# Chapter V. Reducers and Gearbox

## V. 1. Defenition

A gear reducer is a mechanical system of gears in an arrangement such that input speed can be lowered to a slower output speed but have the same or more output torque. The operation of a gear reducer involves a set of rotating gears that are connected to a shaft with a high incoming speed, which is sent to a set of rotating gears where the speed or torque is changed. How many gears are in a gear reducer assembly is dependent on the speed requirements of the application.

The use of a gear reducer occurs when the drive gear is smaller and has fewer teeth than the driven gear. This is unlike the condition where the drive gear is larger with more teeth than the driven gear, which is referred to as overdrive.
Gear reducers are an essential component in cars and trucks where the high rotational speed of the engine is converted such that the slower motion of the tires can interpret and use the power safely.

## V.2. function

Speed reducers primarily serve two functions. First, they take the torque created by the power source (the input) and multiply it. Second, speed reducers, much as the name implies, reduce the speed of the input so that the output is the correct speed.

A gear reducer is generally used for low-speed and high-torque transmission systems. The output gear of a speed reducer has more teeth than the input gear. So, while the output gear might rotate more slowly, reducing the speed of the input, the torque is increased. To sum up, the combination of large and small gears will reduce speed while increasing the torque.

The ratio of the number of rotations of a driver gear to the number of rotations of a driven gear is known as a gear ratio. By changing the torque/speed output, a machine (usually a motor or an engine) can be precisely controlled and better results attained. Torque output of a speed reducer can be calculated by multiplying the output torque of the motor and reduction ration (Note that the actual torque output of the speed reducer shall not exceed its rated torque). In decelerating the motor, gearboxes also reduce the reflected load inertia to the motor by a factor of the square of the gear ratio.

## V.3. Process

### V.3.1. Gear Ratio

The gear ratio is a way of measuring how different sizes of gears interact to transfer energy. The essential aspect of this calculation is the measurement of a circle, which is a major part of gears. The determination of the gear ratio can be understood by examining the circumference of a circle. A gear that makes two rotations to turn a larger gear once has a ratio of 2:1, which means that the output speed has been cut in half.

This example simplifies more complex gear reducers with several gear pairs in a series for converting revolutions per minute (RPMs) to torque. The example below presents a slightly more complex gear reducer with an idler gear between the small gear and the larger.

In determining the gear ratio, the only gears that influence the gear ratio are the drive gear and driven gear. Any gears inserted in between the two are not calculated in the gear ratio. An easy way to calculate the gear ratio is to count the number of teeth in the drive and driven gear. In the example, the drive gear has seven teeth while the driven gear has 30. The drive gear has to turn 4.3 times before the driven gear will turn. Figure V-1.

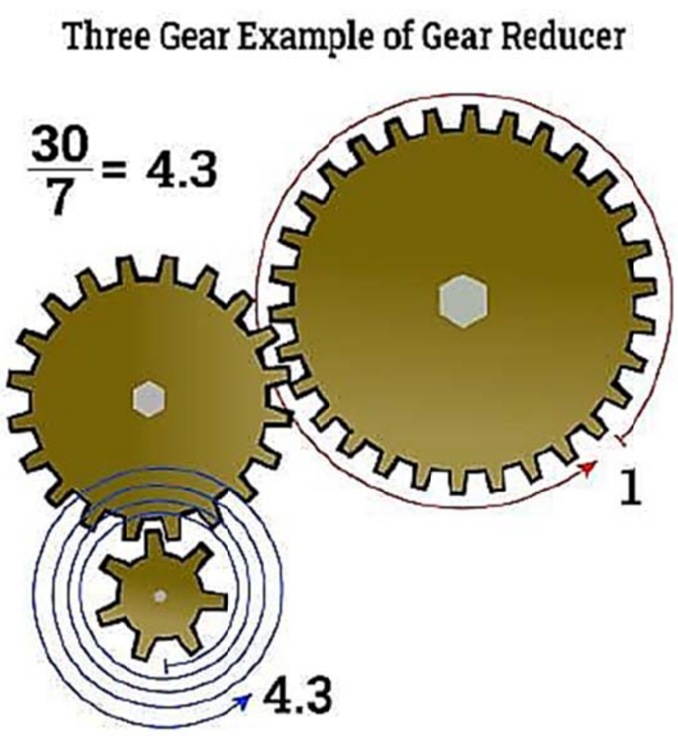



Fig. V–1 three gear example of gear reducer

#### V.3.2. Gear Reducer Torque

Torque is a rotational force that is received by the gear reducer and changed into a different force and speed with the amount of power remaining the same. Gear reducers are a gear or series of gears designed to reduce the torque of a motor, which increases in direct proportion to the reduction of rotations per unit of time or revolutions per minute. This is accomplished by base mounted or shaft mounted gear reducers. Gears are used to multiply or divide torque, which is determined by the size of the gears. The ratio of the gear sizes increases or decreases torque, which is the foundational aspect of the operation of a gear box.

#### V.3.3. Drive Gear

Drive gears or gear drives are designed to change the speed, torque, or direction of a rotating shaft. In their simplest form they are a small gear that drives a larger gear connected to the output shaft. They are essential for providing variable output speed from a constant power source.
In the image below, the silver worm shaft with a worm gear is the drive gear for this two gear gear reducer. The driven gear is the brass colored worm wheel of the worm gear set.

#### V.3.4. Driven Gear

The driven gear is connected to the output shaft and transfers the reduced power to the application. They are the larger of the gear set regardless of how many gears there are in the series and come in a variety of shapes. In the compound gear train example below, there are two driven gears connected to different shafts, B and C. The gear ratio for the driver gear for shaft B and the one for shaft C is the same. Figure V-2.

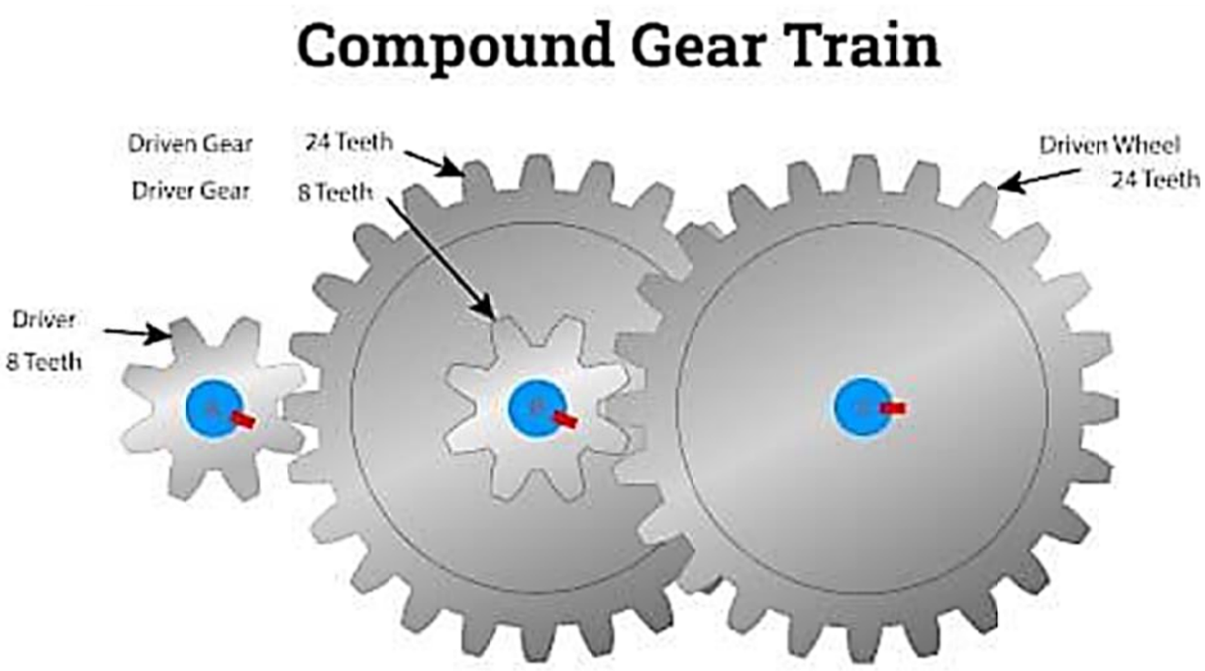



Fig. V–2 compuned gear train

### V.4. Gear Trains

Gear trains are multiple sets of gears meshing together to deliver power and motion more effectively than can be accomplished by one set of gears. Figure V-3 shows the various types of gears that can be used in a gear train. Gears 2 and 3 can be either spur or helical gears and are mounted on parallel shafts. Gears 4 and 5 are bevel gears that mount on shafts that are 90° apart. Gears 6 and 7 comprise a worm gear set and mount on shafts that are at 90° but are non-intersecting. Worm gears have a high ratio and can be non-reversing.

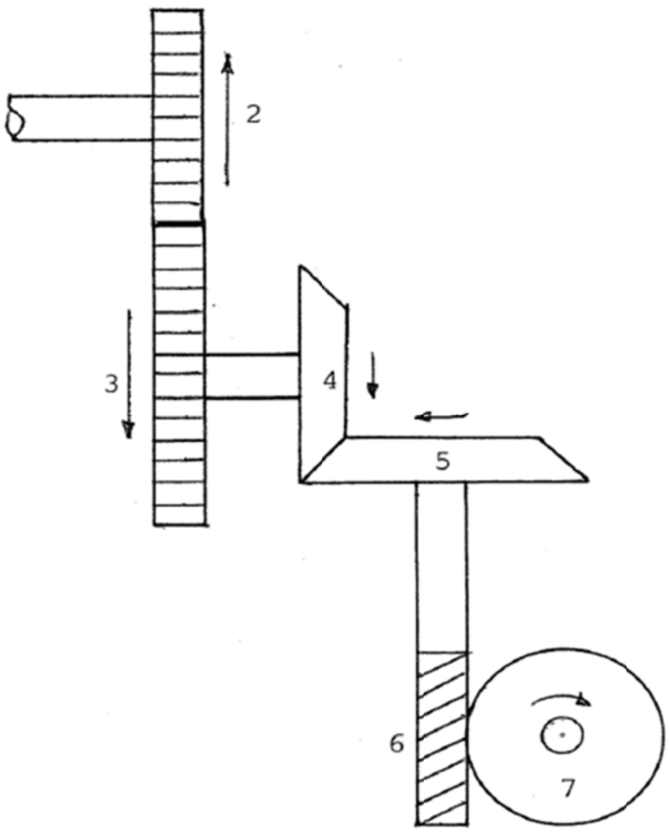



Fig. V–3 Various Gear Types in a Train

Figure V-4 depicts a simple gear train at the top and a compound gear train at the bottom. The simple gear train consists of four in-line gears in mesh. The compound gear train consists of the same four gears, except two are located on the same shaft. The overall ratio of the simple gear train is the product of the three individual ratios and is as follows:

$$(n_2/n_5) = (n_3/n_2)\ (n_4/n_3)\ (n_5/n_4)$$

n equals the rpm and N equals the number of teeth in the respective gears. When cancelling out like quantities, the equation can be reduced to the following:

$$n_2/n_5 = n_5/n_2$$

Suppose Gear 5 has 64 teeth and Gear 2 has 16 teeth, than the overall gear train ratio would be 4 to 1. If Gear 2 is considered the driving member, the simple gear train in Figure 2 is a speed reducing gear train. If the rpm of Gear 2 is 400, the rpm of Gear 5 is 100. Gears 3 and 4 are called idler gears since they have no effect on the overall gear train ratio.

The equation for the overall ratio of the compound gear train is the product of the two individual ratios and is as follows:

$$n_2/n_5 = (n_4/n_2)\ (n_5 / n_3)$$

Assuming that the same four gears are used and that Gear 3 has 32 teeth and Gear 4 has 48 teeth, the overall ratio for the compound gear train is:

$$n_2/n_5 = (48/16)(64/32) = 6$$

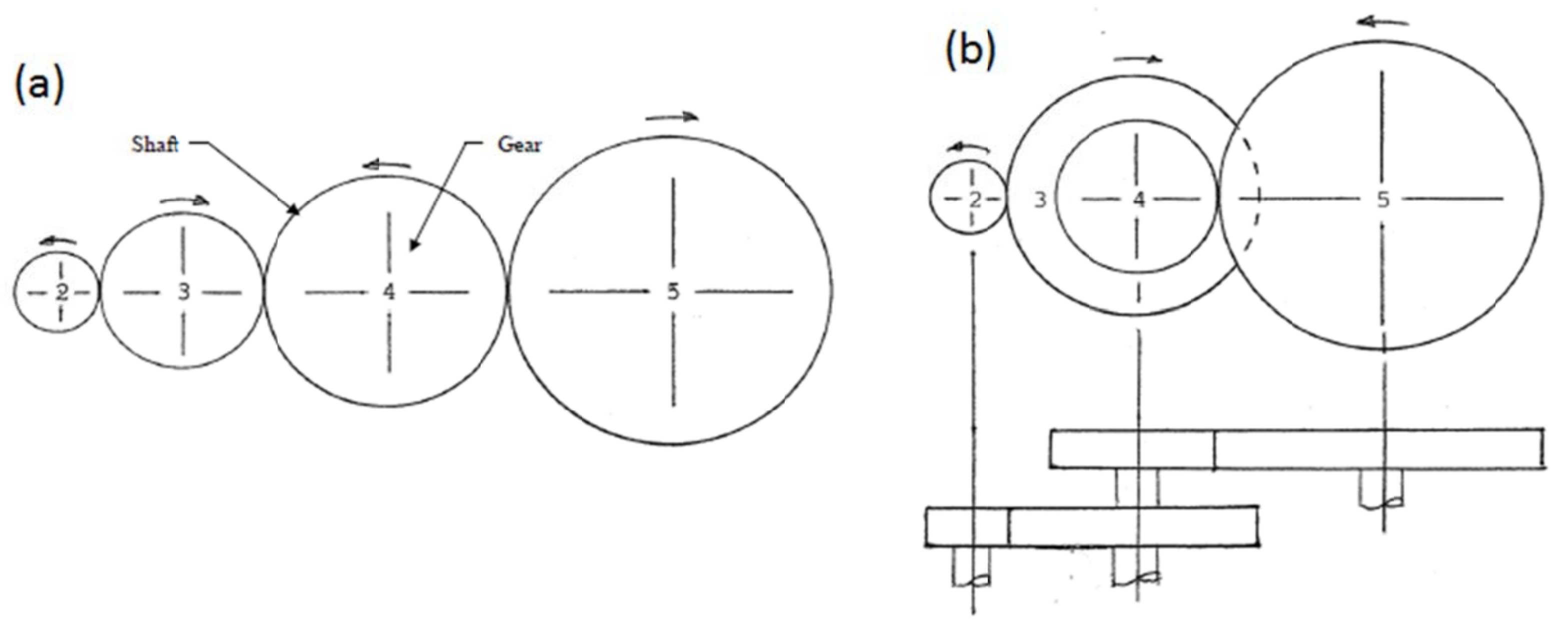



Fig. V–4 (a) Simple Gear Train (b) Compound Gear Train

The following can be said about using compound gear trains over simple gear trains:
1) More ratios can be obtained.
2) The design is more compact.
3) There is one less shaft.

Figure V-5 shows that very large Gears 6 and 7 are needed if a simple gear train is not used. The effect is even greater for a compound gear train.

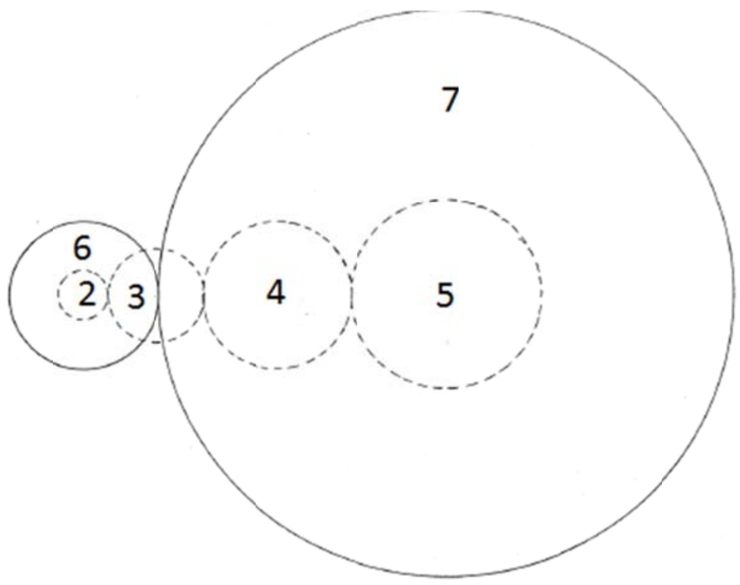



Fig. V–5 Gears 6and 7 needed if Gear is not used

### V.5. Planetary Gears

Planetary gears consist of a set of gears as shown in Figure V-6. The sun gear is surrounded by one or more planet gears which ride inside a ring gear. The planet gears are supported by a carrier. Planetary gears are useful in that they can deliver power over more than one path in a high ratio inline gear setting. One way to do this is to drive the sun gear, hold the ring gear from rotating, and take off from the carrier on the opposite side of the set. The following equation is commonly used to calculate the speed relationships with planetary gear sets:

$$n_c\,(1+N_s/N_r) - n_s\,(N_s/N_r) = n_r$$

- $n_c$ is the carrier rpm.
- $N_s$ is the number of teeth in the sun gear.
- $N_r$ is the number of teeth in the ring gear.
- $n_s$ is the sun rpm.
- $n_r$ is the ring gear rpm.

Let us assume that in Figure V-6the number of teeth in the sun gear equals 48, the number of teeth in the stationary ring gear is 112, and the input speed to the sun gear is 100 rpm. Using the above formula, we can now calculate the output rpm of the carrier as follows:

$$nc\,(1+48/112) - 100\,(48/112) = 0$$

$$n_c = 30$$

The planetary gear set of Figure V-6 can deliver over a 3/1 speed reduction when driving the sun and taking off from the carrier. It can be shown using this relationship, that there are other possibilities planetary gears has in delivering various speed ratios. Planetary gears are used in wind turbine gear boxes. These gearboxes speed up the low rpm rotor rotation to a higher speed generator rotation.

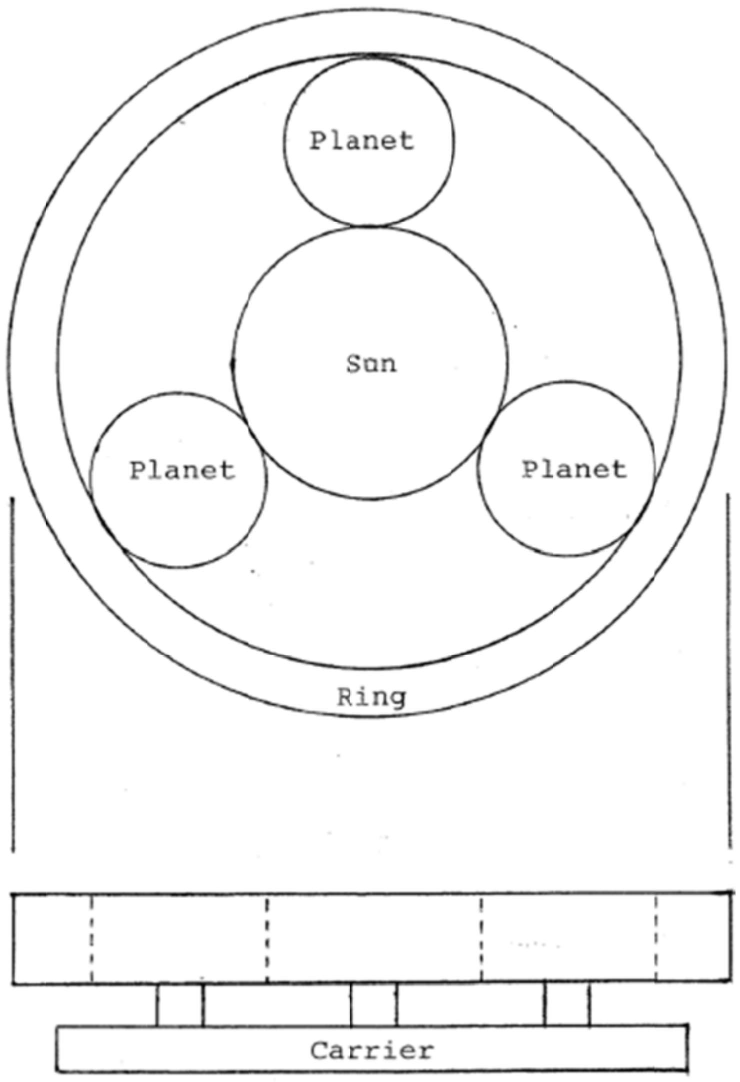



Fig. V–6 Planetary Gear Set

### V.6. Differential Gears

Figure V-7 shows the arrangement of the gears in the center section of an automotive drive axle. Power is transmitted from the pinion gear to the ring gear. From there it travels through the differential gears to the two output shafts. As long as the vehicle is traveling in a straight line, the four differential gears rotate as a unit and do not rotate with respect to each other. When a vehicle travels around a corner, the differential gears rotate at different speeds allowing the outer wheel to travel further than the inner wheel so the tires do not skid on the pavement surface. A disadvantage of the differential gear system is that when one wheel is on a slippery surface, all the power is sent to that wheel making it slip rendering the vehicle immobile. Some vehicles have slip clutch plates mounted behind the differential gears which allows the vehicle to propel itself using the one wheel that is still on a tractive surface. Figure V-8 shows the cross section of a complete automotive drive axle.

The following relationship holds true for the differential gears:

$$n_r = (N_{lo} + N_{ro})/2$$

- $n_r$ is the rpm of the ring gear.
- $N_{lo}$ is the rpm of the left output shaft.
- $N_{ro}$ is the rpm of the right output shaft.

Let us assume that the pinion gear has 30 teeth and that the ring gear has 90 teeth. With the left hand wheel of the vehicle raised up and free to rotate and the right hand wheel resting firmly on the pavement, what is the rpm of the left hand wheel when the pinion gear rotates at 1200 rpm? The rpm of the ring gear is as follows:

$$400 = (n_{lo} + 0)/2 = 800 \text{ RPM}$$

Using the above relationship, the rpm of the left hand wheel which is free to rotate is as follows:

$$1200 \times 30/90 = 400 \text{ rpm}$$

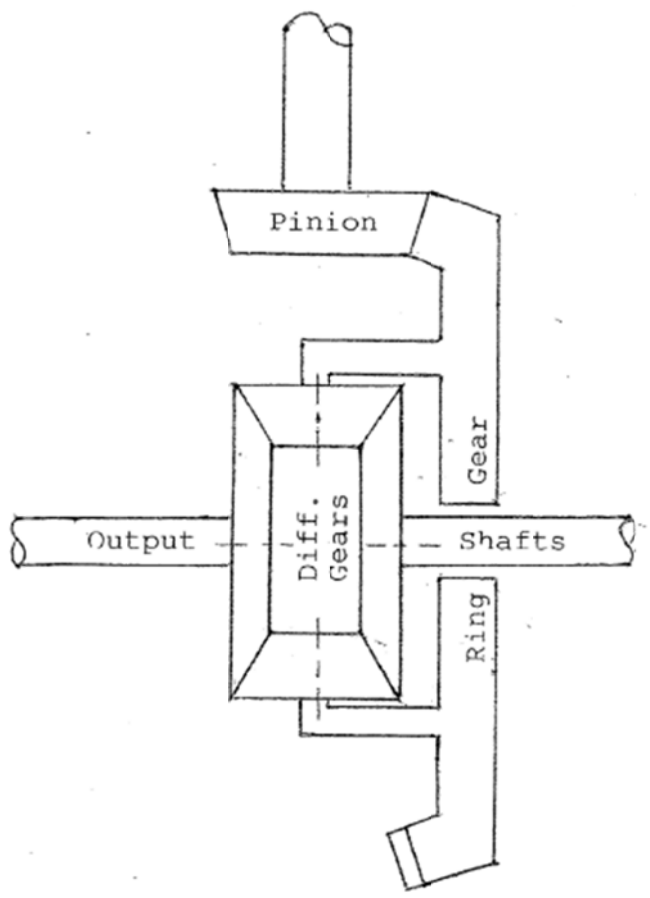



Fig. V–7 Differential Gear Arrangement

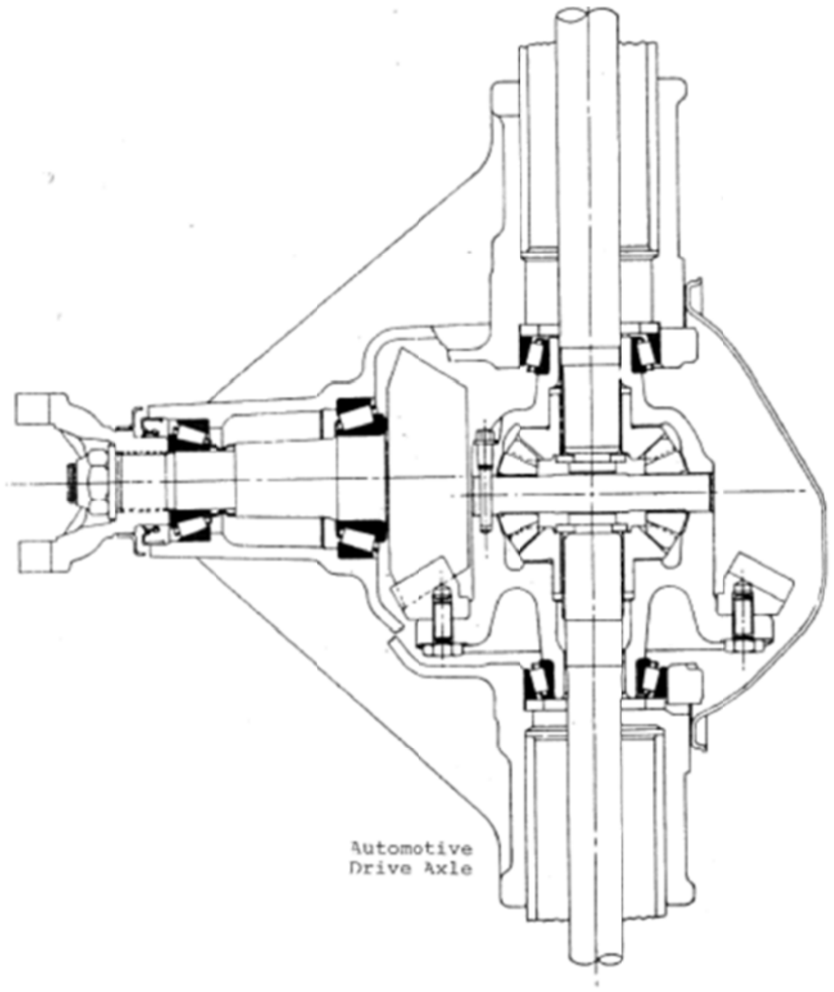



Fig. V–8 Automotive Drive Axle

### V.7. Gearboxes

Gearboxes contain one or more pair of gears inside a housing which has an input shaft and one or more output shafts. The output shafts may be located on the sides or at the back of the gearbox. Gearboxes contain a gear lubricant, are sealed, and usually operate maintenance free. Connected to the input shaft is a high speed power source such as a motor and connected to the output shafts are devices which generally use lower rpms and higher torques to perform a particular task. The device may include a machine tool, a conveyor, an elevator, or the wheels of an automobile.

Figure V-9 has a worm gearbox at the top and a bevel gearbox at the bottom. Worm gearboxes are generally high reduction devices with ratios ranging from 5/1 to 60/1 for single reduction units such as shown in Figure 7 to 3600/1 for double reduction units. Because of the high amount of sliding that occurs at the mesh, worm gears operate at efficiencies below that of other types of gears. To minimize this effect, the gear is usually made of a material with a low coefficient of friction such as bronze. Worm gears can be made to be non-reversing by keeping the lead angle of the worm thread low.

Figure V-9 has a bevel gearbox at the bottom. Bevel gearboxes have input and output axes 90° apart like worm gearboxes; however, bevel gearbox axes intersect as opposed to worm gearbox axes being offset. Bevel gearboxes generally have lower ratios than worm gearboxes and can be used as speed increasers as well as speed reducers. Bevel gearboxes having all steel gears can deliver more horsepower than worm gearboxes with bronze gears. Spiral bevel gears are stronger and quieter than straight bevel gears but are less efficient.

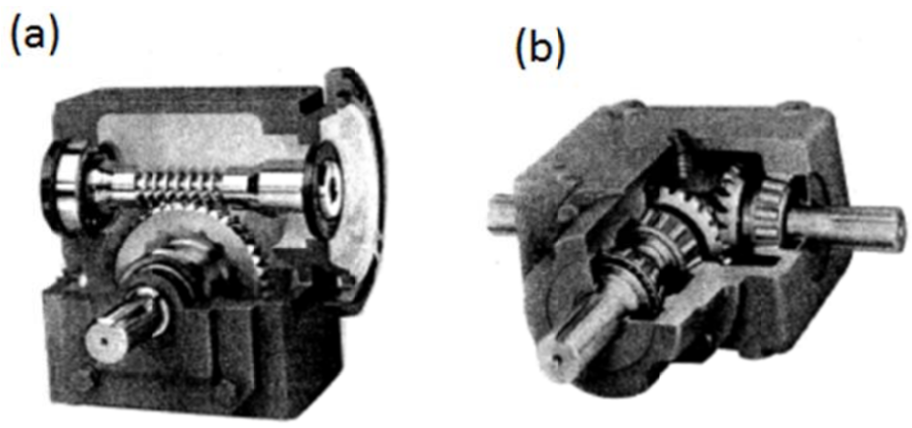



Fig. V–9 (a) Worm Gearbox (b) Bevel Gearbox

Figure V-10 has a double reduction gearbox on top and a gearbox-motor combination unit on bottom. The double reduction gearbox can give twice the ratio as a single reduction gearbox in a slightly larger package. It features helical gears for quieter, more powerful operation over spur gears. The motor-gearbox unit is an integral package that features a double reduction helical gearbox directly attached to a drive motor. Integral motor mounting features excellent alignment with the gearbox input shaft for smooth, vibration-free operation.

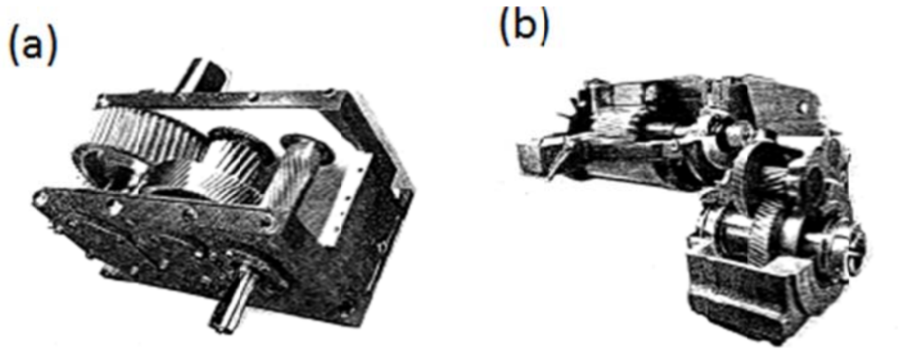



Fig. V–10 (a) Double reduction Gearbox (b) Gearbox with motor

### V.8. Multi-Speed Gearboxes

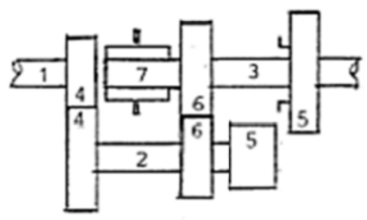
The manual transmission of an automobile is a multi-speed gear box. It incorporates varying the means of reduction through the gearbox in steps for controlling vehicle acceleration and deceleration. Figure V-11 has a schematic of a three-speed automatic synchromesh manual transmission. It is shown in the neutral or non-drive position. There are three shafts and three sets of gears. The shafts include the input shaft (1), the counter shaft (2), and the output shaft (3). The gears include the counter shaft drive gears (4) which are always engaged, the first gearset (5) where the upper gear is shown slid out of mesh, and the second gearset (6) in which the upper gear spins freely on the shaft. The synchromesh clutch (7) is used for second and third gear and is shown in the central or neutral position.

Figure V-12 shows the four shift positions of the manual transmission shown in Figure 9. The top schematic in Figure 10 has the transmission in the neutral position which is what is seen in Figure 9. In the neutral position, the input shaft (1) drives the counter shaft (2) which spins freely. The second schematic shows the transmission in first gear. Through a manually operated lever system, the upper first gear (5) is slid into mesh with the lower first gear allowing power to be delivered to the output shaft (3). The next schematic has the transmission in second gear. The upper first gear (5) is slid out of mesh and the synchronizer clutch (7) positively connects the upper second gear (6) to the output shaft (3) allowing power to be transmitted through the transmission.

Figure V-13 shows the operation of the synchronizer with the second gear. The upper figure shows the synchronizer rotating with the output shaft next to the upper second gear which is free to spin on the same output shaft. The next figure shows the synchronizer moved to the right until the conical surfaces of the synchronizer and the gear touch. This action causes the second gear and the output shaft to rotate as a unit. The third figure has the synchronizer moved all the way to the right until the teeth of the two members mesh. This mesh proves to be a smooth engagement since the two are rotating at essentially the same speed.

Automotive Manual Transmission Schematic

(Shown in Neutral Position)




No 1 is the input shaft (driven by engine).

No 2 is the counter shaft.

No 3 is the output shaft (powers vehicle).

No 4 are counter shaft drive gears (always engaged)

No 5 are first gears (upper slides on shaft).

No 6 are second gears (upper spins freely).

No 7 is the syncronizing clutch (neutral position).

Fig. V–11 Automotive Manual Transmission Schematic (Shown in neutral position)

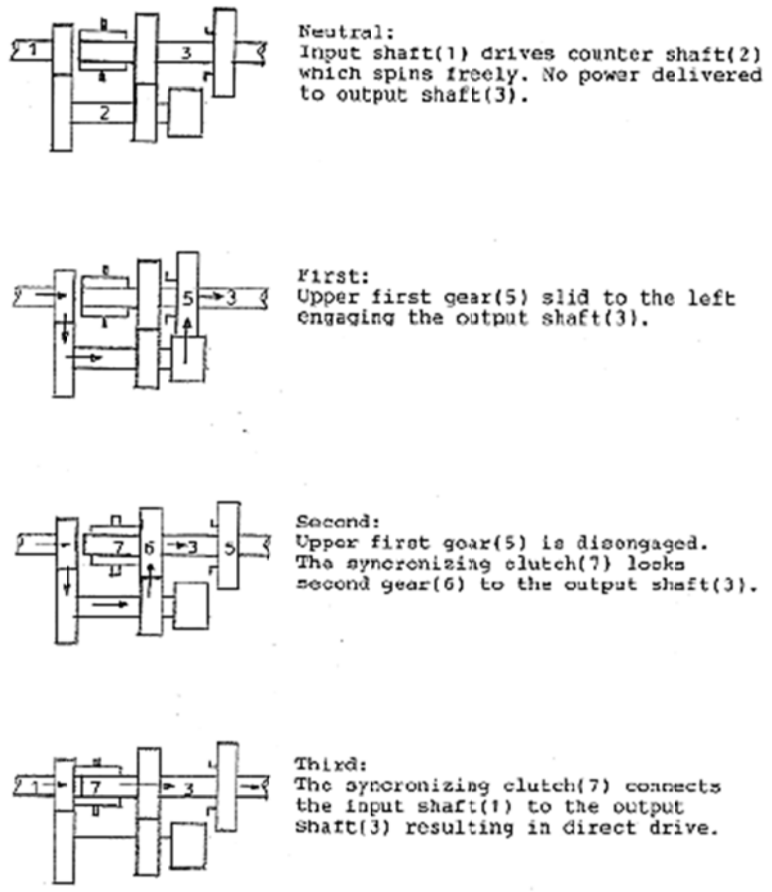



Fig. V–12 Automotive Manual Transmission Shift Positions

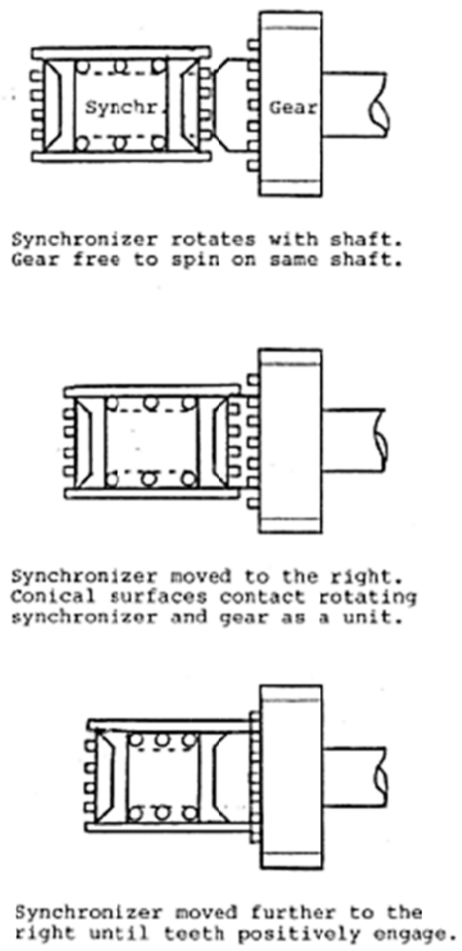



Fig. V–13 Synchronizer moved further to the right until teeth positively engage

The last schematic of Figure 10 shows the synchronizing clutch (7) positively connecting the input shaft (1) directly to the output shaft (3) resulting in direct drive through the transmission. The synchronizing clutch is moved to the left creating the same action that is described above.

Nominally the ratios for gears are 2.75 for first, 1.65 for second, 1.0 or direct drive for third, and 3.25 for reverse which incorporates another shaft not shown in the figures. There are manual transmissions with more than three speeds which incorporate additional gears and synchronizing clutches.