18

Prerequisite: Chapter 17

AUTOMATIC TRANSMISSIONS

OBJECTIVES

After reading this chapter, you should be able to:

- Identify the components of a simple planetary gearset.
- Explain the operating principles of a planetary geartrain.
- Define a compound planetary gearset and explain how its outputs are managed.
- Describe a multiple-disc hydraulic clutch and explain its role in the operation of an automatic transmission.
- Outline torque path powerflow through typical four- and five-speed automatic transmissions.
- Describe the hydraulic circuits and flows used to control automatic transmission operation.
- List the two types of hydraulic retarders used in Allison automatic transmissions and explain their differences.

KEY TERMS

annulus	epicyclic gearset	output retarder	priority valve
carrier	input retarder	planetary gearset	ring gear
clutch pack	multiple-disc clutch	planetary pinion gears	sun gear

INTRODUCTION

This chapter introduces hydromechanical automatic transmissions. The focus is primarily on transmissions manufactured by Allison. Allison has dominated the North American market for automatic transmissions in on-highway trucks for several decades. Allison's competitors for the on-highway, hydromechanical automatic transmission market are ZF and Voith. Many of the principles outlined for Allison transmissions in this chapter also apply to the products of other manufacturers of automatic transmissions.

Hydromechanical automatic transmissions are becoming a thing of the past due to the emergence of electronically controlled transmissions. However, they continue to be a factor in service repair facilities because of the type of vehicle application they are spec'd in. Buses and certain kinds of vocational vehicles such as garbage haulers commonly use automatic transmissions, and these types of vehicles have much greater longevity than linehaul fleet trucks. The result is that repair facilities will continue to see hydromechanical automatic transmissions for a few years yet.

DEFINITIONS

Because of the widespread use of *automated manual transmissions* (AMTs) (see Chapter 20) it is important that the following definitions be understood:

- Hydromechanical automatic transmission: a fully automatic transmission that uses no control electronics. Engine torque is transmitted to it by a torque converter and output ratios are optioned using planetary gearsets. Upshifts and downshifts take place with no direct assistance from the driver. This type of transmission is studied in this chapter.

- Electronic automatic transmission: fully automatic transmission that is controlled by computer. Engine torque is transmitted to it by a torque converter and output ratios are optioned using planetary gearsets. Upshifts and downshifts are managed electronically with no direct assistance from the driver. This type of transmission is studied in Chapter 21.
- Automated standard transmission: standard transmission that is electronically controlled. Engine torque is transmitted to it using a mechanical clutch. This type of transmission is studied in Chapter 20.

Most of the operating principles of the hydromechanical transmissions described in this chapter relate closely to those used in their more recent electronically controlled counterparts. The first generation of Allison electronically controlled automatics was known as Consolidated Electronic Controls (CEC), which essentially adapted the transmissions described in this chapter to some basic electronic management. In addition, most of the basic principles of more recent electronically controlled transmissions up until the most recent Allison TC-10 closely relate to those described here.

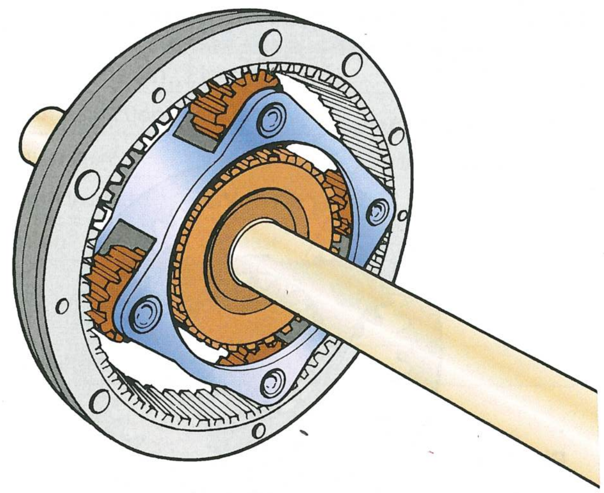
HOW AN AUTOMATIC TRANSMISSION WORKS

Fully automatic transmissions rely on planetary gearsets to transfer power and manage torque from the engine to the driveline. Planetary gearsets differ from the cluster gear arrangements used in standard manual shift transmissions. In hydromechanical automatic transmissions, the shifting of planetary gears is actuated by the use of hydraulic force. A complex system of valves is used to control and direct pressurized fluid in the closed system. The force generated by this fluid is used to apply and release the various clutches and brakes that control planetary gear operation. Factors such as road speed, throttle position, and governed engine speed are used to control and trigger shifts.

Planetary Gearsets

The **planetary gearset** is an old invention. Its first use was actually in early manually shifted transmissions. Although it was replaced by the cluster gear arrangements we looked at in Chapters 15 and 16, transmission designers did not forget the many advantages that planetary gearsets offered. **Figure 18–1** shows a simple planetary gearset. Automatic transmissions tend to use two or more planetary gearsets that work with each other to option a range of output ratios.

FIGURE 18–1 Typical simple planetary gearset



Simpson Geartrain

A Ford Motor Company engineer named Howard W. Simpson spent his retirement exploring the use of planetary gearing in automatic transmissions. Between 1948 and 1955, Simpson was granted close to two dozen patents relating to planetary gearsets. Simpson geartrains remain the standard in heavy-duty truck transmissions and in many passenger car automatic transmissions.

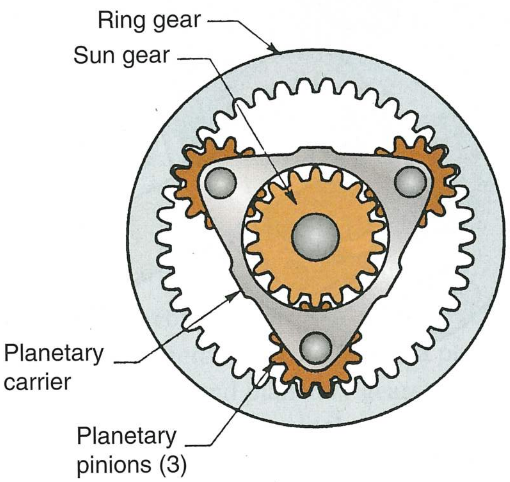
A Simpson geartrain combines a pair of simple planetary gearsets in tandem. This arrangement allows the torque load to be spread over a greater number of gear teeth for strength and also provides a large number of output gear ratios. We begin this chapter by looking at a simple planetary gearset and then we take a look at what happens when we add a second—that is, when we compound the geartrain. Planetary gearsets are the basic building blocks of both hydraulic automatic and electronic automatic transmissions.

You should note that this chapter is a prerequisite to understanding electronic automatic transmissions. Hydromechanical and electronic automatic transmissions share many common principles of operation. Planetary gearsets are also the foundation for the transmissions used in parallel hybrid drivetrain systems. These permit infinitely progressive input torque from two sources.

18.1 PLANETARY GEARSET COMPONENTS

A simple planetary or **epicyclic gearset** can provide overdrive, reverse, forward reduction, neutral, and direct drive ratios. It can also supply fast and slow

FIGURE 18–2 Planetary gear configuration is similar to the solar system, with the sun gear surrounded by the planetary pinion gears. The ring gear surrounds the complete gearset.



speeds for each operating range, with the exception of neutral and direct drive. There are three main components in a simple planetary gearset:

- **Sun gear** with external gear teeth
- **Carrier** with **planetary pinion gears** mounted to it
- An internally toothed **ring gear** or **annulus**

The sun gear is located in the center of the assembly (**Figure 18–2**). It is the smallest gear in the assembly and it is located at the center of the axis. The sun gear can be either a spur or helical gear design. It meshes with the teeth of the planetary pinion gears. Planetary pinion gears are small gears fitted into a framework called the planetary carrier; each turns on its own axis. The planetary carrier can be made of cast iron, aluminum, or steel plate and is designed with a shaft for each of the planetary pinion gears. For simplicity, we use the term *planetary pinions* in place of *planetary pinion gears.* Each planetary pinion is in constant mesh with both the sun gear and the ring gear of the assembly.

Planetary pinions rotate on needle bearings positioned between the planetary carrier shaft and the planetary pinions. The number of planetary pinions in a carrier depends on the load the gearset is required to carry. Passenger vehicle automatic transmissions might use only three planetary pinions, whereas heavy-duty automatics could use as many as five planetary pinions in a planetary carrier. The carrier and its pinions are considered as a single unit.

The planetary pinions rotate in mesh with the sun gear and are enclosed by the ring gear. The ring gear surrounds the components that make up a simple planetary gearset. In some ways, the ring gear acts like a band to hold the entire gearset together. The planetary pinions mechanically connect the sun gear with the ring gear. This means that when the planetary carrier is held stationary, the ring, the planetary pinions continue to rotate on their axes; however, input rotation is reversed by whichever of the other two members acts as output.

To help remember the design of a simple planetary gearset, use the solar system as an example. The sun is the center of the solar system with the planets rotating around it, hence the name *planetary gearset.* When considering the relative *gear* sizes of the three members that make up a simple planetary gearset, to determine ratios, the following is true:

- Sun gear: small gear
- Ring gear: midsize gear
- Planetary carrier assembly: large gear

ADVANTAGES OF PLANETARY GEARSETS

When compared with other gearsets, some notable advantages of a simple planetary gearset include:

- Constantly meshed gears. With the gears constantly in mesh there is little chance of damage to the teeth. Grinding or missed shifts are not a wear or damage factor.
- Gear forces are divided equally. Planetary gearsets are also very compact.
- Versatility. Seven combinations of speed and direction can be obtained from a single set of planetary gears.
- Additional variations of both speed and direction can be added through the use of compound planetary gears.

HOW PLANETARY GEARS WORK

Each member of a planetary gearset—the sun gear, planetary gear carrier, and ring gear—can revolve or be held at rest. Power transmission through a planetary gearset is possible only when one of the three component members is held stationary, or if two of the members are locked together with each other to act as drive members. In this case, the input-to-output ratio would be 1:1.

Any one of the three members—sun gear, pinion gear carrier, or ring gear—can be used as the driving or input member. At the same time, another member might be kept from rotating and thus becomes the held or stationary member. The third member then becomes the driven or output member. Depending on which member is the driver, which is held, and which is driven, either a torque increase or a speed increase is produced by the planetary gearset. Output

TABLE 18–1 Laws of Simple Planetary Gear Operation

Sun Gear	Carrier	Ring Gear	Speed	Torque	Direction
1. Input	Output	Held	Maximum reduction	Increase	Same as input
2. Held	Output	Input	Minimum reduction	Increase	Same as input
3. Output	Input	Held	Maximum increase	Reduction	Same as input
4. Held	Input	Output	Minimum increase	Reduction	Same as input
5. Input	Held	Output	Reduction	Increase	Reverse of input
6. Output	Held	Input	Increase	Reduction	Reverse of input
7. When any two members are driven, direct 1:1 output results.					
8. When no member is held or locked together, output cannot occur. The result is a neutral condition.					

direction can also be reversed through various combinations. You can take a look at the ratio and directional capabilities of a single planetary gearset by studying **Table 18–1**.

Table 18–1 summarizes the input and output rules of a simple planetary gearset. It shows relative output speed, torque, and direction of the various combinations available. It is also helpful to remember the following two points with regard to direction of rotation:

1. When an external-to-external gear tooth set is in mesh, there will be a change in the direction of rotation at the output (**Figure 18–3A**).
2. When an external gear tooth is in mesh with an internal gear, the output rotation for both gears will be the same (**Figure 18–3B**).

Maximum Forward Reduction

With the ring gear stationary and the sun gear turning clockwise, the external sun gear teeth rotate the planetary pinions counterclockwise. This option is shown as combination 1 in Table 18–1 and in **Figure 18–4**. The inside diameter of each planetary pinion pushes against its shaft, moving the planetary carrier clockwise. The small sun gear (driving) has to rotate several times to turn the larger planetary carrier through one complete revolution, resulting in an underdrive. This combination represents the most gear reduction or the maximum torque multiplication that can be achieved in one planetary gearset. Input speed is high, but output speed will be low.

Minimum Forward Reduction

In this combination, the sun gear is stationary and the ring gear rotates clockwise. This option is shown as combination 2 in Table 18–1 and in **Figure 18–5**. The ring gear drives the planetary pinions clockwise and walks around the stationary sun gear. The planetary

FIGURE 18–3 (A) With external teeth in mesh, there is a change in direction at the output; (B) when an external gear is meshed with an internal gear, both turn in the same direction.

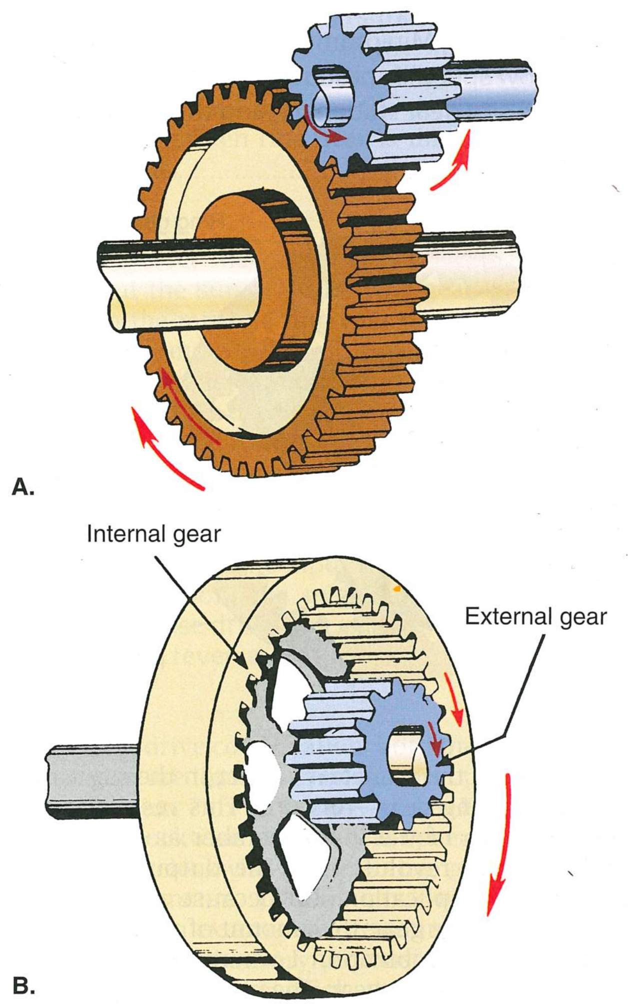


FIGURE 18–4 Maximum forward reduction (greatest torque, lowest speed) is produced with the sun gear as input, the ring gear stationary, and the carrier as the output.

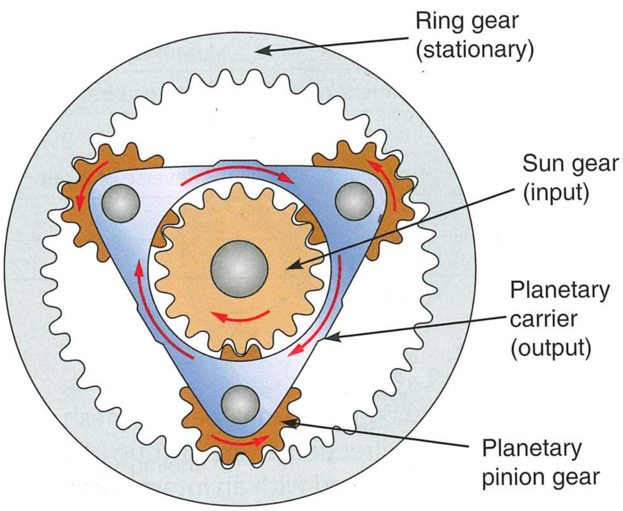
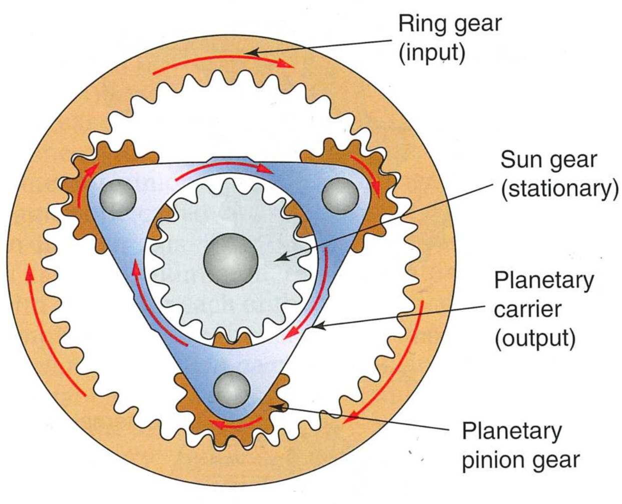
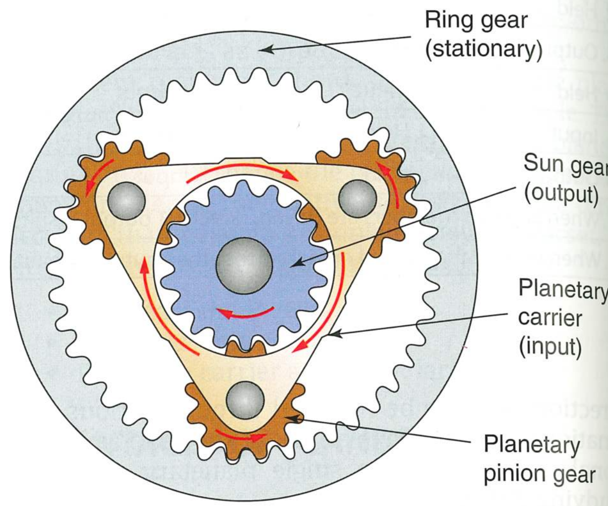


FIGURE 18–5 Minimum forward reduction (good torque, low speed) is produced with the ring gear as input, the sun gear stationary, and the carrier as the output.



pinions drive the planetary carrier in the same direction as the ring gear—forward. This results in more than one turn of the input member as compared to one complete revolution of the output. The result is torque multiplication. But because a midsize gear is driving a large gear, the amount of reduction is not as great as in combination 1 where the smallest gear is driving the largest gear. The planetary gearset operates in a forward reduction mode with the midsize ring gear driving the larger planetary carrier. Therefore, the combination produces minimum forward reduction.

FIGURE 18–6 Maximum overdrive (lowest torque, greatest speed) is produced with the carrier as input, the ring gear stationary, and the sun gear as output.



Maximum Overdrive

In this combination, the ring gear is stationary and the planetary carrier rotates clockwise. This option is shown as combination 3 in Table 18–1 and in **Figure 18–6**. The three planetary pinion shafts push against the inside diameter of the planetary pinions. The pinions are forced to walk around the inside of the ring gear, driving the sun gear clockwise. The carrier is rotating less than one turn input compared to one turn output, resulting in an overdrive condition. In this combination, the planetary carrier the large gear in the assembly is rotating less than one turn and driving the small sun gear at a speed greater than the input speed. The result is a fast overdrive with maximum speed increase.

Slow Overdrive

In this combination, the sun gear is stationary and the carrier rotates clockwise. This option is shown as combination 4 in Table 18–1 and in **Figure 18–7**. As the carrier rotates, the pinion shafts push against the inside diameter of the pinions and they are forced to walk around the held sun gear. This drives the ring gear faster and the speed increases. The planetary carrier turning less than one turn causes the pinions to drive the (midsize) ring gear one complete revolution in the same direction as the planetary carrier. As in combination 3, an overdrive condition exists, but the large-size carrier is now driving the midsize ring gear so a slow overdrive results.

FIGURE 18–19 Four-speed reverse gear torque powerflow

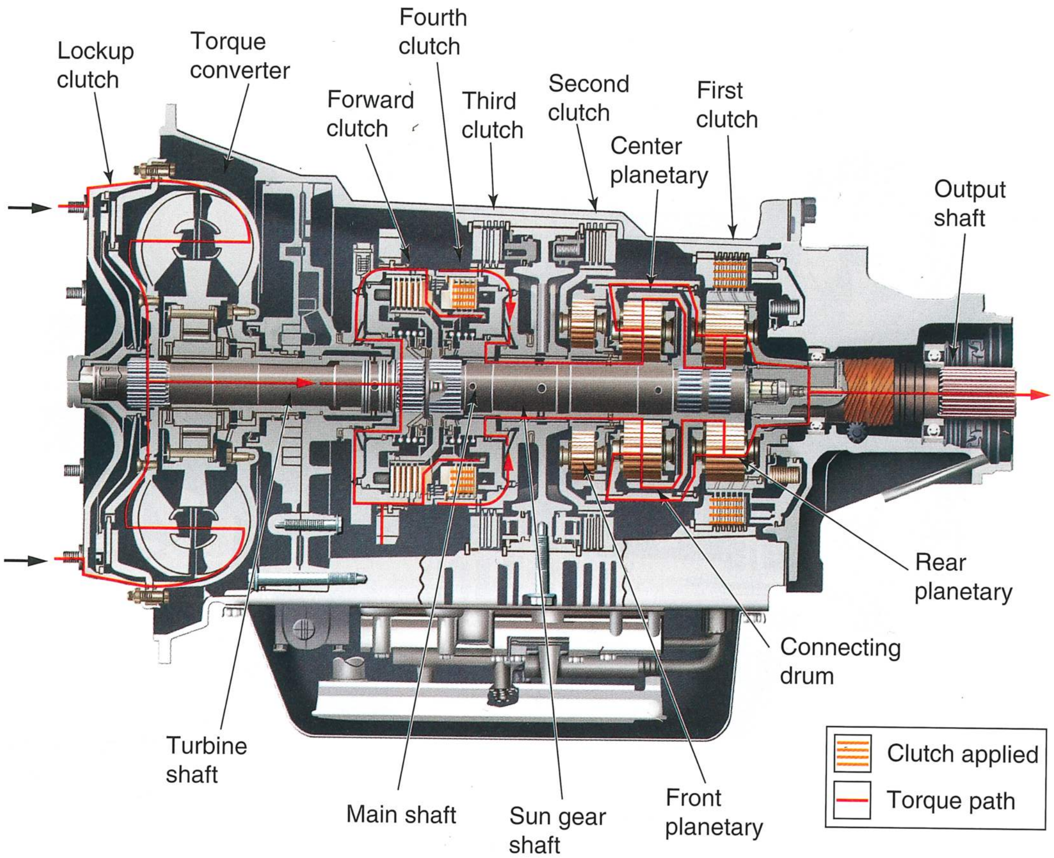


TABLE 18–4 Summary of Four-Speed Clutch Application

Gear Ratio	1st Clutch	2nd Clutch	3rd Clutch	4th Clutch	Forward Clutch
1st gear	ON				ON
2nd gear		ON			ON
3rd gear			ON		ON
4th gear				ON	ON
Reverse	ON			ON	

In deep ratio (DR) models, only first-gear powerflow is through the low planetary gearset. On close ratio (CR) models, the output shaft is splined to the low planetary carrier, so power must flow through the low gearset in all forward gears. We take a look first at DR then at CR powerflows.

DR Neutral

Figure 18–20 shows a DR transmission. Note the position of the low clutch and low planetary gearset at the rear of the transmission. All other components shown in Figure 18–20 through Figure 18–25 are identical to the four-speed transmissions. The neutral torque path is indicated in Figure 18–20. It is identical to the neutral torque path of four-speed transmissions discussed earlier. The forward clutch is not engaged. The first clutch is engaged, but power transfer is not possible. As before, the PTO gear can be engaged and operated with accelerator action.

DR Low (First) Gear

In low or first gear, both the forward and low clutches are applied (**Figure 18–21**). The forward clutch locks the turbine shaft and main shaft together so that they

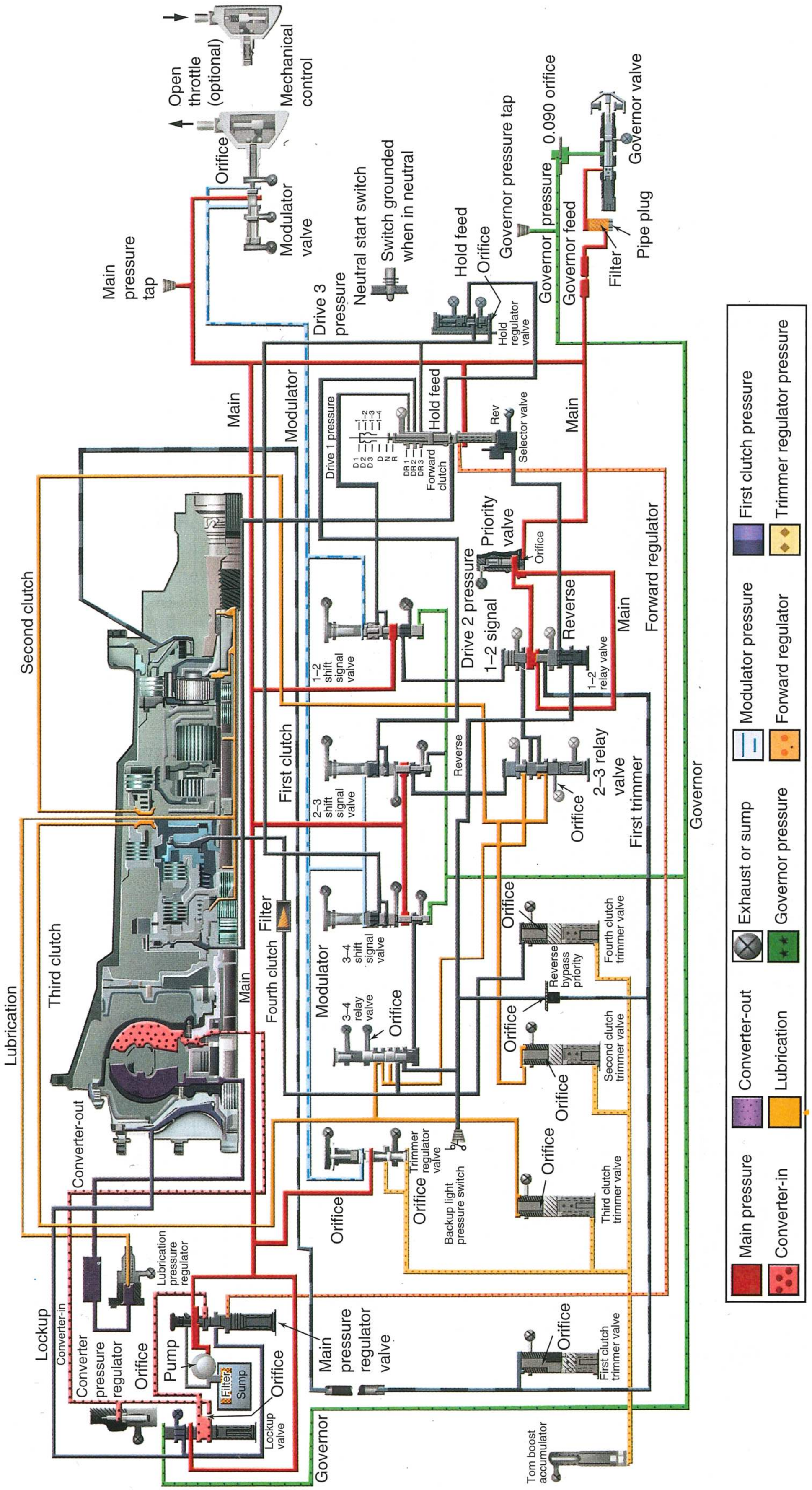


FIGURE 18–25 Hydraulic control circuit of four-speed transmission

consists of three main components: a sun gear, a carrier with planetary pinions mounted to it, and an internally toothed ring gear or annulus.

- Advantages of the planetary gearset are as follows:
  - Constantly meshed gears
  - Gear torque loads are divided equally
  - Compact and versatile
  - Additional ratio and direction variations added by compounding
- In a planetary gearset, any one of the three main members—sun gear, pinion gear carrier, or ring gear—can be used as the driving or input member.
- Depending on which member of the planetary gearset is the driver, which is held, and which is driven, torque or speed increases are produced.
- To produce an output, one of the planetary gear members must be held stationary. In heavy-duty truck transmissions this is achieved with multiple-disc clutches, which can serve as both braking and power transfer devices.
- Compound planetary combinations are several planetary gearsets coupled to produce the required gear ratios and direction. Four-speed, heavy-duty transmissions use three simple planetary gearsets—front, center, and rear. Five-speed transmissions add an additional low planetary gearset for a total of four gearsets.
- In all automatic transmissions, power flows from the torque converter through the transmission planetary gearing and out to the output shaft.
- Transmission oil is drawn from the sump through a filter by the input-driven oil pump.
- Oil pressurized by the pump flows into the bore of the main pressure regulator valve.
- The converter/cooler/lubrication circuit originates at the main pressure regulator valve.
- The selector valve/forward regulator circuit is manually shifted to select the operating range desired.
- Main pressure is directed to the governor valve. The speed of the transmission output shaft controls the position of the governor valve, which determines the amount of pressure in the governor circuit.
- The modulator actuator varies modulator pressure as the accelerator pedal moves.
- Lockup clutch engagement and release are controlled by the modulated lockup valve and the lockup relay valve.
- There are five separate clutches in four-speed transmissions and six clutches in five-speed models, each clutch having its own circuit.
- Hydraulic retarders are one of several types of auxiliary braking systems used on heavy-duty trucks; they are applied by the driver as needed.

REVIEW QUESTIONS

1. Which of the following can be considered the largest *gear* in a simple planetary gearset?
   a. the sun gear
   b. the ring gear
   c. the carrier assembly
   d. the pinions
2. What results when any two members of a simple planetary gearset are locked together to act as the input?
   a. reverse output
   b. direct 1:1 drive
   c. overdrive
   d. underdrive
3. When the planetary carrier of a simple planetary gearset is the held member:
   a. there is a reverse in rotation direction at the output member
   b. direct 1:1 drive occurs
   c. an overdrive condition results
   d. an underdrive condition results
4. What results if a large external tooth gear is meshed with and driving a smaller external tooth gear?
   a. Output speed increases; output direction is the same as input.
   b. Output speed decreases; output direction is the reverse of input.
   c. Output speed increases; output direction is the reverse of input.
   d. Output speed decreases; output direction is the same as input.
5. What is the function of multiple-disc clutches in a truck hydromechanical automatic transmission?
   a. to hold components stationary
   b. to lock components together to transfer torque
   c. to open and close hydraulic valves
   d. both a and b
6. In a close ratio transmission, all powerflows must pass through the ________ before reaching the output shaft.
   a. front planetary gearset
   b. rear planetary gearset
   c. low planetary gearset
   d. center sun gear shaft
7. What assists governor pressure in moving any shift signal shafts during an upshift?
   a. the priority valve
   b. the modulator valve
   c. the trimmer valve
   d. the inhibitor valve

8. What component helps avoid shift shock by reducing pressure to the clutch apply circuits during initial application and then gradually increasing the pressure?
   a. the priority valve
   b. the modulator valve
   c. the trimmer valve
   d. the inhibitor valve
9. Which type of hydraulic retarder is located between the torque converter and the transmission gearing?
   a. an input retarder
   b. an output retarder
   c. a torque retarder
   d. none of the above
10. Which type of hydraulic retarder applies a friction clutch while the unit is charging with hydraulic fluid?
   a. an input retarder
   b. an output retarder
   c. a torque retarder
   d. all of the above
11. Which of the following does the most to determine the position of the governor valve?
   a. input shaft speed
   b. output speed
   c. main pressure
   d. accelerator position
12. Which of the following does most to determine modulator pressure?
   a. engine speed
   b. torque converter turbine speed
   c. range shift position
   d. accelerator pedal position
13. Which of the following devices has an operating principle similar to that of a hydraulic retarder?
   a. a torque converter
   b. a planetary gearset
   c. a hydraulic clutch
   d. an S-cam brake
14. How many planetary gearsets are used in an Allison five-speed automatic transmission?
   a. two
   b. three
   c. four
   d. five
15. What regulates main pressure in an Allison automatic transmission?
   a. transmission input speed
   b. the main pressure regulator
   c. the trimmer valve
   d. the governor valve