplate clutch unit prior to its placement in the transmission case. It takes less time to correct a problem while the part is on the bench than when the transmission is assembled. When the holding device is installed, other factors such as sealing rings on the shafts and placement of thrust washers and bearings may contribute to leakage. Knowing that the holding device air checked OK will help to narrow the diagnosis. Follow your repair manual for specifics regarding air test points. Air pressure should not be greater than 50 psi while testing holding devices for leakage.

Diagnosis
Multiplate Clutch
Assemblies

Proper diagnosis is the key to inspection so that you know where to look for the cause of the problem. Based on the customer complaint and your test drive, determining the holding devices deserves particular attention during your visual inspection before disassembly.

Visually inspect piston seals and piston surfaces to verify a fault or damage. The seals should be replaced when the transmission is overhauled. Visually check steel plates and clutch discs for heat discoloration, distortion, and surface scoring or scuffing. Check the plates and discs for free movement on the hub or drum splines. This free movement will ensure that the steel plates and discs do not have contact, which causes heat and premature wear.

Make sure that the ball valve in the piston moves freely by shaking it to hear it rattle. Some carburetor cleaner may be used to dissolve any varnish build-up that may cause the valve to stick.

Sealing rings on the various shafts should also be checked for deformation or breakage, especially if the fault has been determined to be in this particular holding device and no fault has been found. Particular care for these sealing rings during reassembly is critical as well.

Brakes

There are two types of brakes: the band type and the wet multiplate type. The band type is used for the second coast brake (B1) on some transmission models. The multiplate type is used on the overdrive brake (B0), second coast brake on some models and the second brake (B2).

Brake Band

The brake band is located around the outer circumference of the direct clutch drum. One end of this brake band is located to the transmission case with a pin, while the other end contacts the brake piston which is operated by hydraulic pressure.

Band Type Brake

The brake band locks a planetary gear component to the case of the transmission.

Outer Spring
Piston Rod
Inner Spring
Piston
Cover
Direct Clutch Drum
Second Coast
Brake Band
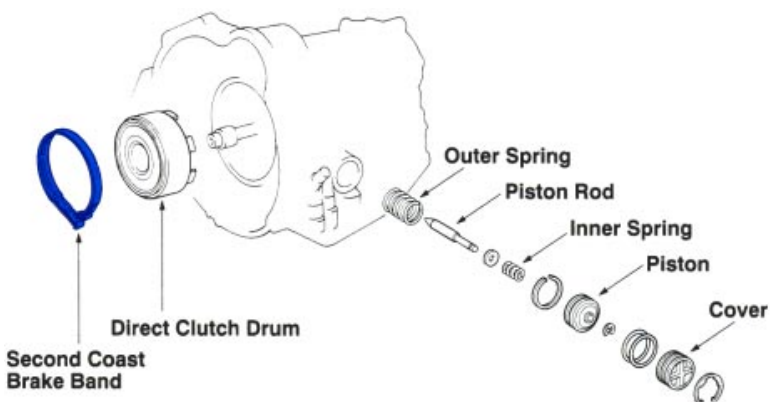
Band Operation
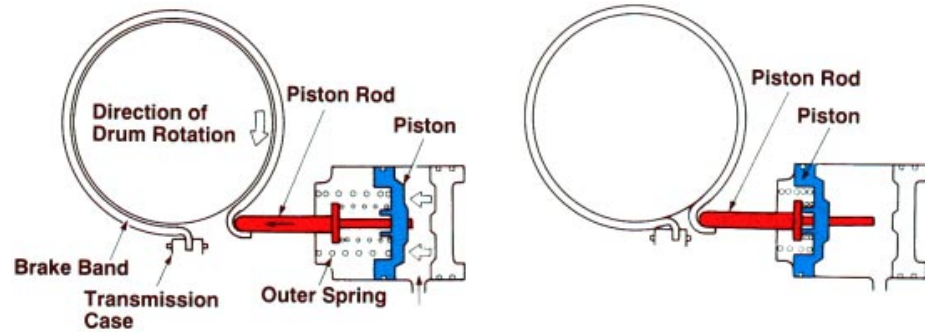
When hydraulic pressure is applied to the piston, the piston moves to the left in the piston cylinder, compressing the outer spring. The inner spring transfers motion to the piston rod, moving it to the left with the piston, and pushes one end of the brake band. This reduces the harsh engagement of the band. As the inner spring compresses, the piston comes in direct contact with the piston rod shoulder and a high frictional force is generated between the brake band and drum. As the other end of the brake band is fixed to the transmission case, the diameter of the brake band decreases. The brake band clamps down on the drum, holding it immovable, which causes the drum and a member of the planetary gear set to be held to the transmission case.

When the pressurized fluid is drained from the cylinder, the piston and piston rod are pushed back by the force of the outer spring so the drum is released by the brake band.

Brake Band
Assembly Inspection

The piston oil sealing rings should be visually inspected for damage. Also inspect the cylinder bore for any damage which may destroy the new sealing ring. Inspect the 0 rings on the cover to ensure against leaks. Visually inspect the brake band clutch material for damage. If the clutch material is discolored or parts of the printed numbers are no longer visible, replace the brake band. Visually inspect the direct clutch drum for any damage to the band mating surface.

Adjustment
and Clearance

Adjustment for the brake band is accomplished by piston rods of two different lengths. Rods are available to enable the clearance between the brake band and drum to be adjusted. By placing a mark on the piston rod and then applying air to the B1 port, measure between the mark and the cylinder housing to determine the clearance. Air pressure should be in the range of 57 to 114 psi in order to achieve full application and travel. This specification should not be confused with the 30 psi specification for air testing holding devices.

Brake Band Adjustment

Adjustment is accomplished by a piston rod of two different lengths.

Air Pressure 57 to 114 psi
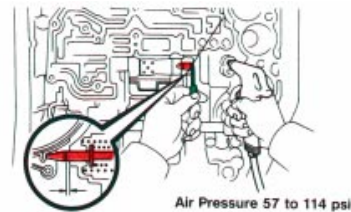
Multiplate Brake The multiplate brake serves the same function as the brake band and is constructed in a similar manner to the multiplate clutch. It locks or holds a rotating component of the planetary gear set to the case of the transmission.

Hydraulic pressure actuates the piston and return springs return the piston to the rest position in the clutch drum when pressure is released. Friction discs are steel plates to which friction material is bonded. They are always located between two steel plates. The friction disc inner diameter is slotted to fit over the splines of the clutch hub, similar to the multiplate clutch; however, the steel plates spline to the transmission case, thus providing an anchor.

Multiplate Brake

Holds a rotating component of the planetary gear set to the case of the transmission.
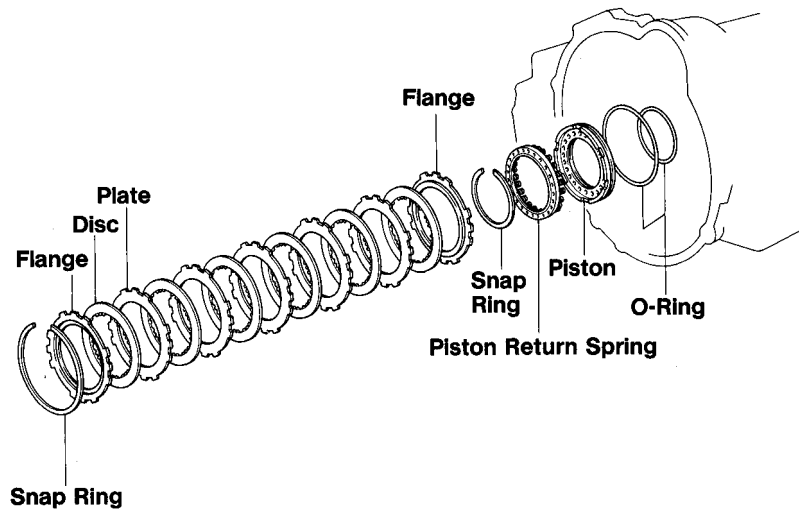
Multiplate Brake Inspection The inspection is very similar to multiplate clutches except there is no ball valve in the piston and sealing rings on the shafts. The apply circuits are found in the case of the transmission. Visually inspect piston seals and piston surfaces to verify a fault or damage. The seals should be replaced when the transmission is overhauled. Visually check steel plates and clutch discs for heat discoloration, distortion, and surface scoring or scuffing. Check the plates and discs for free movement on the hub or drum splines. This free movement will ensure that the steel plates and discs do not have contact, which causes heat and premature wear.

One-Way Clutch A one-way clutch is a holding device which requires no seals or hydraulic pressure to apply. They are either a roller clutch or sprag clutch. Although the sprag clutch is most often used in Toyota automatics, we'll mention both. Their operation is similar in that they both rely on wedging metal between two races. Two one-way clutches are used in the Simpson Planetary Gear Set. The one-way clutch No. 1 is used in second gear and the one-way clutch No. 2 is used in first gear.

A one-way sprag clutch consists of a hub as an inner race and a drum, or outer race. The two races are separated by a number of sprags which look like a figure "8" when looking at them from the side view. In the illustration below, the side view of the sprag shows four lobes. The two lobes identified by L1 are shorter than the distance between the two races. The opposite lobes are longer than the distance between the races. As a result, when the center race turns clockwise, it causes the sprag to tilt and the short distance allows the race to turn.
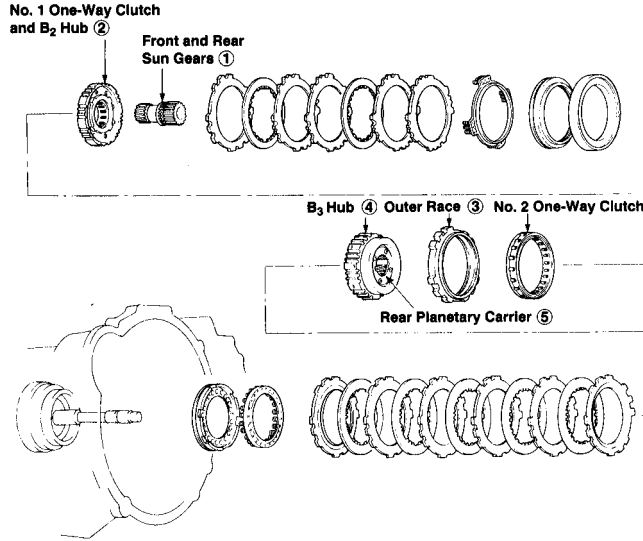

One-Way Clutch
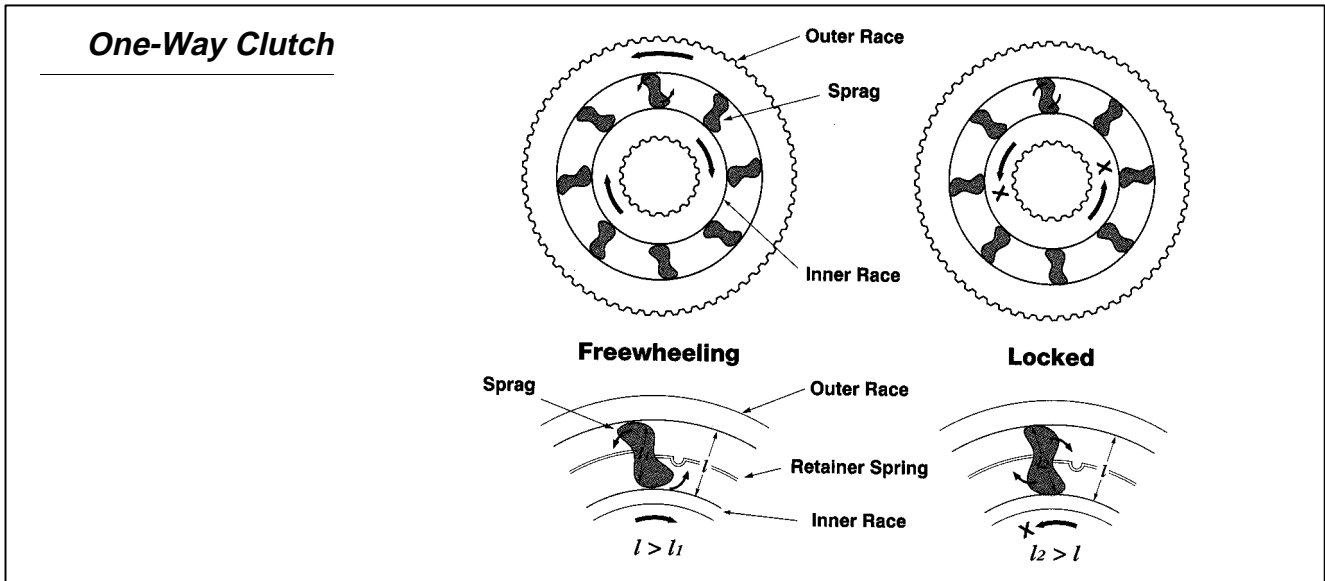
When the center race turns counterclockwise, it tries to move the sprag so that the long distance is wedged against the outer race. This causes the center race to stop turning. To assist the sprags in their wedging action, a retainer spring is installed, which keeps the sprags slightly tilted at all times in the direction which will lock the turning race.

A one-way roller clutch consists of a hub, rollers and springs surrounded by a cam-cut drum. The cam-cut is smaller on one end than the other. The spring pushes the roller toward the narrow cut. When the race rotates clockwise, the rollers compress the spring and the race is allowed to turn. If the race is rotated in a counterclockwise direction, it forces the roller into the narrow end of the cam cut and locks the race.

No. 1 and No. 2 One-Way Clutch

F1 operates with the second brake (B2) to hold the sun gear from turning counter-clockwise. F2 prevents the rear planetary carrier from turning counterclockwise.

No. 1 One-Way Clutch and B₂ Hub ②

Front and Rear Sun Gears ①

B₃ Hub ④ Outer Race ③ No. 2 One-Way Clutch

Rear Planetary Carrier ⑤

One-way clutch No. 1 (F1) operates with the second brake (B2) prevent the sun gear from turning counterclockwise. The one-way clutch No. 2 (F2) prevents the rear planetary carrier from turning counterclockwise.

One-Way Clutch Assembly Inspection

Visually check for signs of slippage, overheating, or galled races. Lubrication holes to the races should be clear of debris to ensure adequate lubrication. Check the clutch to ensure that it rotates in one direction and is locked in the opposite direction. A clutch which locks by hand may slip under the torque produced by the engine. So it is imperative to properly diagnose prior to disassembly to ensure that it is repaired properly the first time. Your diagnosis will also require a familiarity with the holding devices to know where to inspect for a fault.

CAUTION One-way clutches can be installed backwards, so be careful; follow the repair manual instructions!

Check Installation of One-Way Clutches
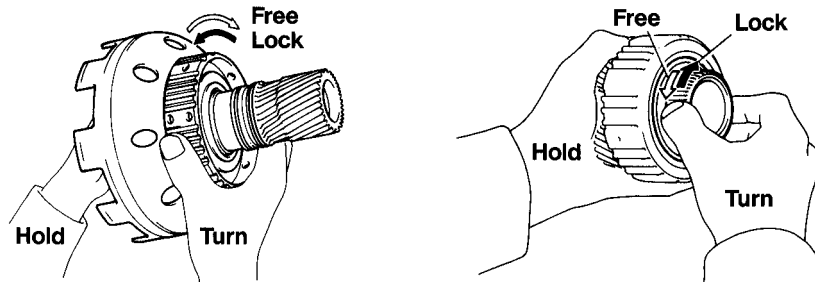
Free
Lock

Free
Lock

Hold

Hold
Turn

Hold
Turn

Notes

WORKSHEET 2
Planetary Gear Set Operation

On each of the planetary gear set diagrams, draw arrows to show the direction of rotation for each of the components under the conditions listed in the tables. Also write in the table whether an increase or reduction is taking place.
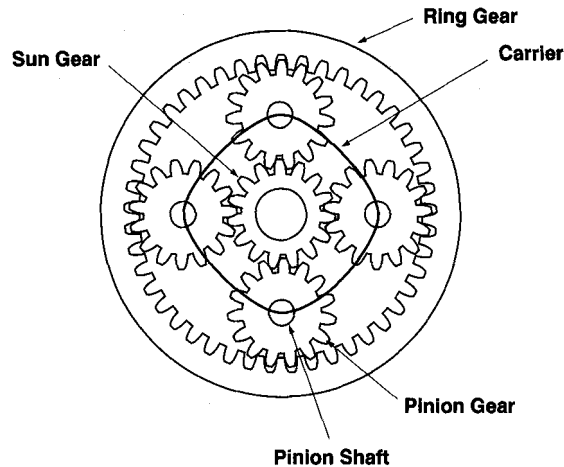
1.

| Fixed Member | Drive Member | Driven Member | Rotational | | Direction |
			Speed	Torque	
Sun Gear	Ring Gear	**Carrier**			

2.
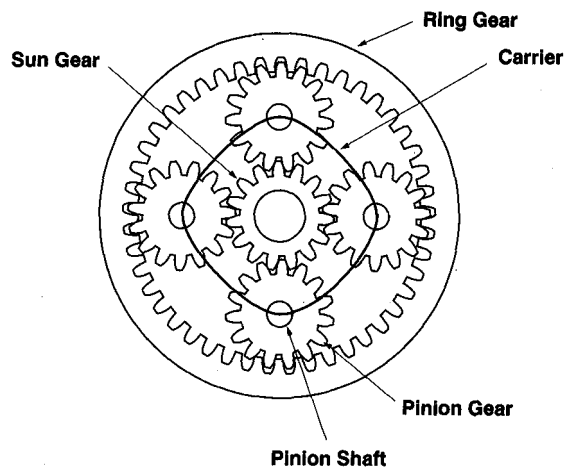
| Fixed Member | Drive Member | Driven Member | Rotational | | Direction |
			Speed	Torque	
Sun Gear	Carrier	**Ring Gear**			

WORKSHEET 2
Planetary Gear Set Operation (Continued)

1.

Fixed Member	Drive Member	Driven Member	Rotational		Direction
			Speed	**Torque**	
Ring Gear	Sun Gear	**Carrier**			

2.
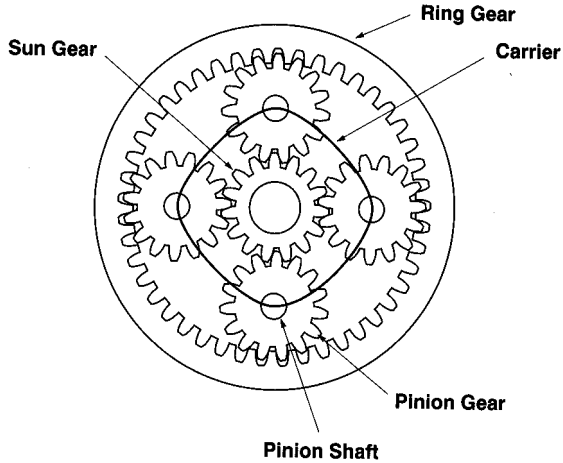
Fixed Member	Drive Member	Driven Member	Rotational		Direction
			Speed	**Torque**	
Ring Gear	Carrier	**Sun Gear**			
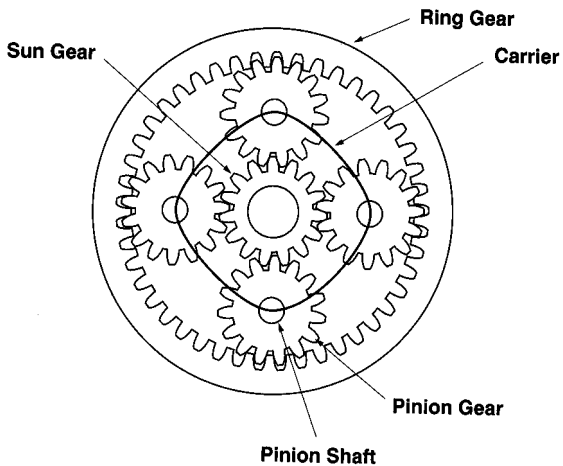
WORKSHEET 2
Planetary Gear Set Operation (Continued)

1.

Fixed Member	Drive Member	Driven Member	Rotational		Direction
			Speed	**Torque**	
Carrier	Ring Gear	**Sun Gear**			

2.
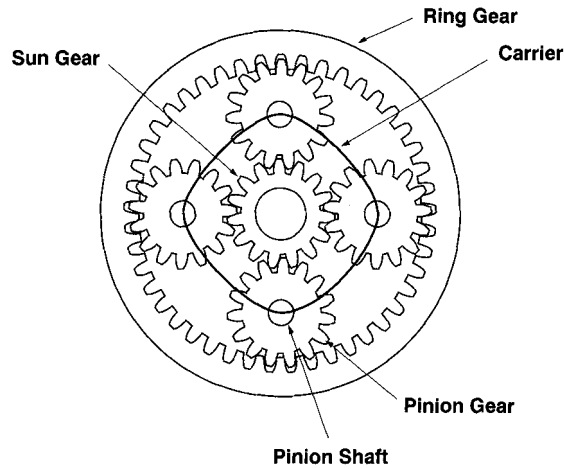
Fixed Member	Drive Member	Driven Member	Rotational		Direction
			Speed	**Torque**	
Carrier	Sun Gear	**Ring Gear**			

Notes