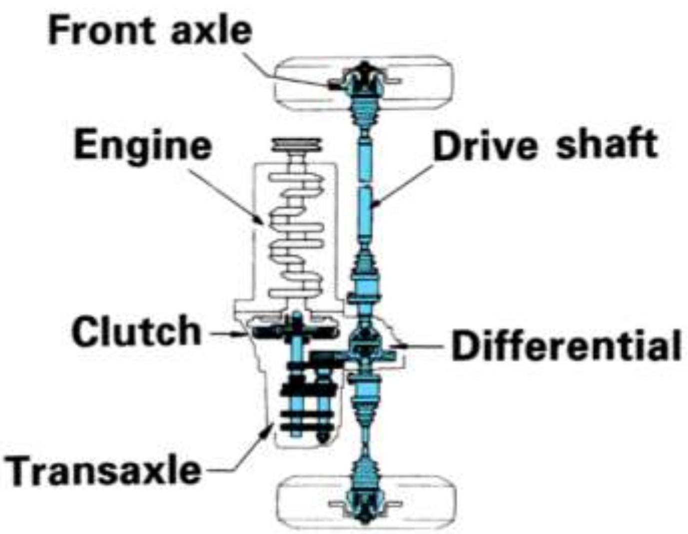
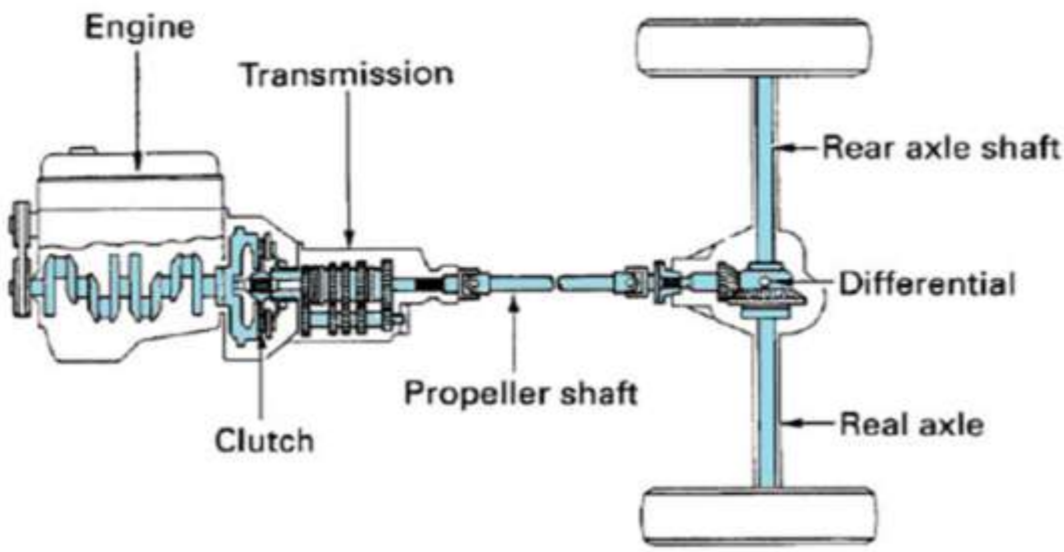
Contents

Transmission and drive train components transmit the power developed by the engine to drive the wheels of a vehicle. The most common arrangements are shown below.

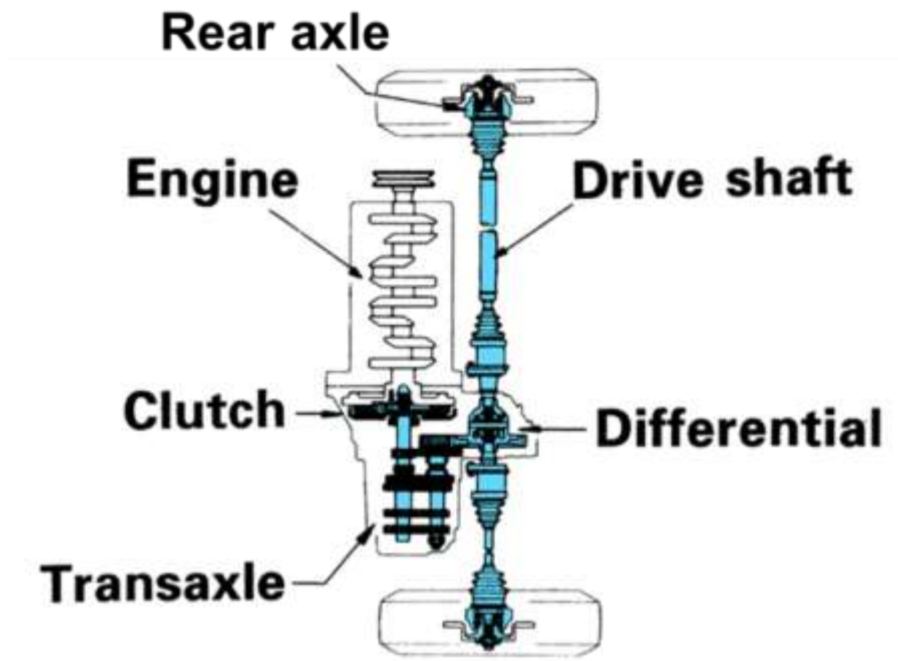
Front wheel drive (transverse engine)



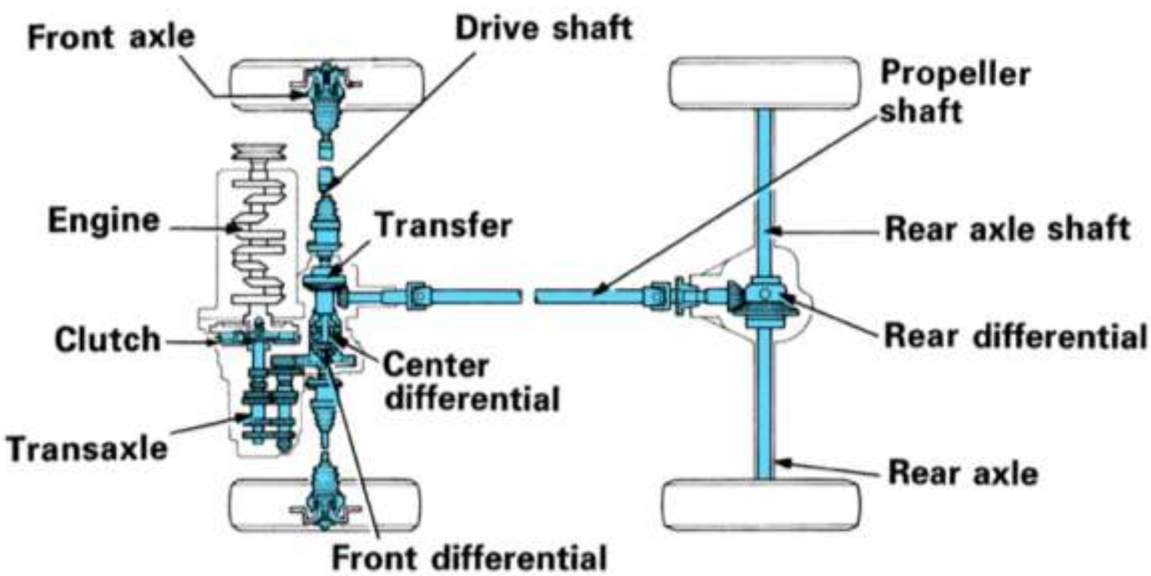
Rear wheel drive (inline engine)



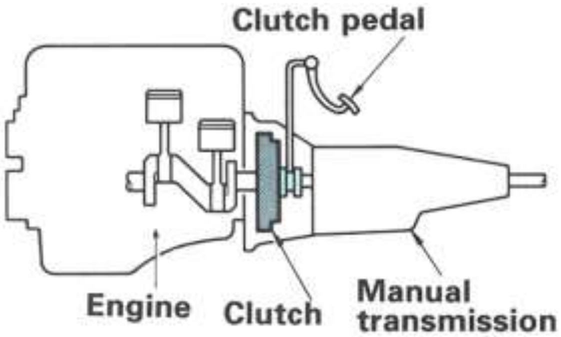
Rear engine (rear wheel drive)



4 wheel drive (transverse engine)



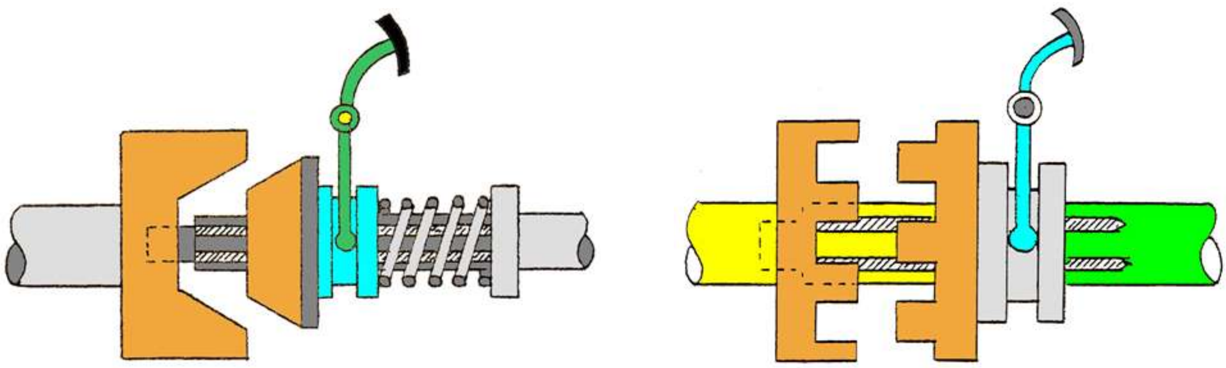
Clutch



The clutch is located between the engine and transmission to engage and dis-engage the power transmission from the engine by pedal operation. The clutch can transmit the power from the engine gradually in order to start driving smoothly from rest or whilst changing gears during drive.

The basics

A clutch is a component that is designed to connect together two rotating shafts (as opposed to a brake that is designed to connect a rotating shaft to a stationary component). Clutches can classified as one of two types – positive engagement (dog clutch) or gradual engagement (friction clutch). Positive engagement clutches normally use teeth in order to provide a positive connection, whereas gradual engagement clutches use friction.



Vehicle clutches are always gradual engagement; positive engagement clutches would not be suitable. However, positive engagement clutches (dog clutches) are used inside the gearbox in order to lock selected gears to shafts – this is explained in full later in this handbook.

Requirements of a vehicle clutch

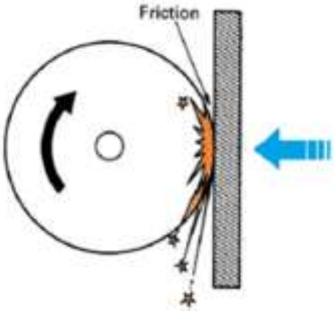
- it must connect power smoothly
- it must transmit power without slipping
- it must disengage quickly and smoothly
- it must have good heat radiating properties
- it must be well balanced
- it must be trouble free and have a long service life
- it must be easy to inspect, adjust and repair.

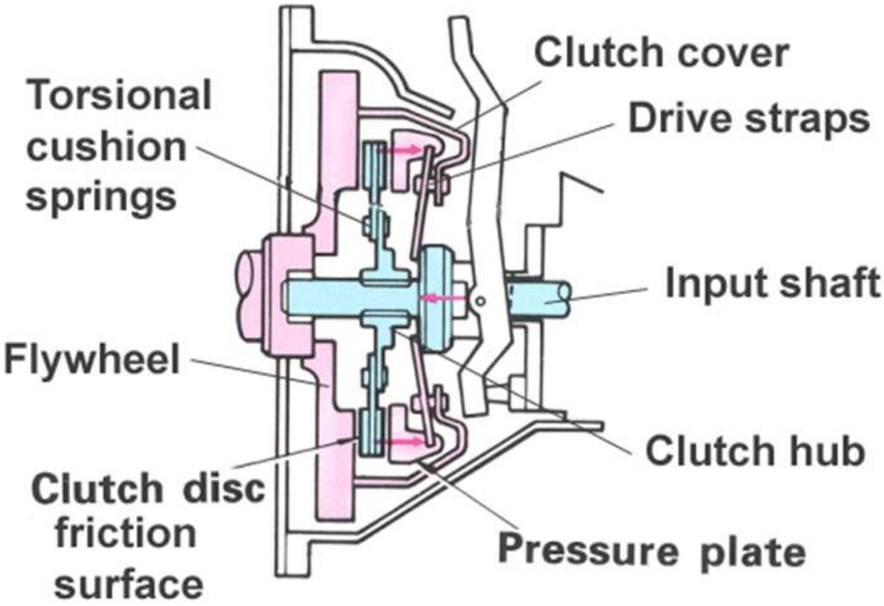
The ability of a clutch to transmit torque (clutch capacity) is normally between 1.2 and 1.4 times the maximum torque of the engine. Commercial vehicles usually have a capacity between 1.5 and 2.5. If the clutch is too light, slipping will take place and lead to premature failure. Too large a clutch will tend to cause the engine to stall and is inefficient.

Identify the following parts

Friction

The most common type of clutch fitted to a vehicle is of a friction type. The friction clutch allows smooth engagement through slipping the friction disc until the engine has engaged with the transmission. This means the take up of drive will be smooth and progressive.





Operation

Clutch pedal released

As the engine rotates the flywheel and clutch cover rotate at the same speed as they have a permanent connection. The friction disc is connected to the input shaft of the transmission. When the clutch is in the released position the friction plate is clamped between the pressure plate and the flywheel. This means the engine and the input shaft of the transmission rotate as one.

Clutch pedal depressed

When the clutch pedal is depressed the release bearing provides a rotating connection between the transmission and the clutch cover. As the clutch pedal is depressed the release bearing applies pressure to the diaphragm spring which in turn pivots on the clutch cover and lifts the pressure plate. The releasing of the pressure plate means that the clutch friction disc is no longer clamped between the flywheel and the pressure plate. This means that the engine and transmission are disconnected from each other.

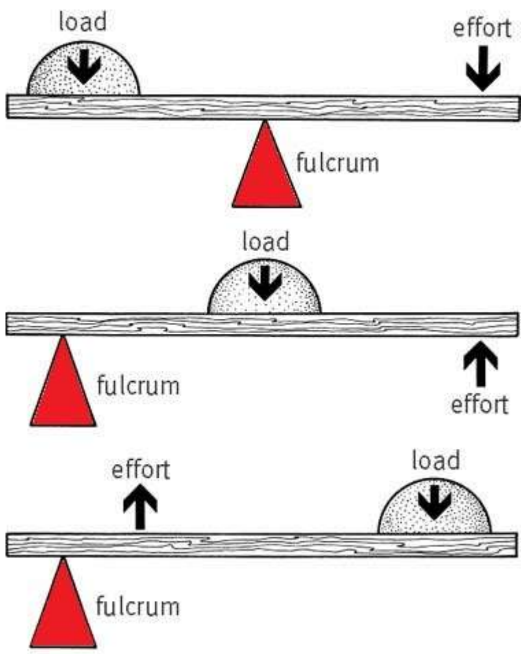
Levers

From the moment the driver presses a pedal the force exerted by the driver may not be enough to operate the clutch. In this situation the use of a mechanical advantage is the easiest way to overcome the problem.

Mechanical advantage is used daily in the automotive workshop can you think when?

How this is achieved

Using a fulcrum point (the point at which the lever pivots). The lever can be used to achieve the force required.

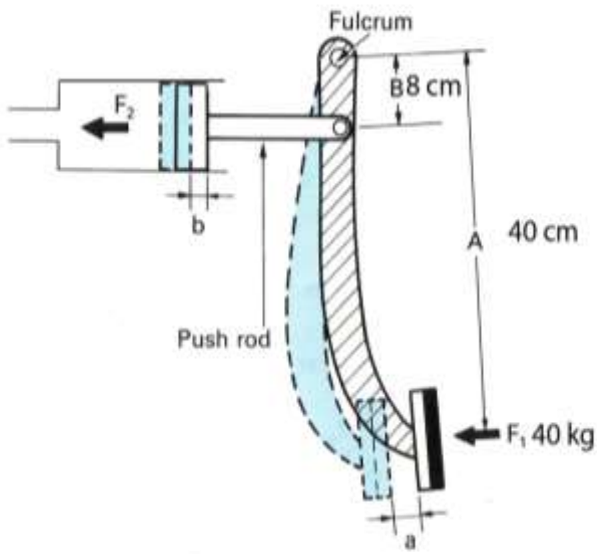


Using the following formula, mechanical advantage can be calculated.

Formula:

$$MA = F_1 \times A = F_2 \times B$$

$$F_2 = \frac{F_1 \times A}{B}$$



$$F_2 = 40 \times \frac{40}{8}$$

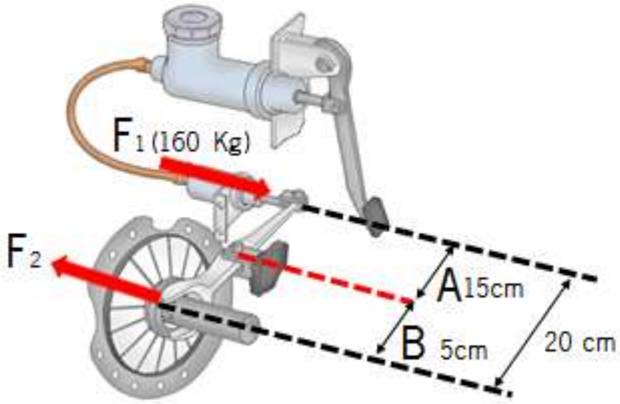
$$F_2 = \frac{40}{8} = 5$$

$$F_2 = 40 \times 5$$

$$F_2 = 200\text{kg}$$

The pedal force has now increased from 40Kg to 200Kg

Example 2



Formula:

$$MA = F_1 \times A = F_2 \times B$$

$$F_2 = F_1 \times \frac{A}{B}$$

$$F_2 = 160 \times \frac{15}{5}$$

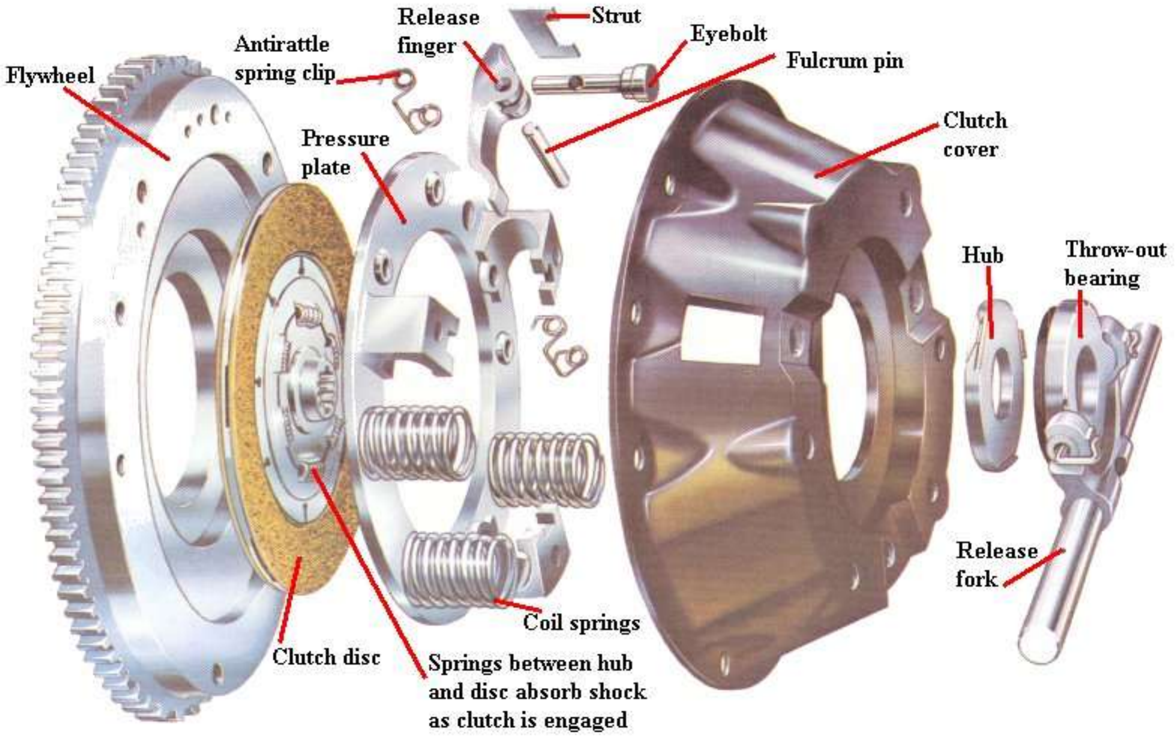
$$F_2 = 480\text{Kg}$$

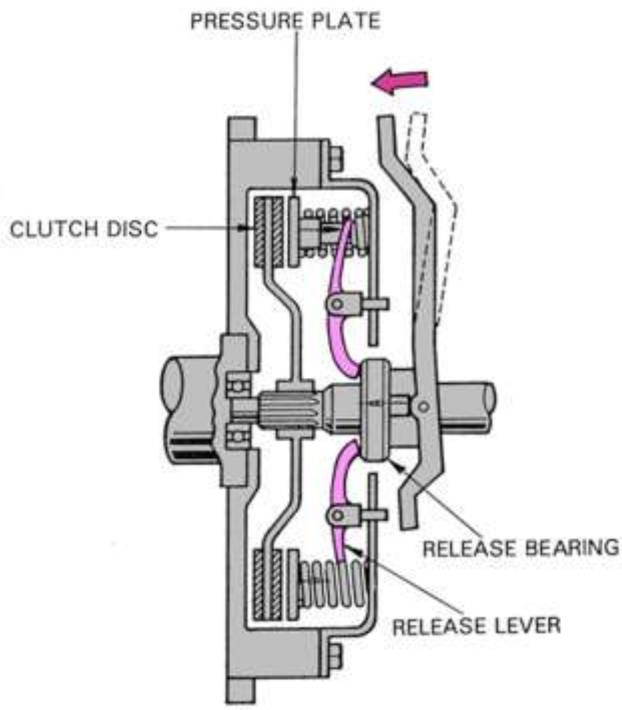
Overall the mechanical advantage from the pedal to the force on the release bearing has resulted from an input force of 160Kg to an output force at the clutch of 480Kg.

Clutch cover types

Coil spring type

There are two main types of clutch cover assembly. The coil spring type uses coil springs to trap the friction disc between the pressure plate and the flywheel.

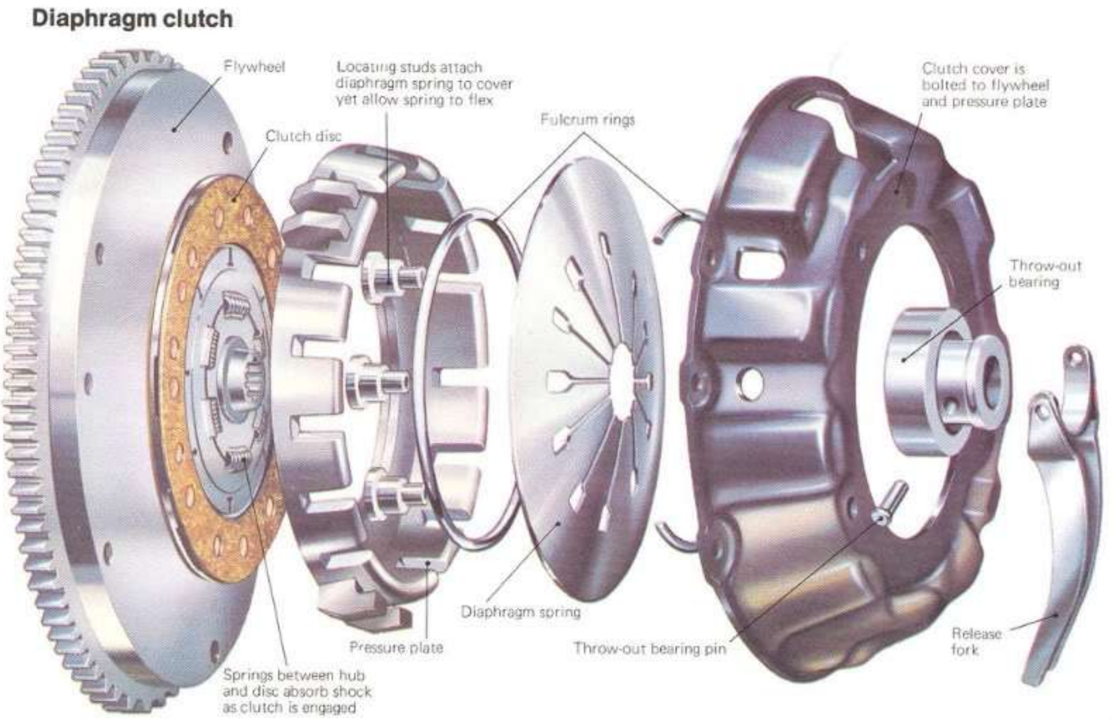




The cover assembly is bolted to the flywheel and rotates at engine speed. The friction disc is splined to the gearbox input shaft. Trapped between pressure plate and flywheel by spring pressure, the disc will transmit power to the transmission. Depressing the clutch pedal will cause the lever to move the release bearing and relieve the pressure exerted by the spring on the disc. This will cause the disc to spin freely between the flywheel and the pressure plate. Power cannot therefore be transmitted to the transmission.

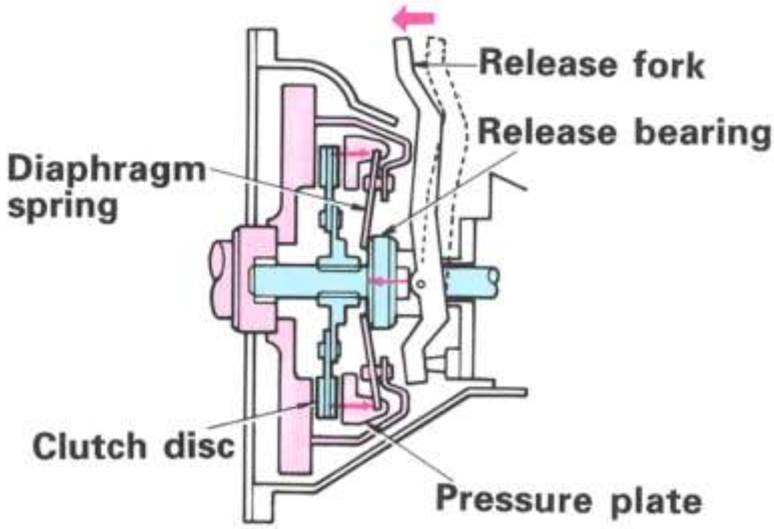
Diaphragm clutch

This type of clutch uses a diaphragm spring to control pressure.



A diaphragm clutch uses a diaphragm spring to control pressure on the friction plate. The diaphragm is made up of a circular, slightly conical, tempered steel disc with radial slits cut from its centre to give flexibility.

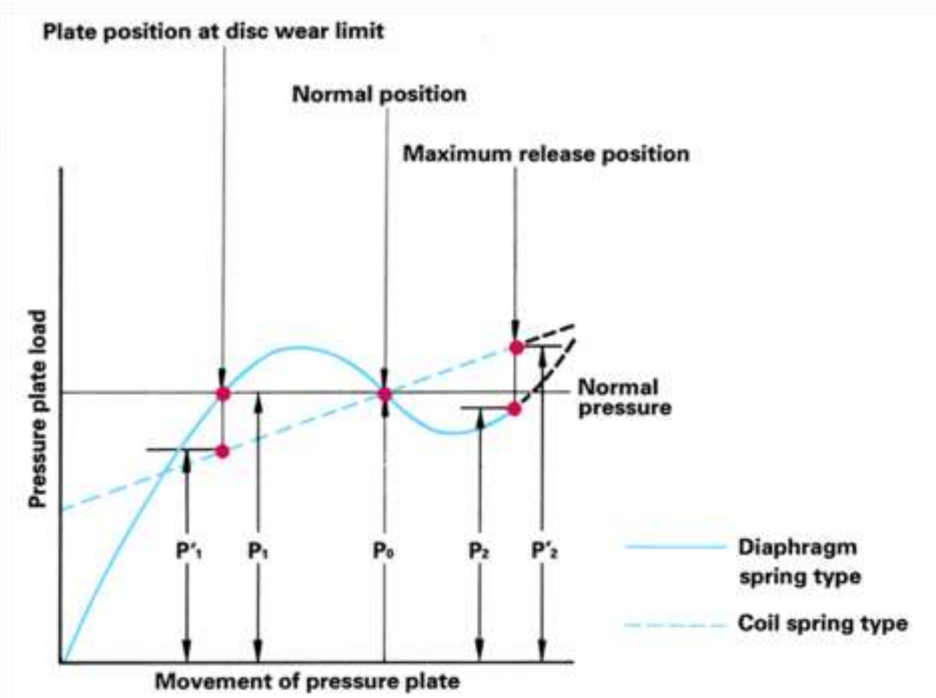
This design features only five main parts, cover, diaphragm spring, fulcrum rings, pressure plate and



driving straps.

As the clutch is assembled the pressure plate pushes the diaphragm spring away from the flywheel and deflects the spring to a near flat shape. In this position the diaphragm springs reaction results in the clamping force on the friction disc.

Advantages of a diaphragm clutch compared with a coil spring clutch



The graph above shows that when the clutch is new (normal position on the graph) the pressure exerted by the pressure plate and also the clutch pedal effort is equal for both types. However the effort required holding the pedal fully depressed (maximum release position on the graph) is less for the diaphragm spring clutch. Wear of the disc will cause the pressure exerted by the pressure plate to significantly reduce when using coil springs but it will remain much the same using a diaphragm spring clutch.

The clutch assembly rotating at high engine speed is subject to centrifugal force. This has an adverse effect on coil springs but the diaphragm is unaffected. The diaphragm spring also consists of fewer parts and because it is circular in shape it is easily balanced to avoid rotational vibration.

Advantages

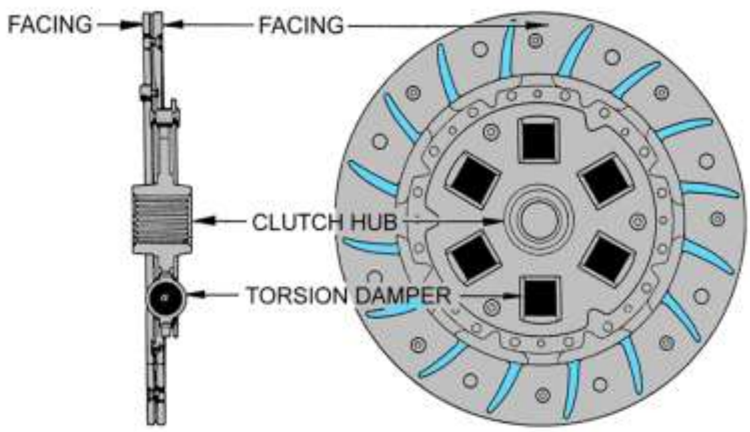
- Compact
- Light weight
- Suitable for high engine speeds as it is unaffected by centrifugal force
- A lower pedal force is required to operate
- Clamping force does not decrease as wear on the friction disc occurs

Friction disc

The friction disc has the job of transmitting the engines power smoothly and once engaged continuously without slipping. This is achieved by building the friction plate in such a way that ensures it can be applied and disconnected accurately and quickly without:

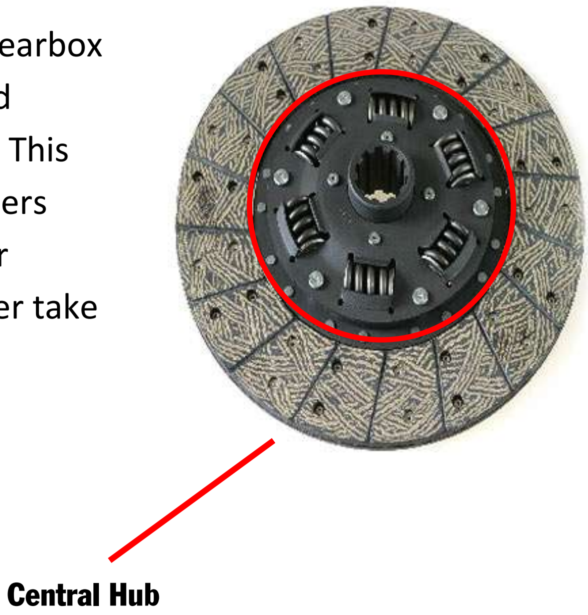
- Buckling, due to heat
- Dragging, due to the plate rubbing against the flywheel during disengagement

The friction disc is made up of a friction material riveted to both sides of the disc facing and a central clutch hub which receives the input shaft from the transmission.

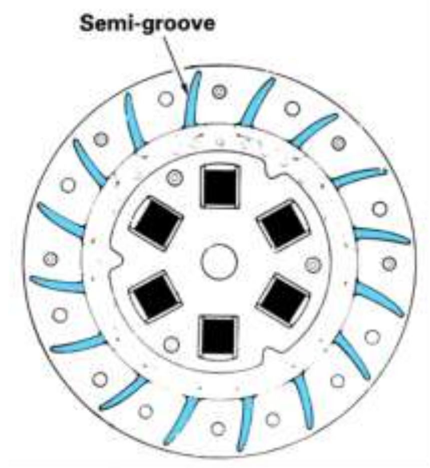


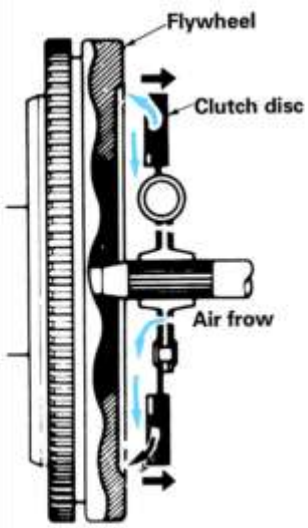
The friction material is sandwiched between a spring steel blades. This spring effect aids with absorbing shocks and controls dragging by disengaging quickly when the spring steel blade returns to its original shape.

The central hub is splined to fit on the gearbox input shaft and is free to rotate a limited distance in relation to the friction faces. This movement is governed by torsion dampers made usually from coil springs or rubber inserts and reduces initial shock at power take up



Grooved friction material





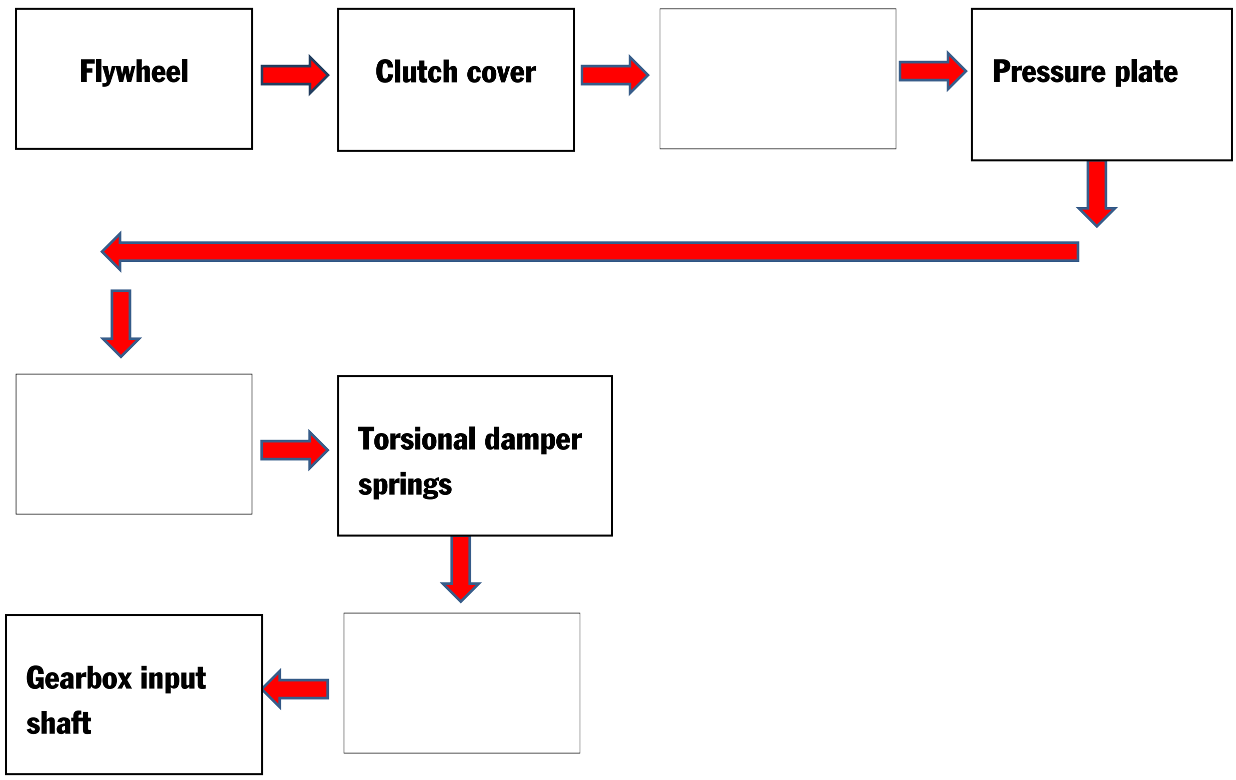
There is a tendency for the disc to stick to the flywheel or pressure plate when released in much the same way that two sheets of glass are hard to separate due to air pressure. Grooves in the friction faces help air to enter the gap forming when the pressure plate moves away from the disc.

Multi plate clutches

Multi plate clutches are often used when high levels of torque are transmitted to the transmission in a limited sized application. The extra torque would require a larger friction surface area to cope with the extra load and in turn a much larger clutch assembly and flywheel would be needed. The alternative would be to use a multi plate design. This would ensure that the friction plate surface area is large enough to cope with the torque but the overall size and weight are kept to a minimum.

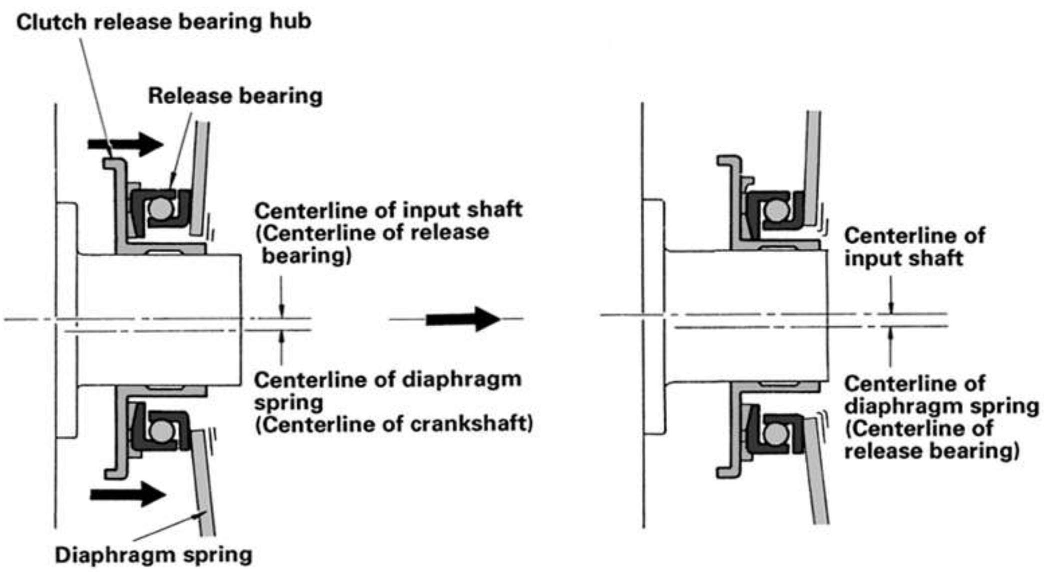
Exercise 1

Complete the torque flow chart below to show how torque is transmitted from the engine to the gearbox. Assume the clutch is a diaphragm spring clutch.



Self-centring release bearing

To reduce noise the release bearing is designed to automatically keep the centre line of the release bearing aligned with the centre line of the gearbox input shaft



Types of diaphragm clutch

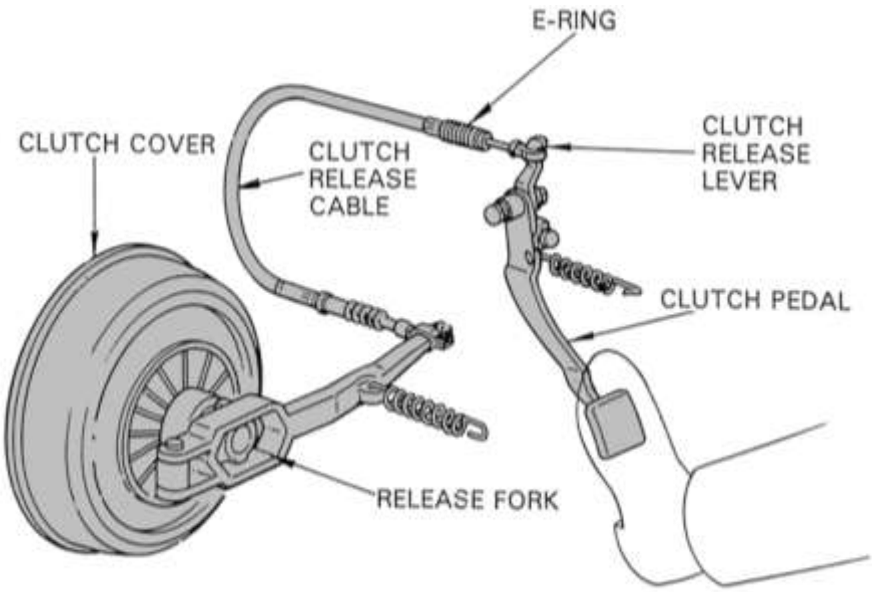
If the diaphragm spring pivots on the clutch cover to release the disc the clutch is often referred to as a push type clutch. If the diaphragm pivots on the pressure plate the clutch is referred to as a pull type clutch

Push type clutch

Pull type clutch

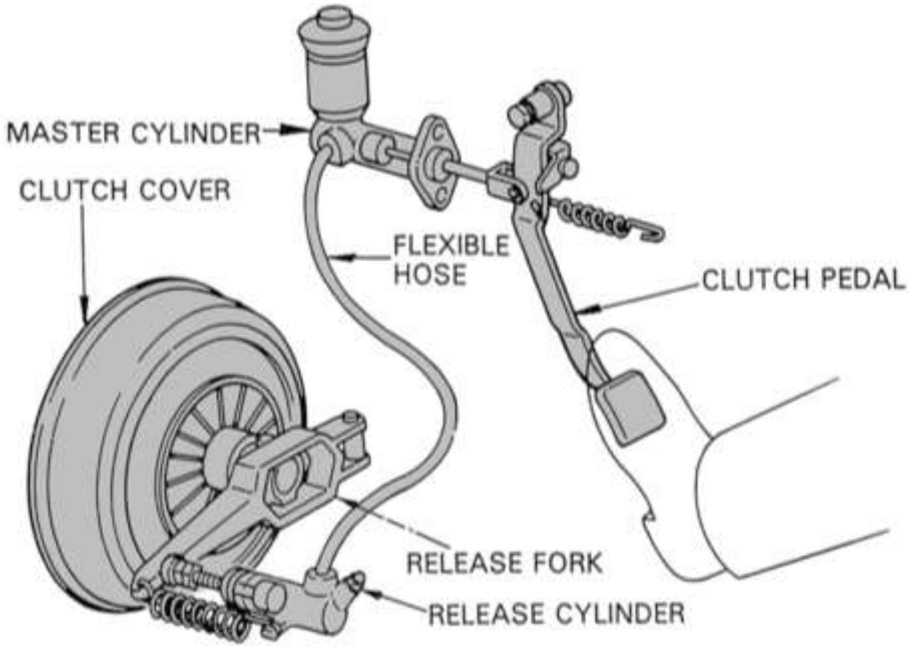
Clutch operating mechanism

Cable operated clutch



The clutch is usually operated by the driver using a mechanical (cable) or a hydraulic circuit. This is an example of a mechanical system. A cable connects the clutch pedal and release fork. A means of adjustment is provided although an automatic adjustment system is now normal. A return spring is often fitted at either end to assist in returning the release fork.

Hydraulic operated clutch

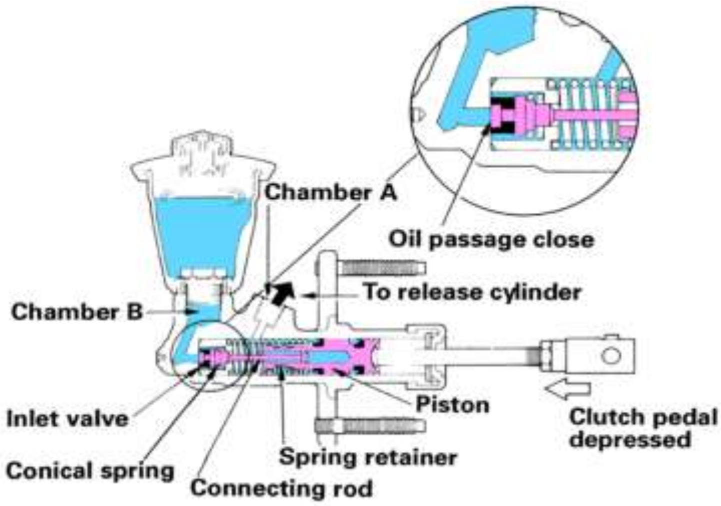


A clutch master cylinder, consisting of a fluid reservoir, piston with seals, push rod and cylinder forces hydraulic fluid through a pipe connecting the release or slave cylinder

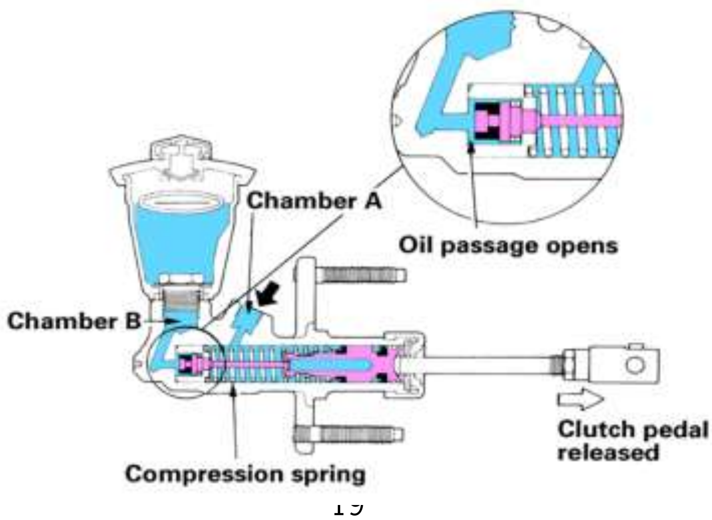
Hydraulic mechanism

The hydraulic system has become the favoured solution for clutch actuation in recent years. It has the benefits of damping vibration as well as self-adjusting. It is often much smoother than a cable operated clutch.

Clutch master cylinder



The diagram above shows the operation inside the master cylinder when the clutch pedal is depressed. The passage way to chamber B and the fluid reservoir is closed by the movement of the piston acting on the inlet valve and conical spring. Further movement of the piston displaces hydraulic fluid via chamber A to the release or slave cylinder.



In this diagram the clutch pedal has been released. The returning piston allows fluid to return to the cylinder and opens chamber B reconnecting it with chamber A.

Clutch fluid

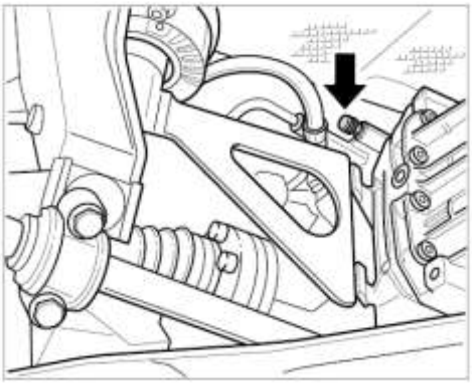
The fluid used in the clutch system is commonly brake fluid and is often fed from the brake fluid reservoir. The system must be bled just like the braking system to ensure no air is in the pipes that can be compressed during operation.

Bleeding procedure

1. Remove the cover over the brake fluid reservoir. Fill reservoir to its top edge with new brake fluid. Connect the bleeding device to the brake fluid reservoir. → see figure

2. Switch on the bleeding device and set an overpressure of approx. 1.3 bar.

3. Open the bleeder valve -arrow- on the clutch slave cylinder.



4. Move pedal extremely slowly to the "Pedal fully depressed" position. When doing so, guide the pedal by hand so that it does not move forward abruptly.

5. Allow the brake fluid to rinse through for 30 seconds.

6. Afterwards, activate complete pedal travel manually very slowly for a further 60 seconds. After about 10 to 15 pedal strokes, leave the pedal in its normal position. Once this filling period has elapsed, check that no more bubbles appear at the bleeder valve (use a collecting bottle with transparent hose). Then close the bleeder valve.

7. Switch off and disconnect the bleeding device. Check the brake fluid level. It should not be above the MAX. mark.

8. Activate the clutch pedal slowly, five times.

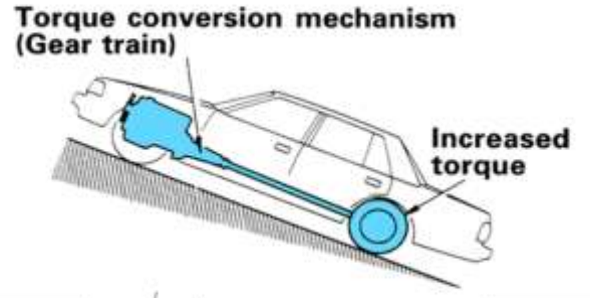
9. Fit the cover over the brake fluid reservoir.

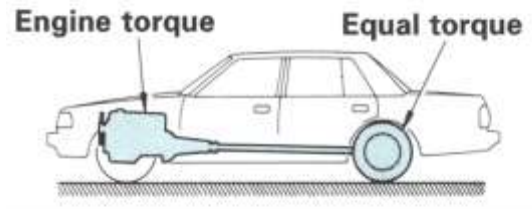
Slave cylinders

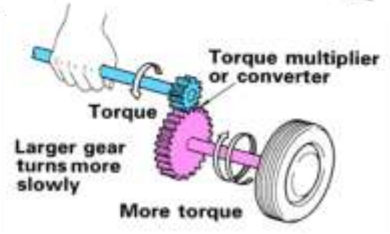
The slave cylinder is the actuator attached to the master cylinder. The pedal pressure is transferred to the slave cylinder. The force can act on the release fork or directly on to the diaphragm spring.

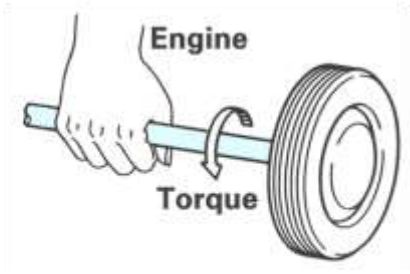
Torque transmission

Torque generated by the engine remains nearly constant, while engine power output increases in proportion to engine speed.







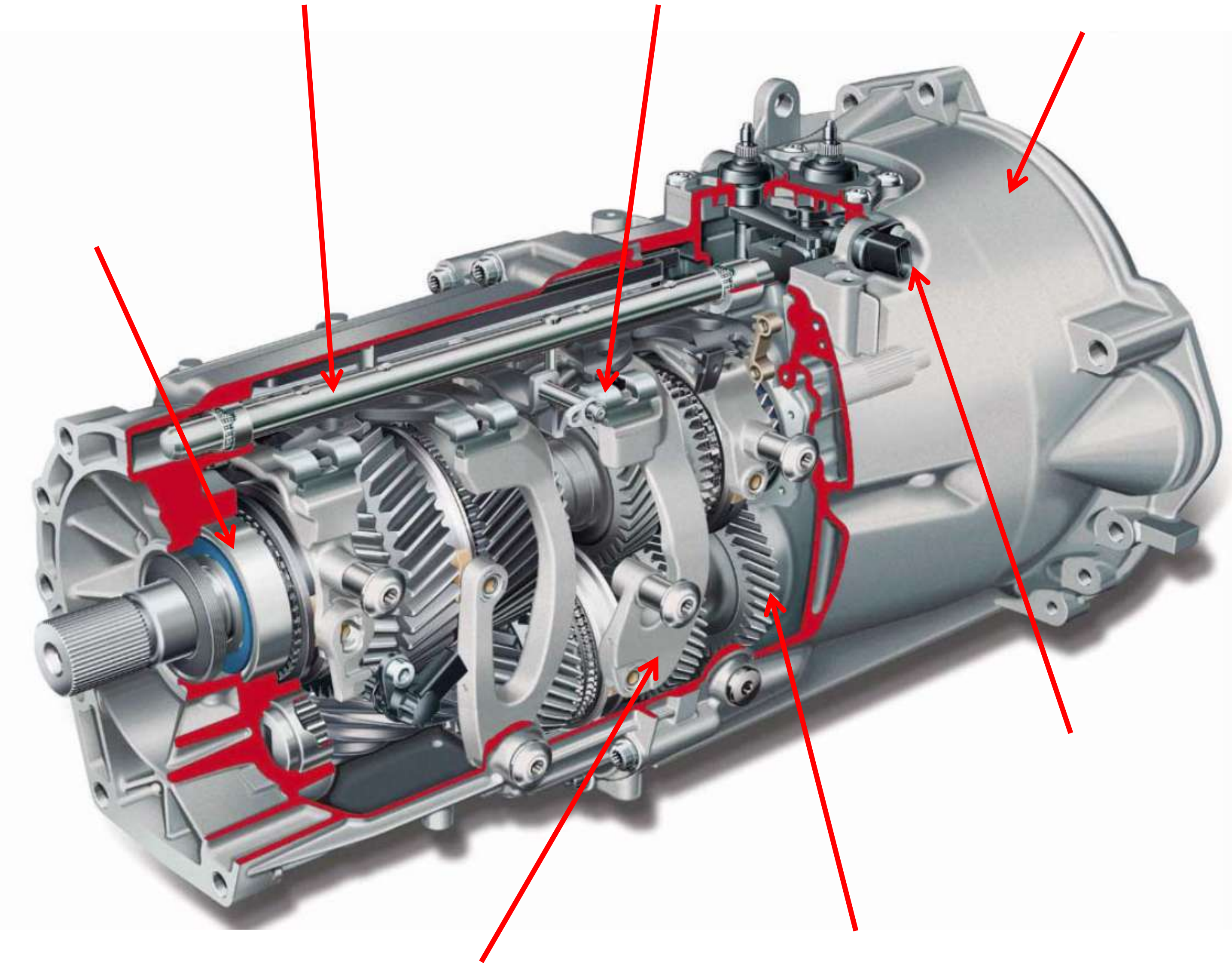


When a vehicle is pulling away on an incline the torque output from the engine must be increased so the vehicle can start off. When a vehicle is moving on a level road, the constant engine torque is enough to keep the vehicle moving.

The transmission

The transmission has the job of varying the torque output by varying gear ratios to suit the driving condition of the vehicle. The transmission can also change the direction of drive by providing a reverse gear.

Label the following diagram



Gears

Gears are rotating levers. Levers are capable of multiplying force and gears are able to do this also – they can increase rotational force (torque).

Three main types of gearing are used in a manual transmission system:

Spur gears

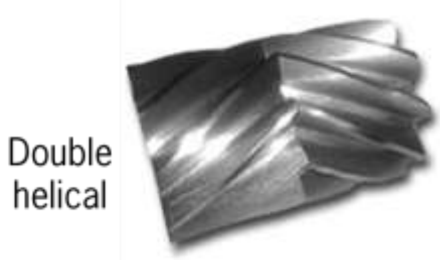
Spur gearing has teeth that are cut parallel to the rotating axis. These are noisy when operating at high speeds.

Helical gears

Helical gearing has teeth cut at an angle to the rotating axis. This provides more tooth surface area, allowing the gearing to run quieter.

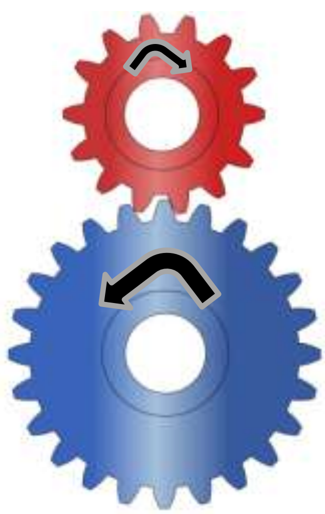
Double helical gears

Double helical gearing incorporates two sets of helical teeth on one gear. Very quiet operation, although expensive to manufacture.



Gear ratio

The illustration opposite shows a simple gear train. It can be seen that the red gear is meshed with the blue gear. If we consider the red gear to be driving the blue gear we could describe the red gear as the *driver* and the blue gear as the *driven*. If the blue gear is twice the diameter of the red gear, it will be travelling at half the red gears speed. So the speed

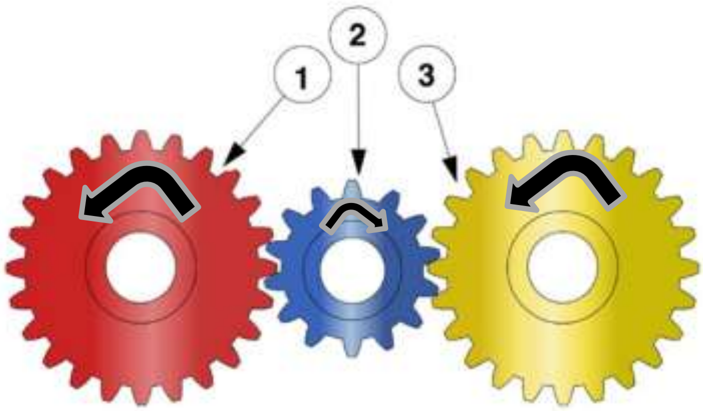


has reduced. If the speed has reduced, then something must have increased for all things to remain equal – it is the turning torque that has increased. In fact, because the driven gear (blue) is twice the diameter of the driver gear (red), the speed will have halved and the torque will have doubled.

Now imagine that the blue gear is the driver and the red gear the driven. If the driver is turning at a speed of 100 RPM, the driven gear will be turning at 200 RPM. The speed has doubled and the turning torque will have halved.

From these examples it can be seen that it is the relationship between the sizes of the driver and driven gears that dictates output speed and torque. This relationship is referred to as the ratio.

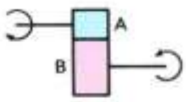
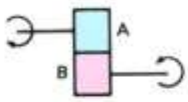
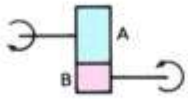
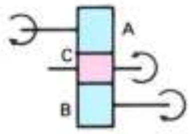
Idler gears



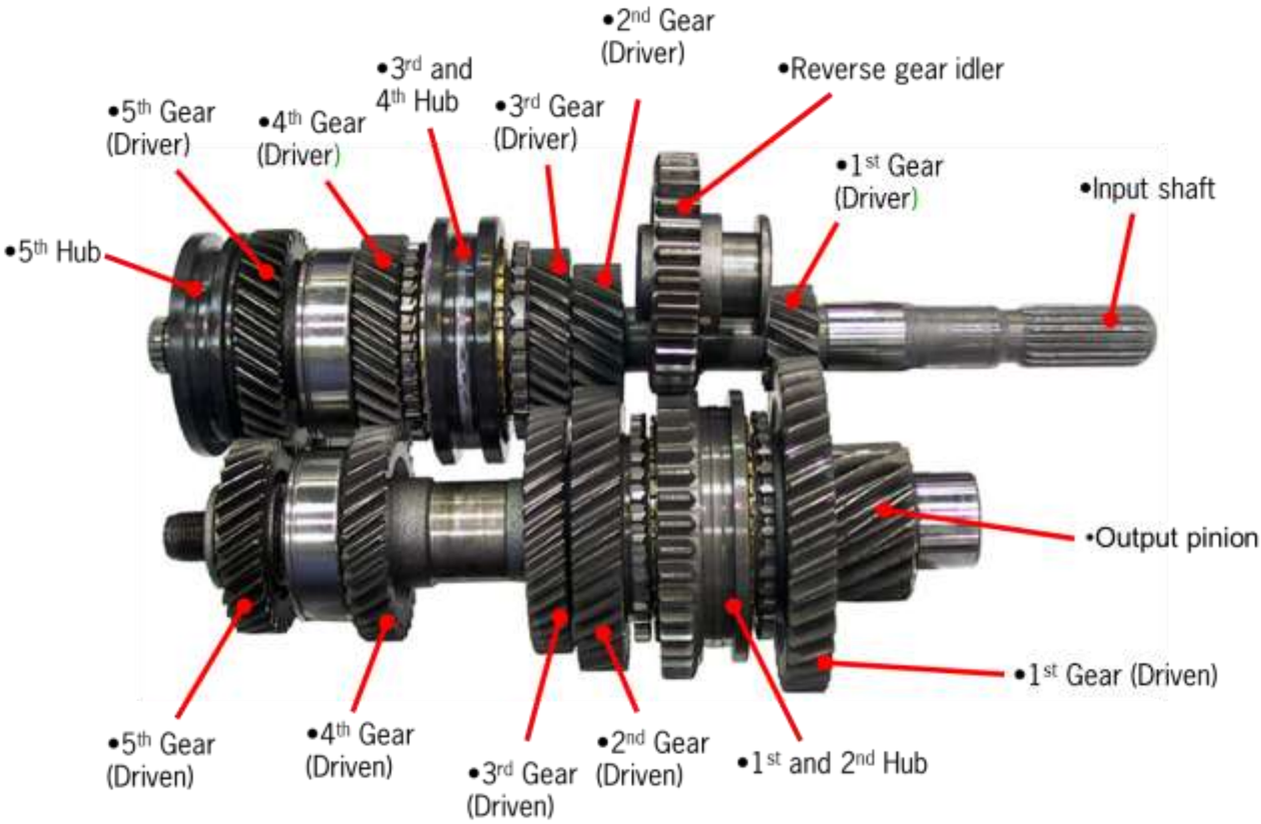
If you study the simple gear train in the last diagram it can be seen that the direction of rotation (DOR) will be reversed between the driver and driven gears. This may not always be suitable for certain applications. A simple way of rectifying this is the use an idler gear. Study the illustration to the right. It can be seen that if the red gear is the driver and the yellow gear the driven, their DOR will be identical at all times thanks to the idler gear (blue) – red CW, blue ACW and yellow CW. It should be noted that an idler gear has no effect whatsoever on the ratio between the driver and driven gears. Some gear trains (such as geared crankshafts and camshafts have many idler gears in order to bridge the distance between the two assemblies. These idlers are often given other duties such as driving water pumps, balance shafts and injection pumps. With a simple gear train - If the number of idlers is odd (3, 5, 7 etc.) the DOR of driver and driven gears will always be identical. If the number of idlers is even, the DOR will always be reversed.

Simple gear trains

A: Drive gear B: Driven gear

No. of teeth	A < B	A = B	A > B	A = B
Gear combination				
Speed of B versus A	Reduced	Equal	Increased	Equal (C is an idle gear)
Torque of B versus A	Increased	Equal	Decreased	Equal
Direction of rotation	Opposite	Opposite	Opposite	Same

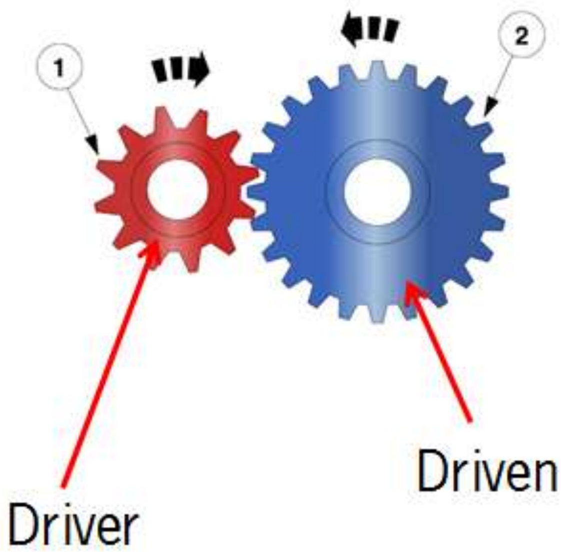
Gear train overview (front wheel drive)



Calculating gear ratios

A simple gear ratio can be calculated in the following way:

$$\text{Ratio} = \frac{\text{Driven}}{\text{Driver}}$$



This formula indicates that to calculate the ratio you must divide the size of the driven gear by the size of the driver. To identify the size of the gears you can use any common measurement to both such as diameter, radius, circumference or number of teeth. The easiest to use is the number of teeth.

Exercise 2

Calculate the gear ratios for the following size variations for the simple gear train illustrated in the diagram opposite:

1. Red gear (driver) 10 teeth

   Blue gear (driven) 20 teeth

   Answer =

2. Red gear (driver) 35 teeth

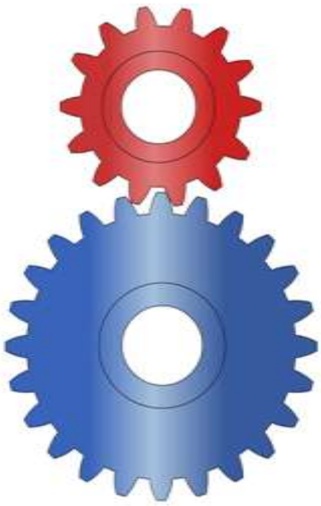
   Blue gear (driven) 280 teeth

   Answer =

3. Red gear (driver) 10 teeth

   Blue gear (driven) 40 teeth

   Answer =

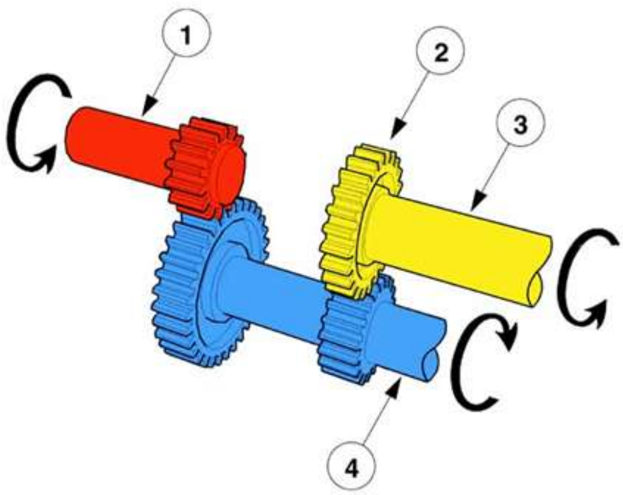


Any gear train that results in the driven gear turning slower than the driver is referred to as an underdrive gear and conversely, any gear train that results in the driven gear turning faster than the driver is referred to as an overdrive gear.

Now go back to your answers to exercise 2 and label them underdrive or overdrive.

Compound gear train

Any gear train that has two or more simple gear trains connected



together via a shaft is referred to as a compound gear train.

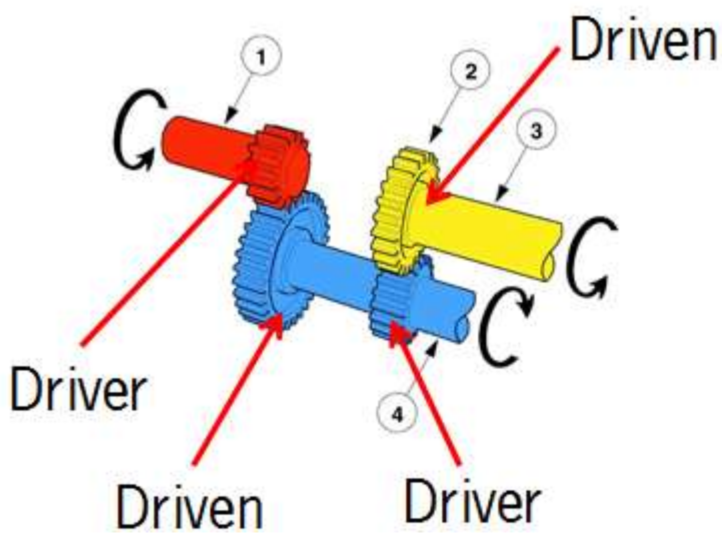
Study the illustration opposite. If we assume that the red gear (1) is the driver and the yellow gear (3) is the driven it can be seen that the DOR of these two gears is the same. And this is with an *even* number of gears. If you want to achieve a reversal of DOR with a compound gear train, then you must use an odd number of gears (the complete opposite to a simple gear train).

There are a number of advantages to using a compound gear train. A very large ratio can be achieved in a relatively small space (smaller gearboxes mean less weight); a greater tooth contact area is achieved providing more strength, and the construction of a multiple selectable ratio gearbox is far easier to achieve.

Calculating compound gear ratios

$$\text{Ratio} = \frac{\text{Driven}}{\text{Driver}} \times \frac{\text{Driven}}{\text{Driver}}$$

The first step in using this formula is to identify accurately which gears are drivers and which are driven.



Example calculation

Red – 10 teeth

Large blue – 20 teeth

$$\text{Ratio} = \frac{\text{Driven}}{\text{Driver}} \times \frac{\text{Driven}}{\text{Driver}}$$

Small blue – 10 teeth

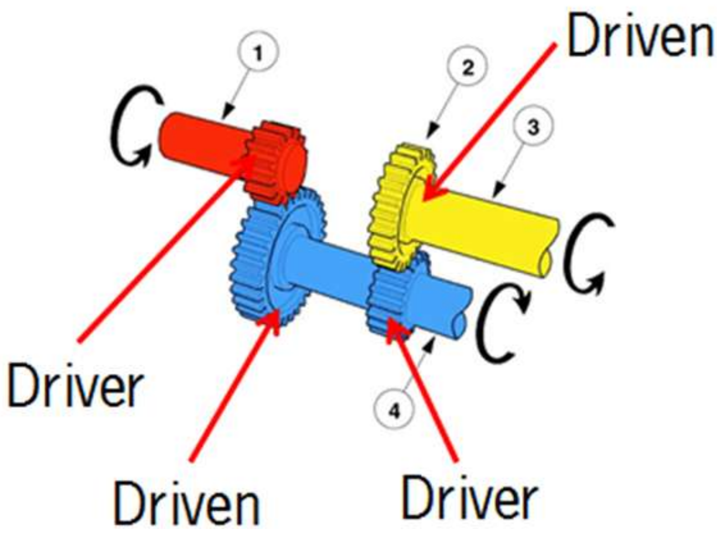
Yellow – 20 teeth

$$\frac{20}{10} \times \frac{20}{10} = 2 \times 2$$

$$2 \times 2 = 4$$

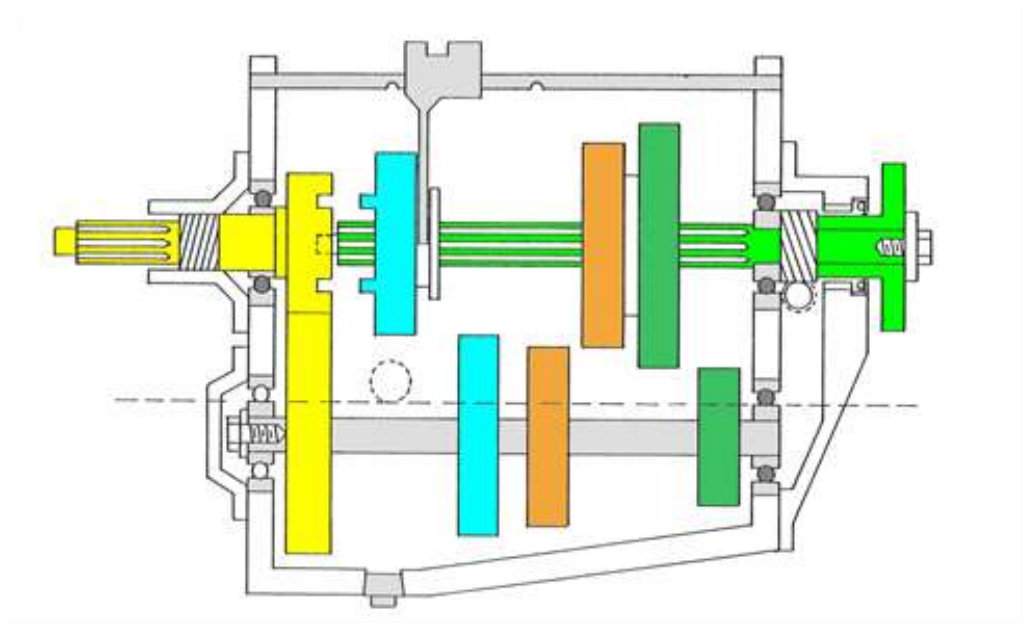
Ratio 4 : 1

Therefore torque = 400Nm



In this example, if the first driver (red gear) was turning at a speed of 4000 RPM then the last driven gear (yellow) would be turning at a speed of 1000 RPM. If the first driver was turning with a torque of 100 Nm, then the last driven gear would be turning with 400 Nm.

Sliding mesh gearboxes



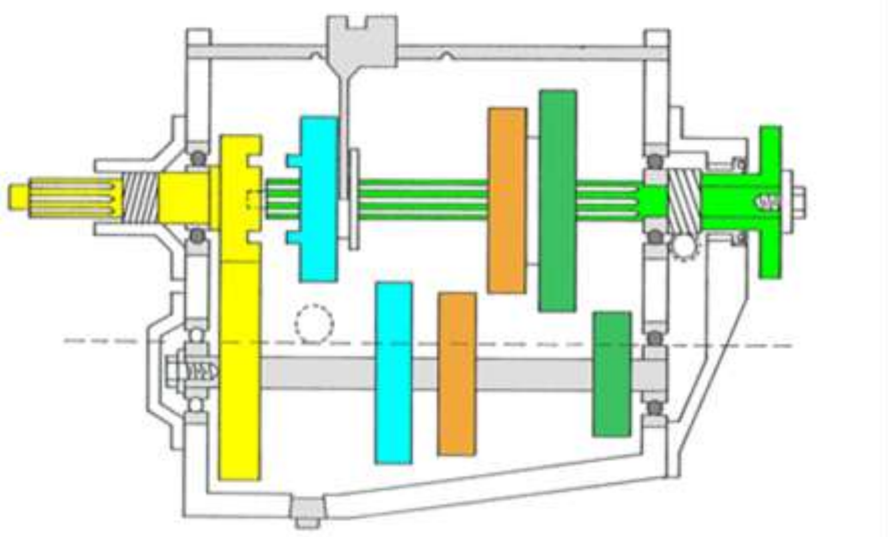
Exercise 3

The illustration above shows a sliding mesh gearbox. Mark on the illustration the input shaft, the layshaft / counter shaft and the main shaft.

The sliding mesh gearbox is simply a set of selectable compound gear ratios. The driver slides into mesh the relevant gear dictated by engine load and road conditions. The gear lever operates the selector mechanism within the gearbox to ensure that the gear that he selects is engaged. It should be noted that all gears on the layshaft are cast onto it and that all gears on the mainshaft are mounted to it via splines to enable them to slide into mesh.

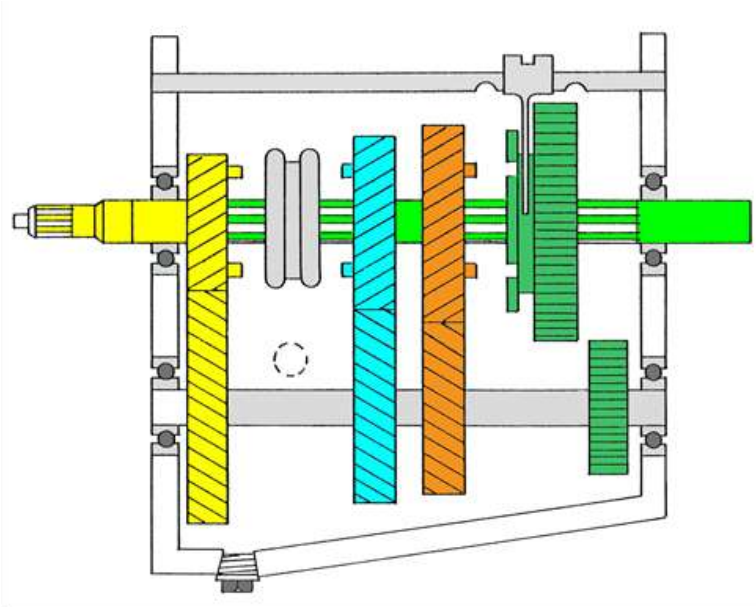
Although functional, the sliding mesh gearbox had its limitations (or more to the point the drivers did) – synchronising the speeds of the shafts whilst changing gear took a high degree of driver skill. It was done through a process known as ‘double-clutching’. If the double-clutching technique was not used, the variance in gear rotational speed within the box would result in crunching of the gear teeth and subsequent damage. Because of this, the sliding mesh gearbox was often referred to as a crash box.

Exercise 4



Mark on the diagram above 1st, 2nd, 3rd and 4th gear ratios.

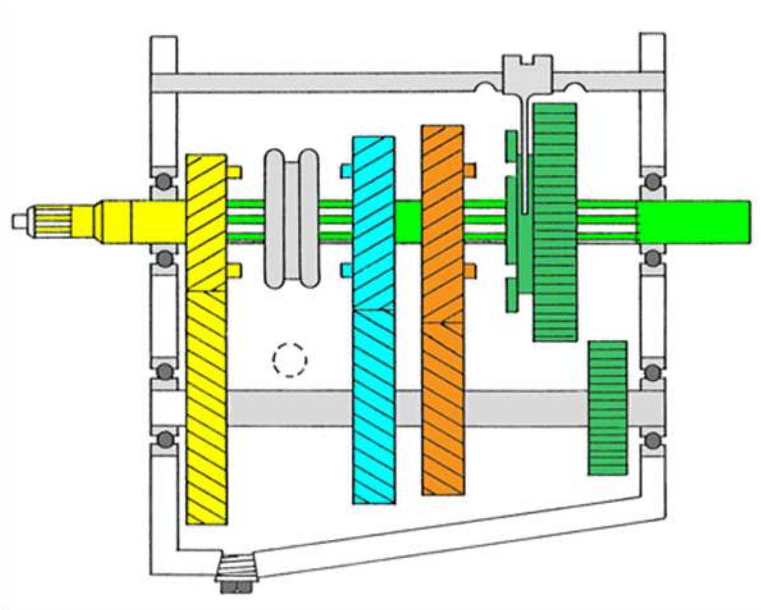
Constant mesh



The diagram above shows a constant mesh gearbox. This was the next step in gearbox development leading on from sliding mesh.

It can be seen that all gears on constantly meshed (hence the name) with the exception of 1st gear. First gear remains sliding mesh, as strictly speaking, this gear should not be selected until the vehicle is stationary - and if this is the case all shafts will be stationary within the box and synchronisation will not be an issue.

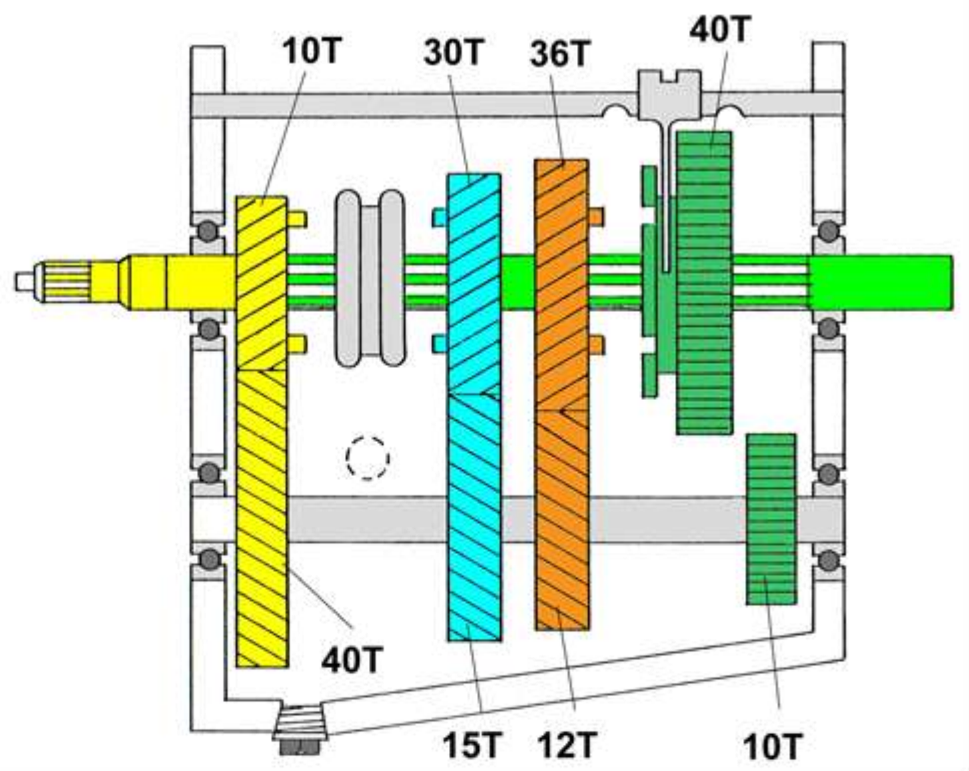
Like the sliding mesh gearbox, all gears on the layshaft / countershaft are cast onto it, but 2nd and 3rd driven gears on the mainshaft are mounted on bushes (not splines) and are therefore able to freely rotate on this shaft without imparting any drive to it. When the driver would like one of these gears to impart its drive to this shaft he must therefore lock the gear to the shaft. To do this, he slides into engagement with the gear a dog clutch (see clutches section in this handbook). As the dog clutch is splined to the shaft, locking the two together effectively splines the gear to the shaft also. It will therefore drive the shaft through the medium of the dog clutch.



Exercise 5

Redraw the dog clutch on the diagram above showing 3rd gear engaged. Add to your diagram arrows showing the torque flow through the gearbox.

Exercise 6



In the illustration above it can be seen that gear sizes have been added (number of teeth). Calculate the following gear ratios (show all your working):

1st gear

2nd gear

3rd gear

4th gear

What is reverse gear ratio (assume the idler has 25 teeth)?

Now assume that the input shaft is rotating with 100 Nm of torque. Calculate mainshaft torque with each of the following gears engaged:

1st gear

2nd gear

3rd gear

4th gear

Reverse

Now assume that the input shaft is turning at a speed of 4800 RPM. Calculate mainshaft speed with each of the following gears engaged:

1st gear

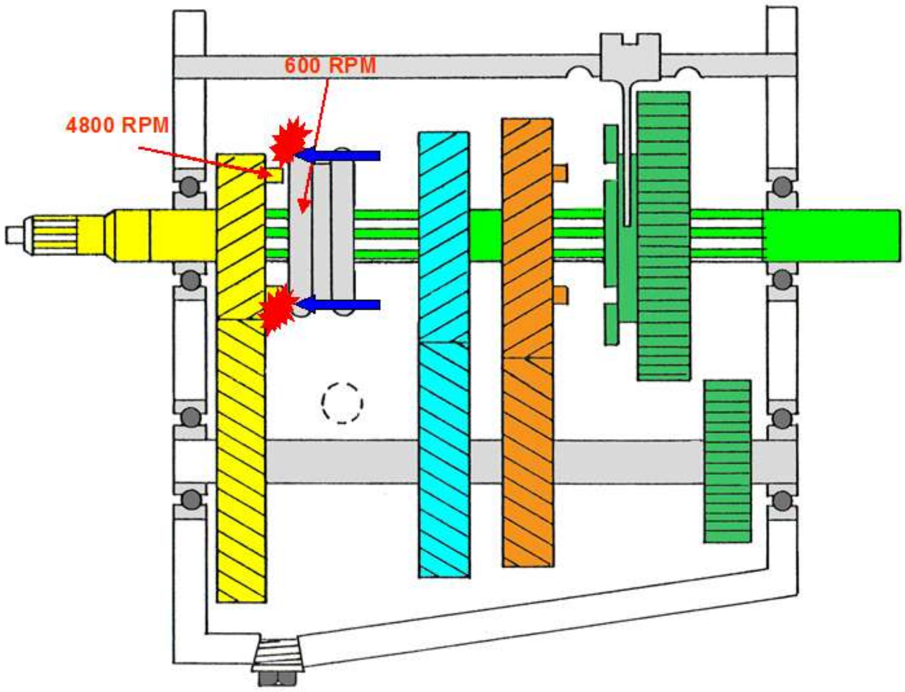
2nd gear

3rd gear

4th gear

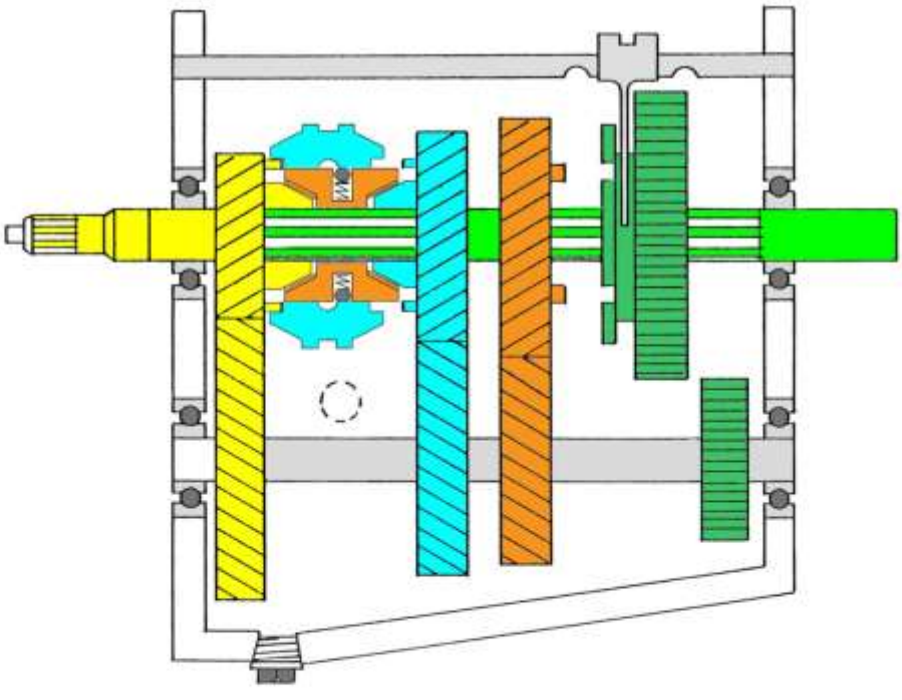
Reverse

The problem

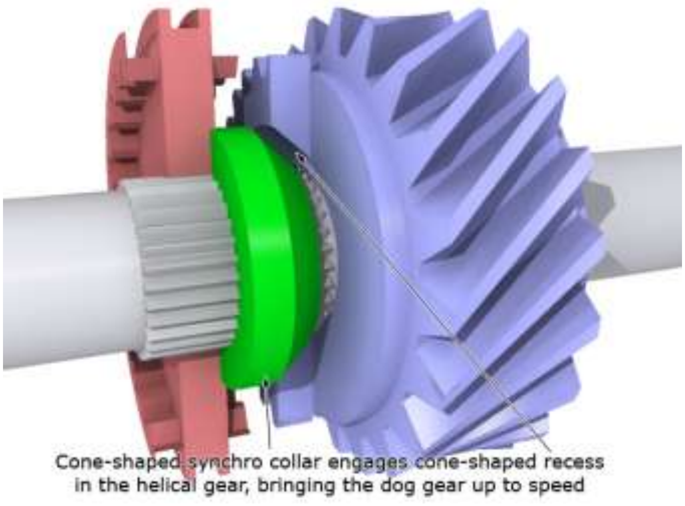


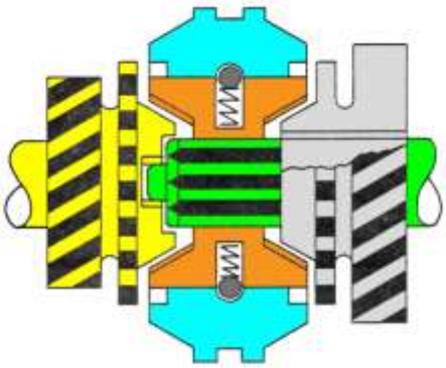
During exercise 6 you calculated that for an input shaft speed of 4800 RPM the mainshaft would be rotating at a speed of 600 RPM with 3rd gear engaged. As 3rd / 4th gear dog clutch is mounted to the mainshaft via splines it will always rotate at mainshaft speed. So when 3rd gear is engaged and the input shaft is rotating at 4800 RPM, the 3rd / 4th gear dog clutch is rotating at 600 RPM. When the driver changes from 3rd to 4th gear he disengages 3rd / 4th gear dog clutch from third gear and attempts to mesh it directly with the input shaft dog teeth which are rotating at 4800 RPM. There is a difference in speed between these two assemblies of 4200 RPM (input shaft 4800 RPM - dog clutch 600 RPM = 4200 RPM). Unless the driver 'double clutches', crash!

The solution

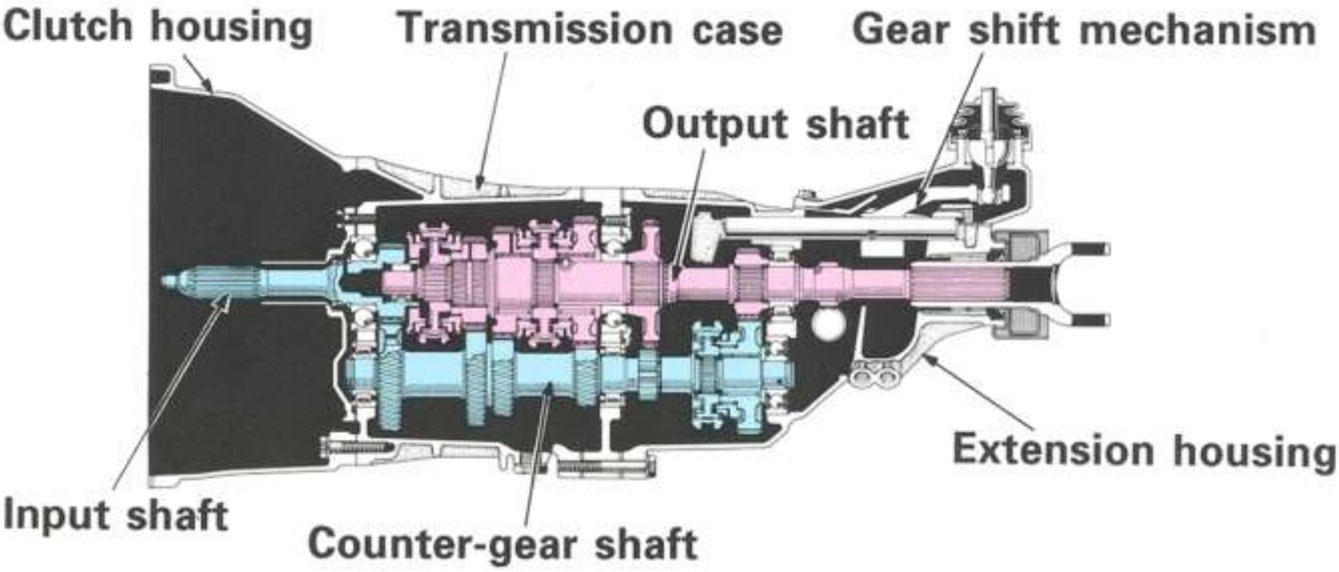


The answer to our synchronisation problem is to sandwich between the opposing dog teeth a friction clutch (see the clutches section of this handbook). This is in the form of a cone clutch and this clutch is able to generate friction between the two assemblies in order to synchronise their speeds prior to engagement of the dog teeth. It can be seen from the illustration opposite that only spring loaded ball bearings apply force to the cone clutch assembly. If the driver pushes or pulls too hard on the gear lever, he will be able to 'beat the synchro' and the two opposing sets of dog teeth will be brought together prior to synchronisation. The modern gearbox uses baulk ring synchromesh in order to prevent this. 'Baulk' means to resist. This type of synchromesh is explained in detail later in this handbook.





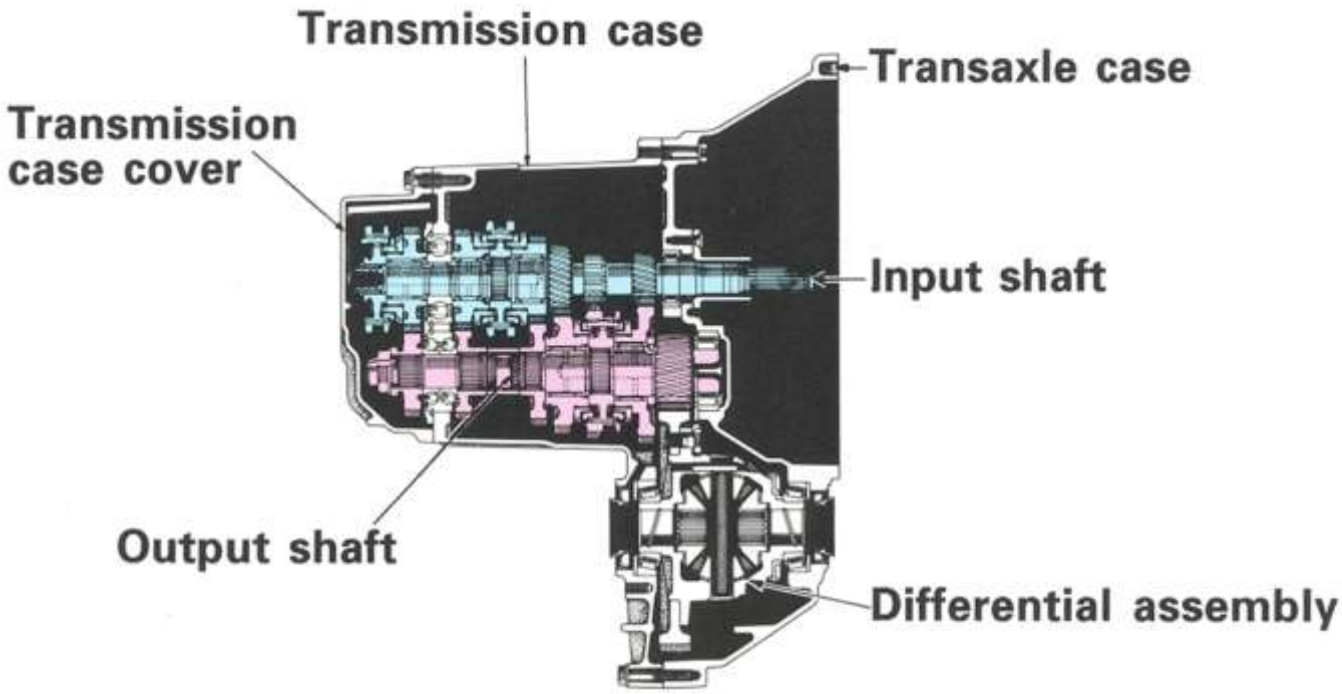
Manual transmission – front engine rear wheel drive



The rear wheel drive transmission has the following major components.

- clutch housing
- transmission casing
- output shaft
- gear shift mechanism
- input shaft
- counter gear shaft
- extension housing.

Manual transmission - front engine front wheel drive

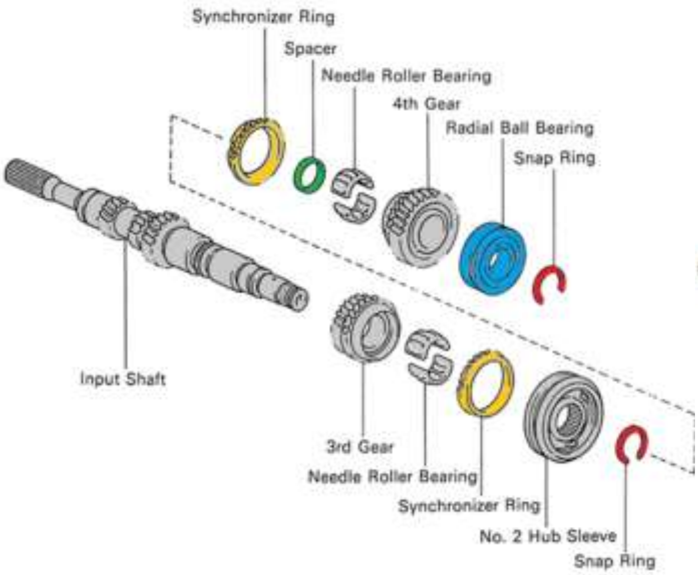


The transmission for a front engine front wheel drive vehicle has the following major component.

- transmission case or housing
- clutch housing
- input shaft
- Final drive / differential assembly
- output shaft
- transmission case cover or end casing.

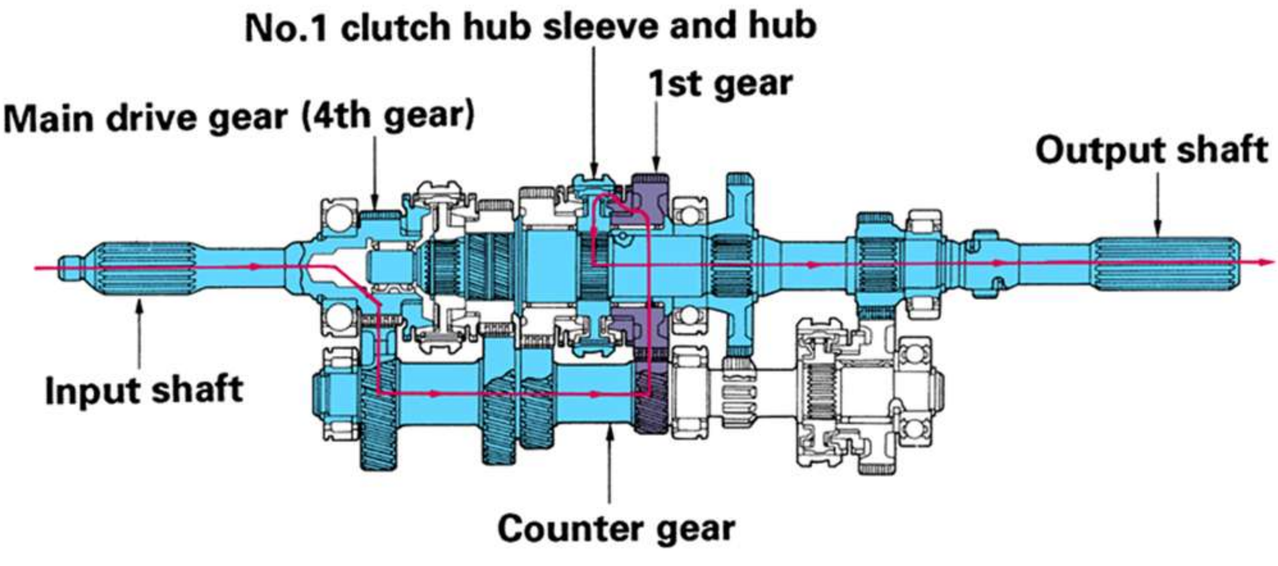
The shafts

The shafts have their assemblies mounted onto them in various ways. Some assemblies are cast directly onto the shaft whereas others are mounted onto needle roller bearings (dependent upon whether the assembly is required to drive permanently or only when locked to the shaft). These assemblies are kept in lateral alignment through the use of snap rings and spacers.



Torque flow in front engine rear wheel drive transmission

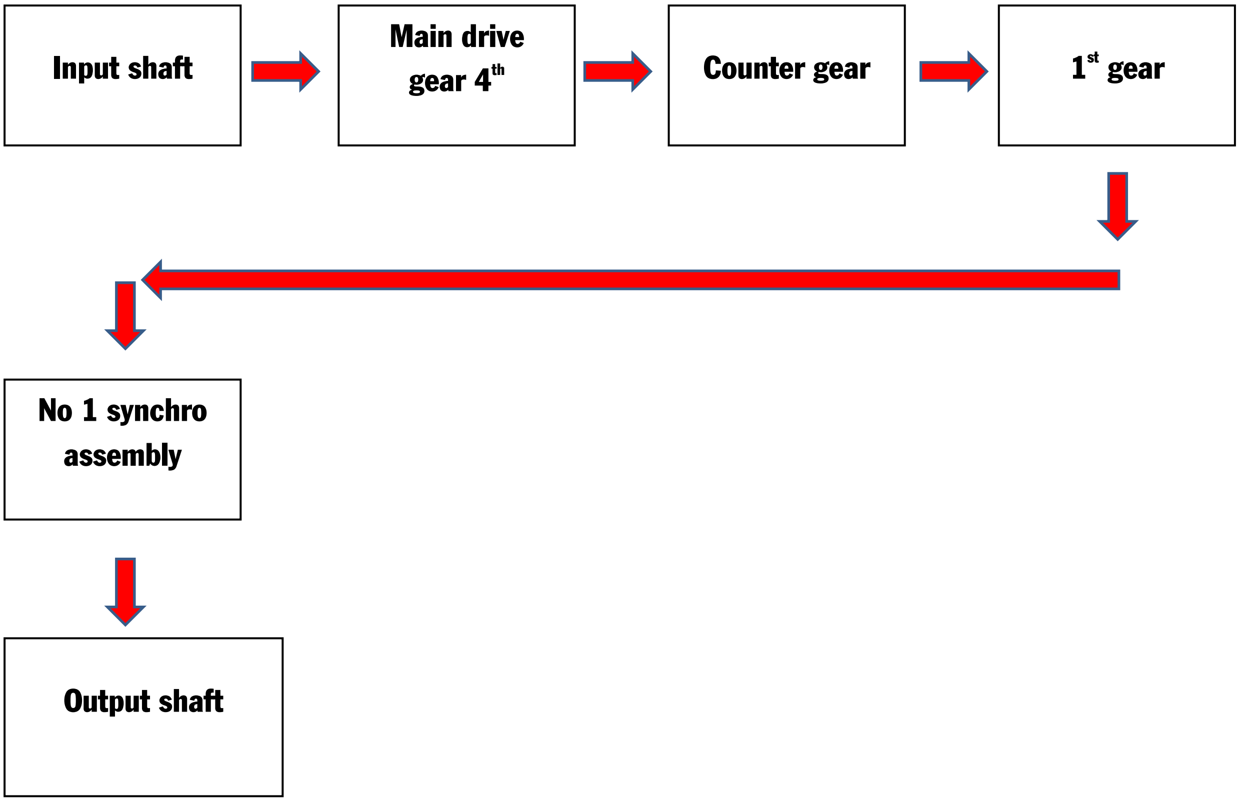
1st gear selected



Principle components of this front engine rear wheel drive transmission are input shaft, output shaft, counter or lay gear, synchroniser assemblies and the gears themselves. With the exception of the reverse idler gear (shown later) the gears are in 'constant mesh' with each other. Locking individual gears to the shafts effects gear selection. The synchroniser assemblies synchronise gear speeds prior to engagement to prevent gear crunching.

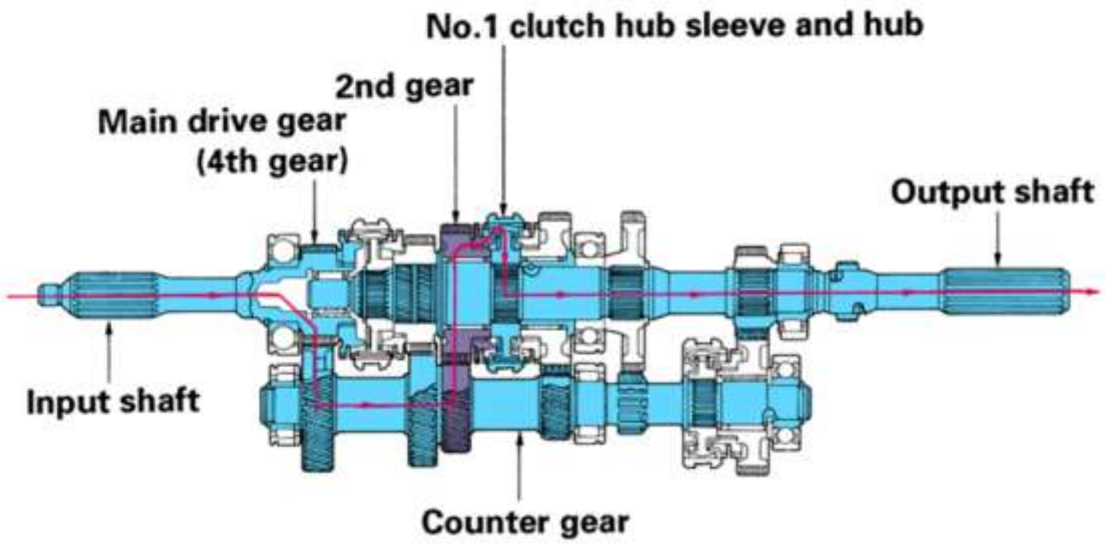
Torque flow diagram

Input shaft – Main drive gear 4th – Counter gear – 1st gear – No. 1 Synchro assembly – Output shaft



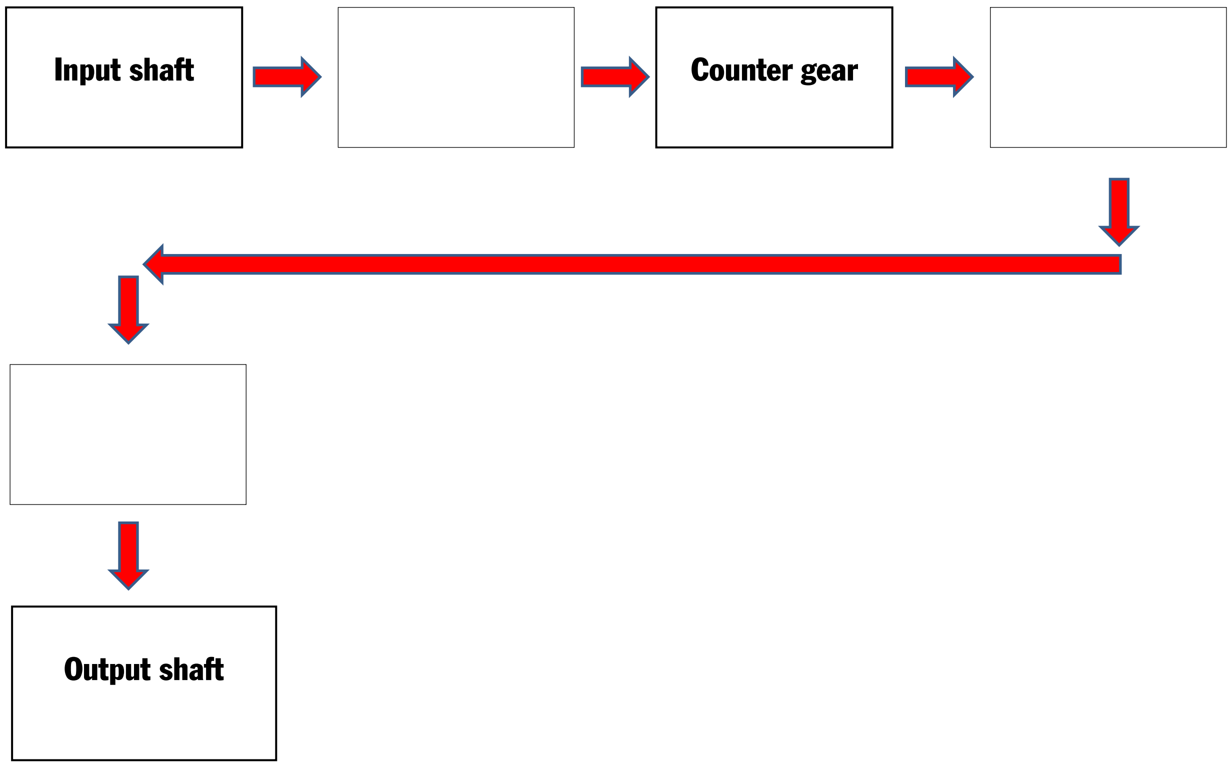
Torque flow in front engine rear wheel drive transmission

2nd gear selected

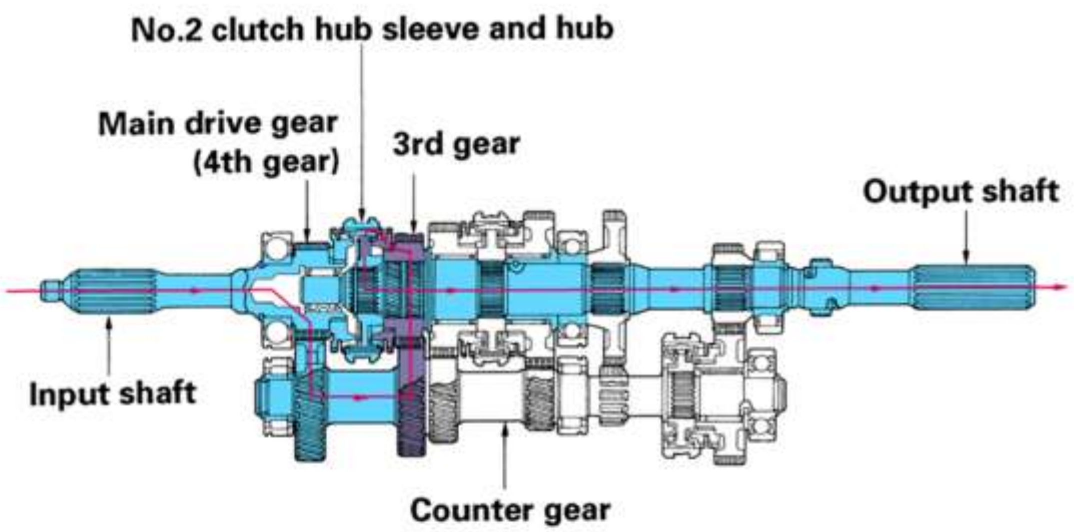


Exercise 7

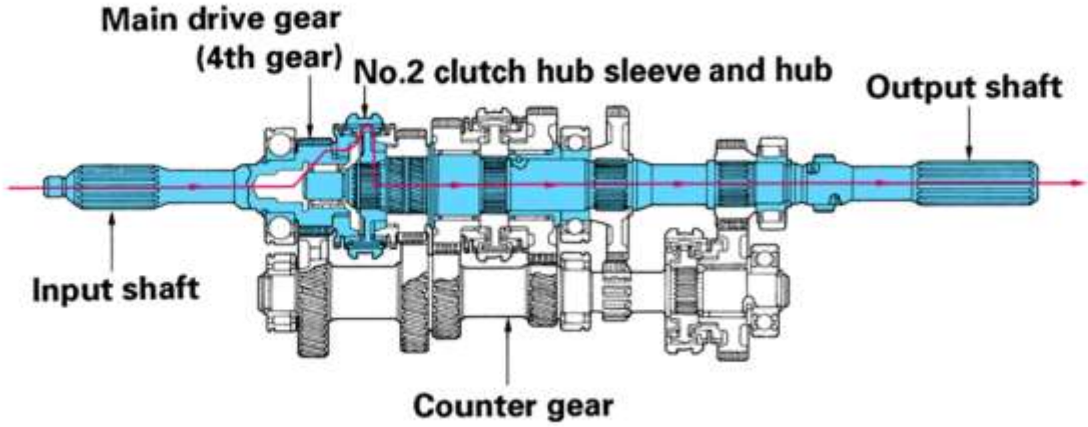
Complete the following torque flow diagram for 2nd gear



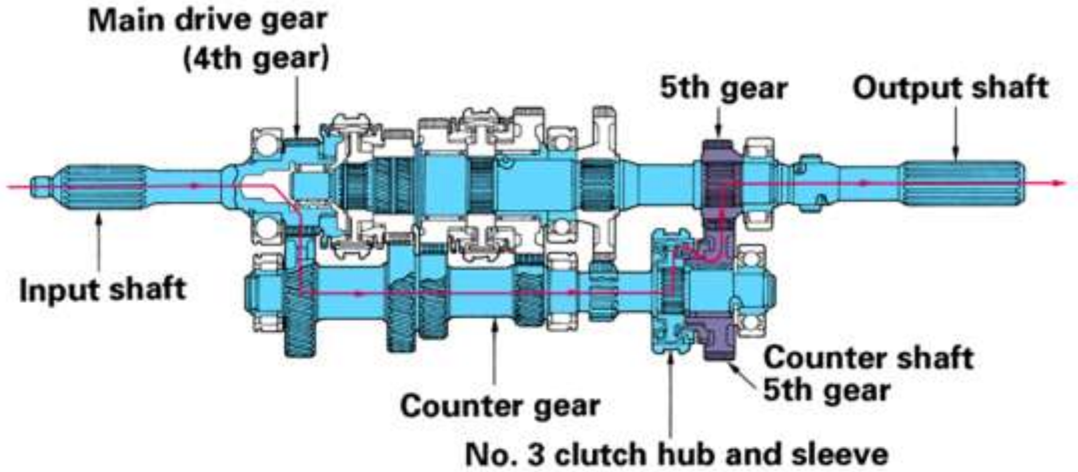
3rd gear selected



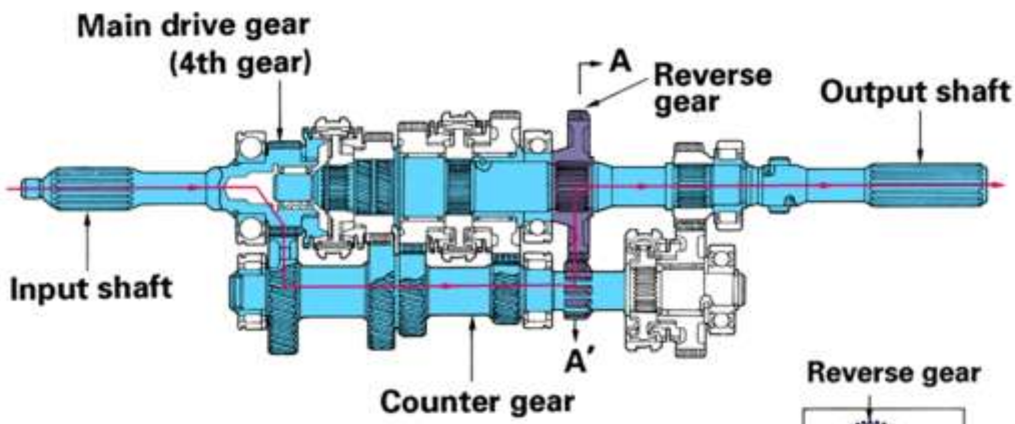
4th gear selected

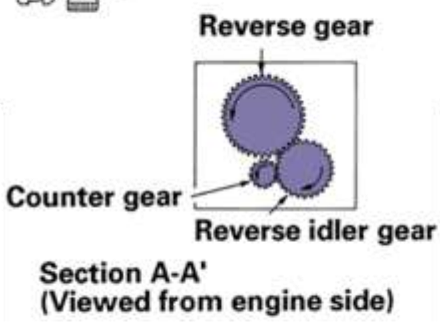


5th gear selected



Reverse gear selected

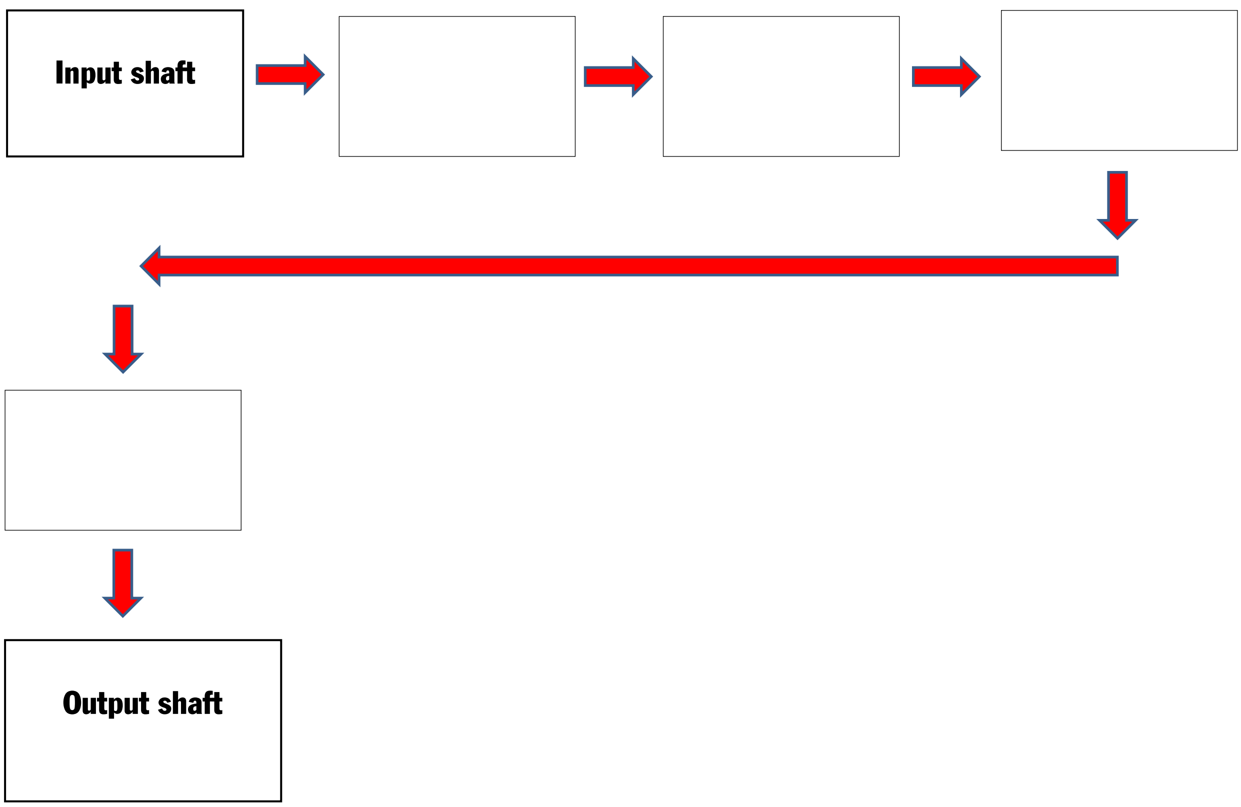




The reverse idler gear is usually engaged without the use of synchromesh as this gear should only be engaged when the vehicle is stationary, clutch disengaged (shafts stationary in the gearbox). The reverse idler is nearly always sliding mesh.

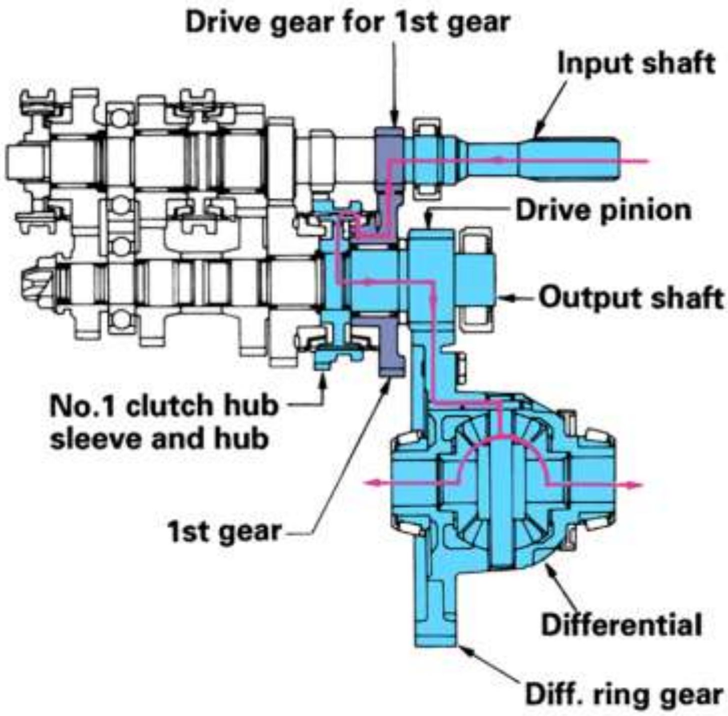
Exercise 8

Complete the following torque flow diagram for reverse gear



Torque flow in front engine front wheel drive transaxle

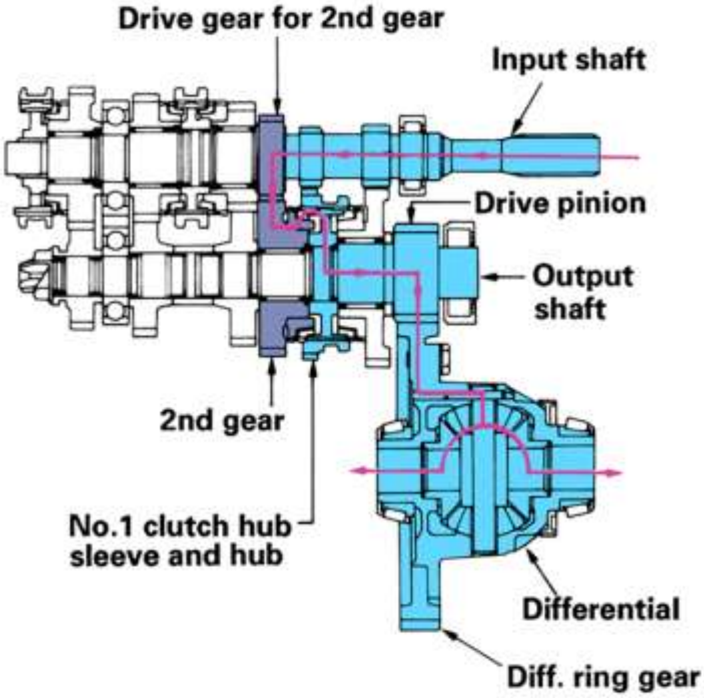
1st gear selected



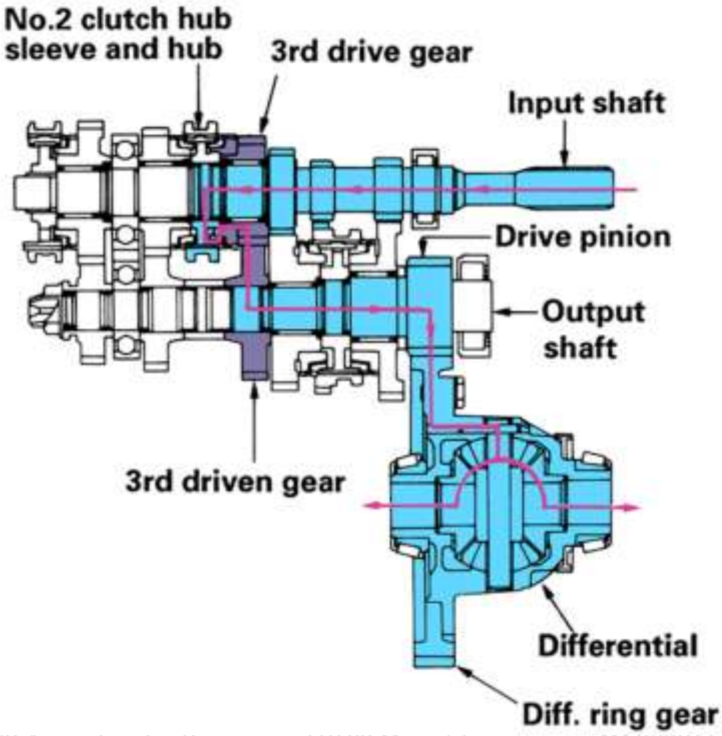
Torque flow diagram

Input shaft → **1st gear driver** → **1st gear driven** → **Number 1 clutch hub** → **Output shaft** → **Final drive pinion** → **Diff ring gear**

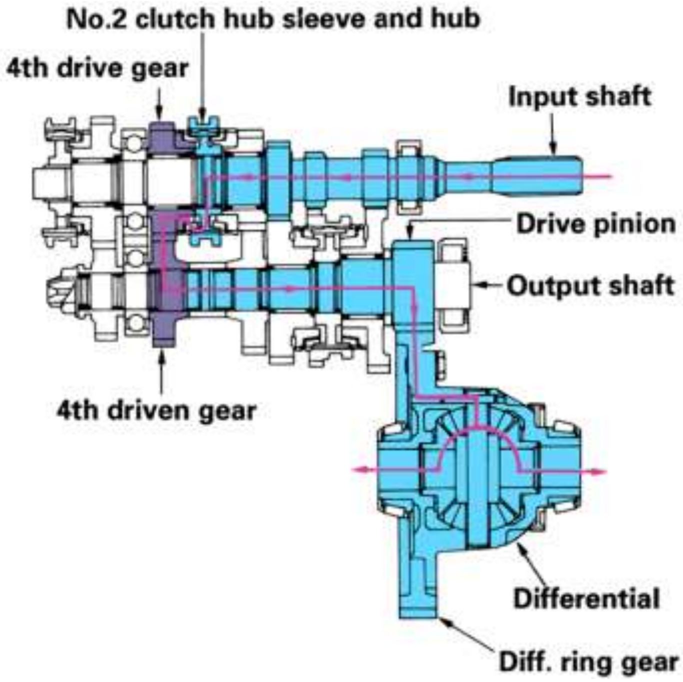
2nd gear selected



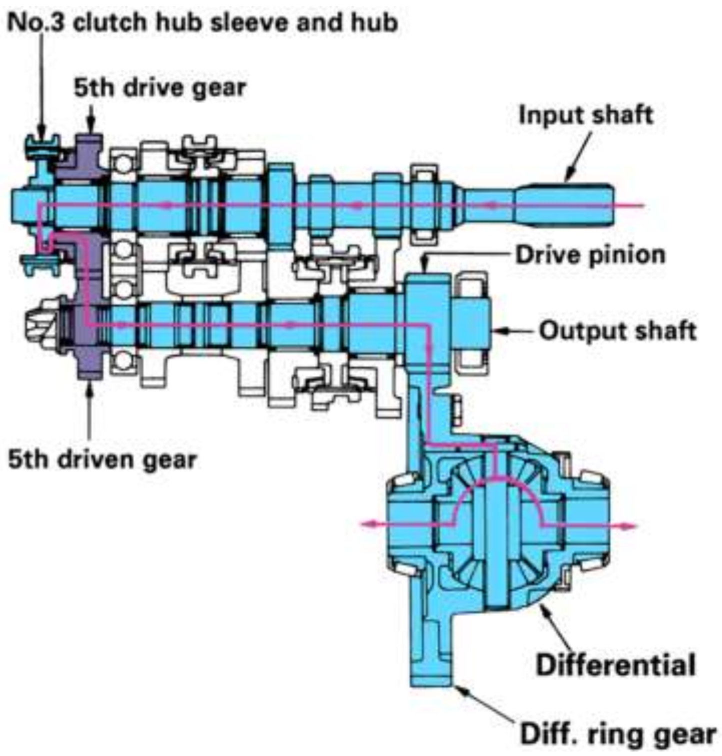
3rd gear selected



4th gear selected

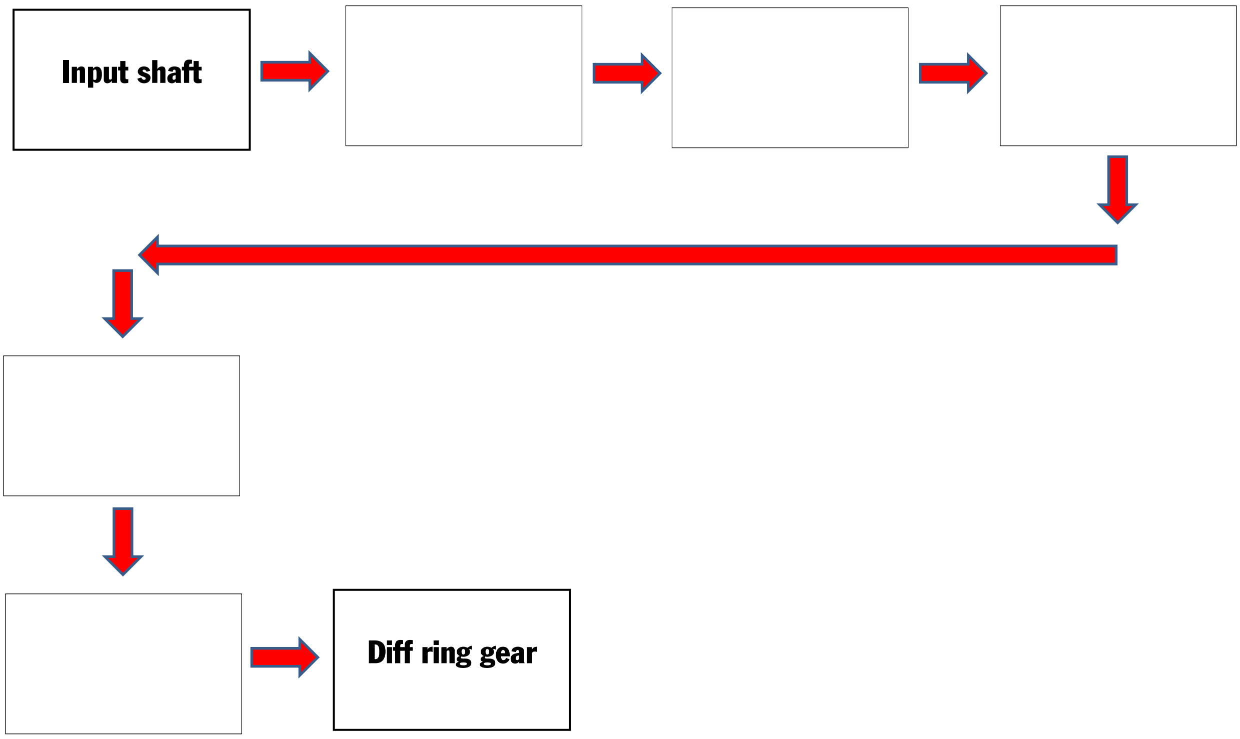


5th gear selected

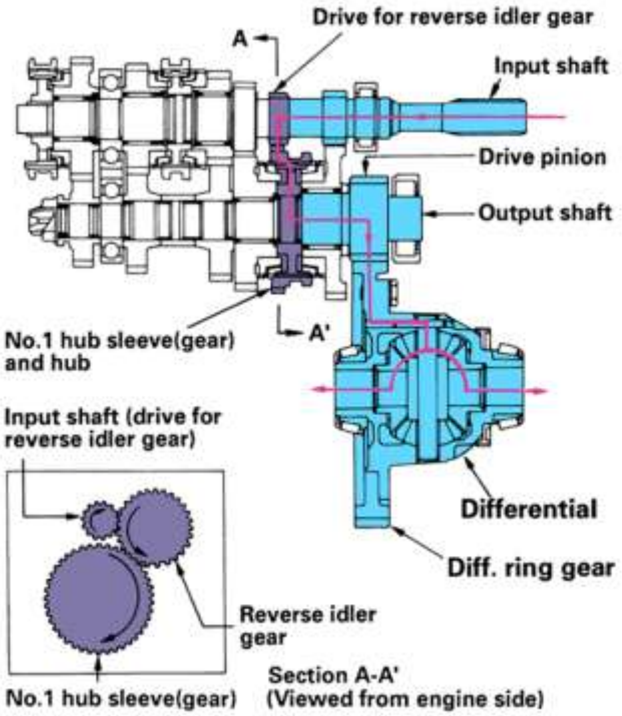


Exercise 9

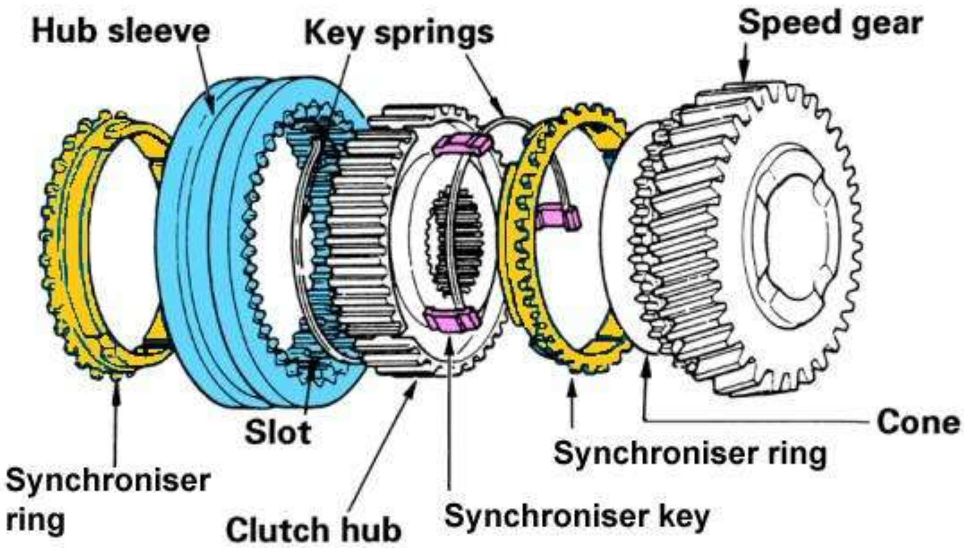
Complete the following torque flow diagram for 5th gear:



Reverse gear selected



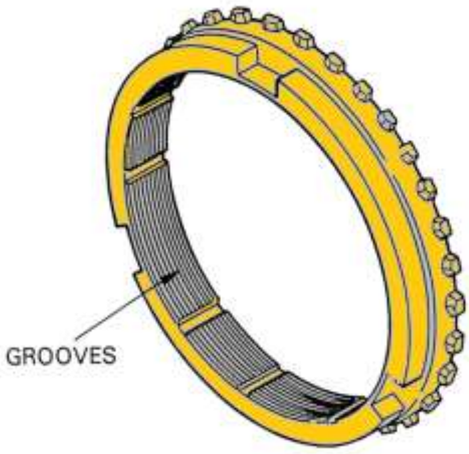
Key type synchromesh mechanism



We have studied the need for gear synchronisation and the solution to this need. It has been mentioned previously the fact that the driver is able to 'beat the synchro' if we use the very simple assembly illustrated previously. Baulk ring synchromesh uses an ingenious mechanism to physically prevent the driver from bringing the teeth of the dog clutches together until synchronisation has been achieved. Some manufacturers refer to the baulk ring itself as a synchroniser ring. This term will be used throughout this handbook.

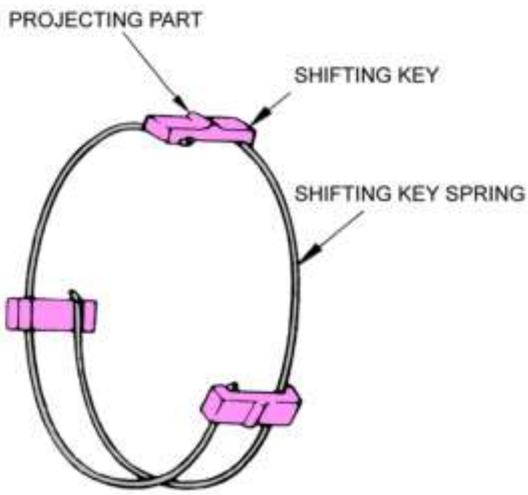
Synchroniser ring

Grooves are provided on the inner surface of the Synchroniser ring. They have the effect of cutting through the oil film to increase friction between the ring and the cone



Shifting keys

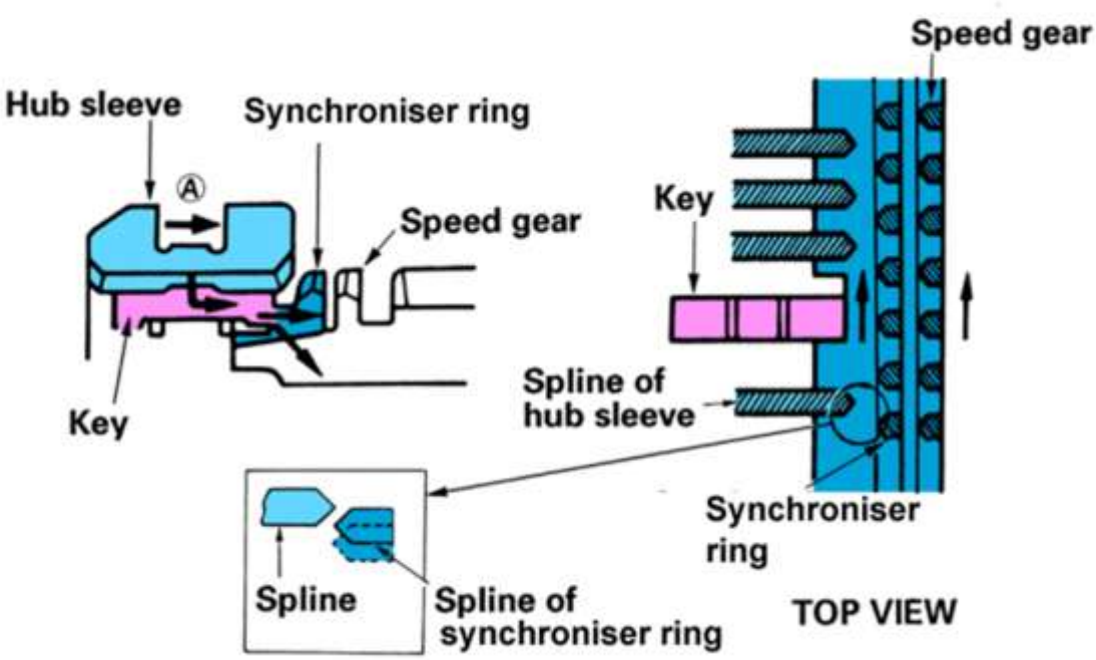
The shifting keys are kept under tension by the shift key spring



Synchromesh operation

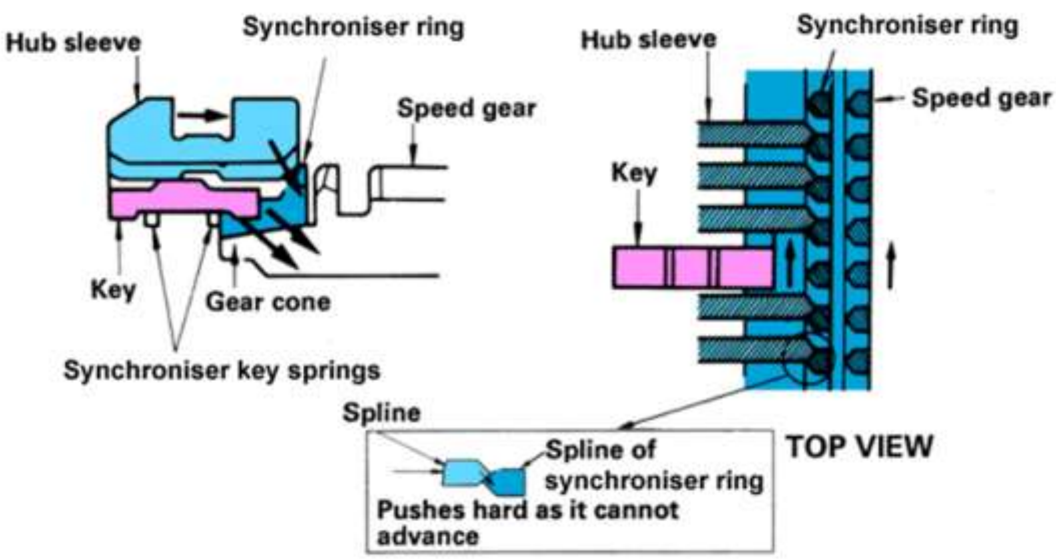
The shift leaver located in groove A moves the hub sleeve in the direction shown. The key situated between the hub sleeve and the clutch hub now pushes on the synchroniser ring against the cone of the gear. Because of friction the synchroniser ring moves in the direction of rotation.

Stage 1



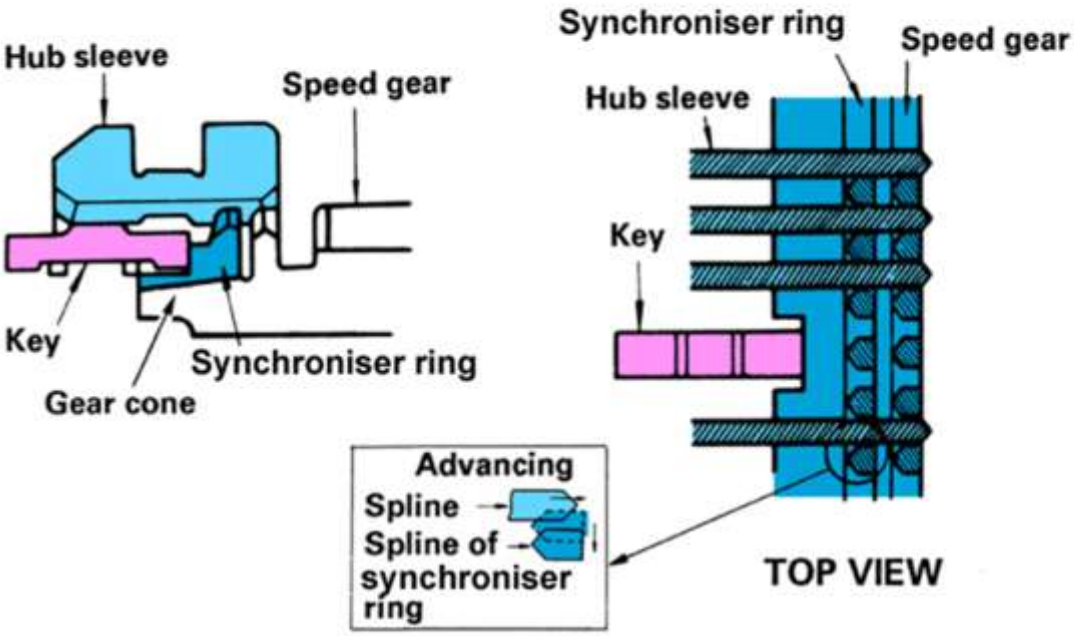
Stage 2

Further movement of the hub sleeve overcomes the key spring and the hub sleeve rides up onto the crest of the key. Misalignment of the hub sleeve and the synchroniser ring forces the synchroniser ring against the cone of the gear.



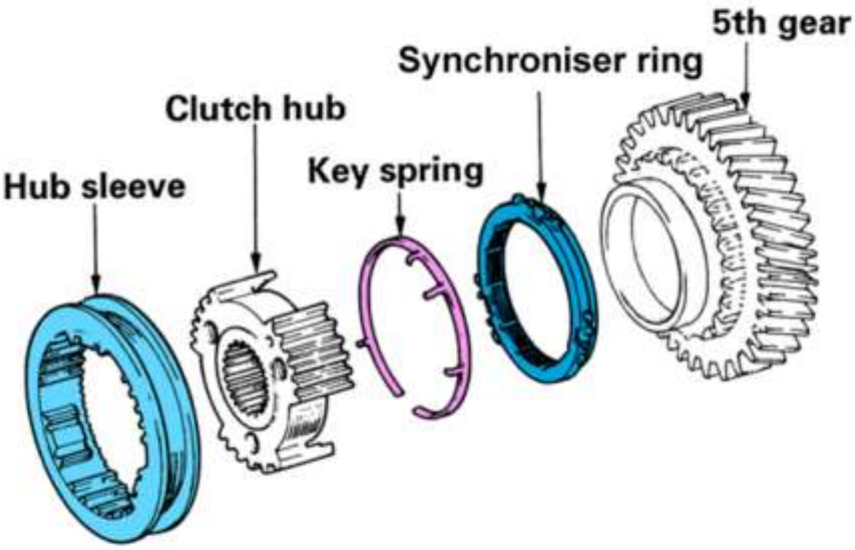
Friction causes the speed of the gear and the hub sleeve to synchronise

Finally when the speeds are synchronised the synchroniser ring can rotate freely and the splines in the hub mesh with the splines on the synchroniser ring



Alternative methods

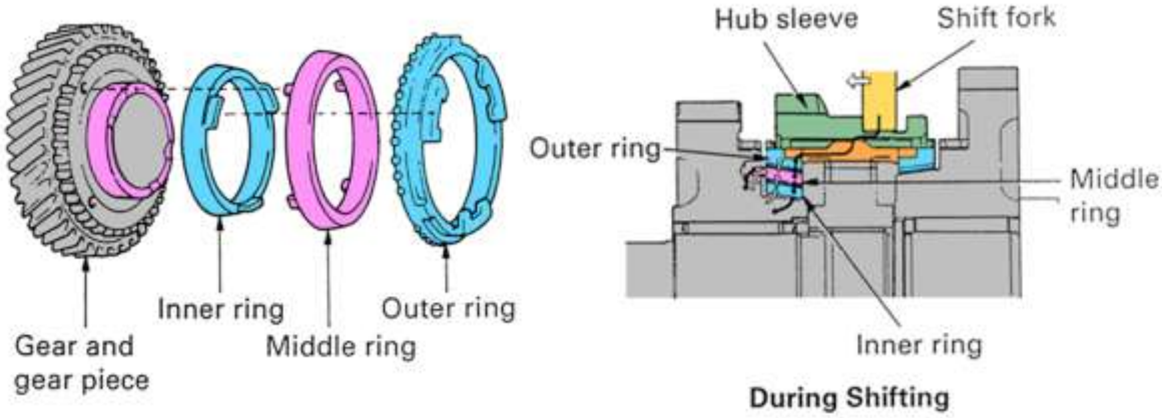
An alternative to the key type synchroniser is the keyless synchroniser assembly which uses a key spring with claws to carry out the function of the keys and key springs as described earlier.

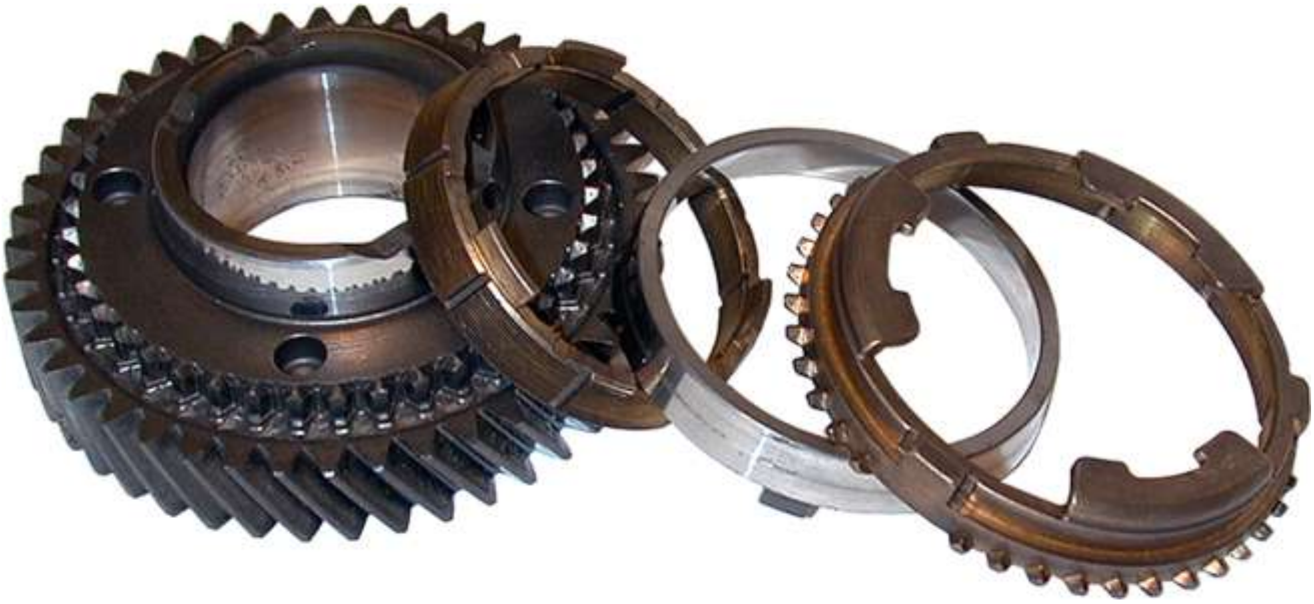


The key spring has four claws. One claw is used to locate the key spring in place. The remaining claws act much the same as the synchroniser keys in the key type synchromesh system.

Multi cone synchromesh

The triple cone, or double synchromesh, improves gear selection by practically doubling the friction surface



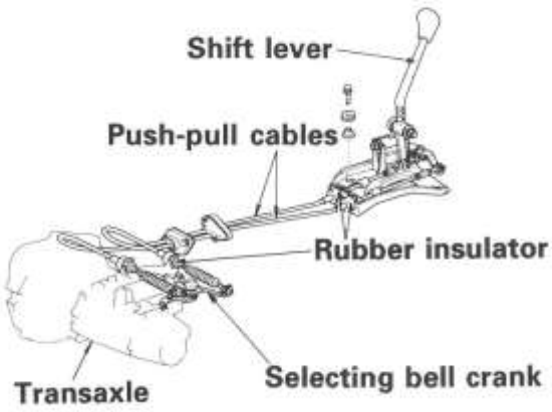


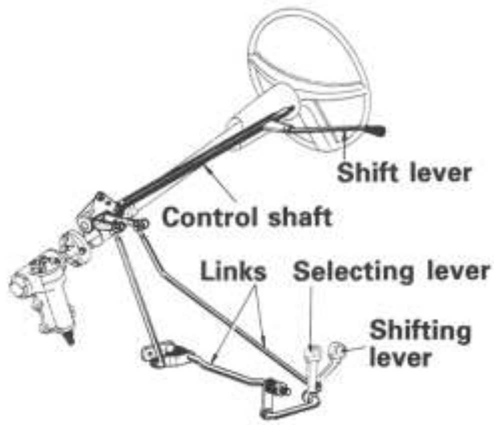
Triple cone or double synchromesh assembly

Gearshift control mechanisms

Gear selection mechanisms can be of the remote (indirect) or the direct control type. Indirect mechanisms can be floor mounted, dashboard mounted or located on the steering column

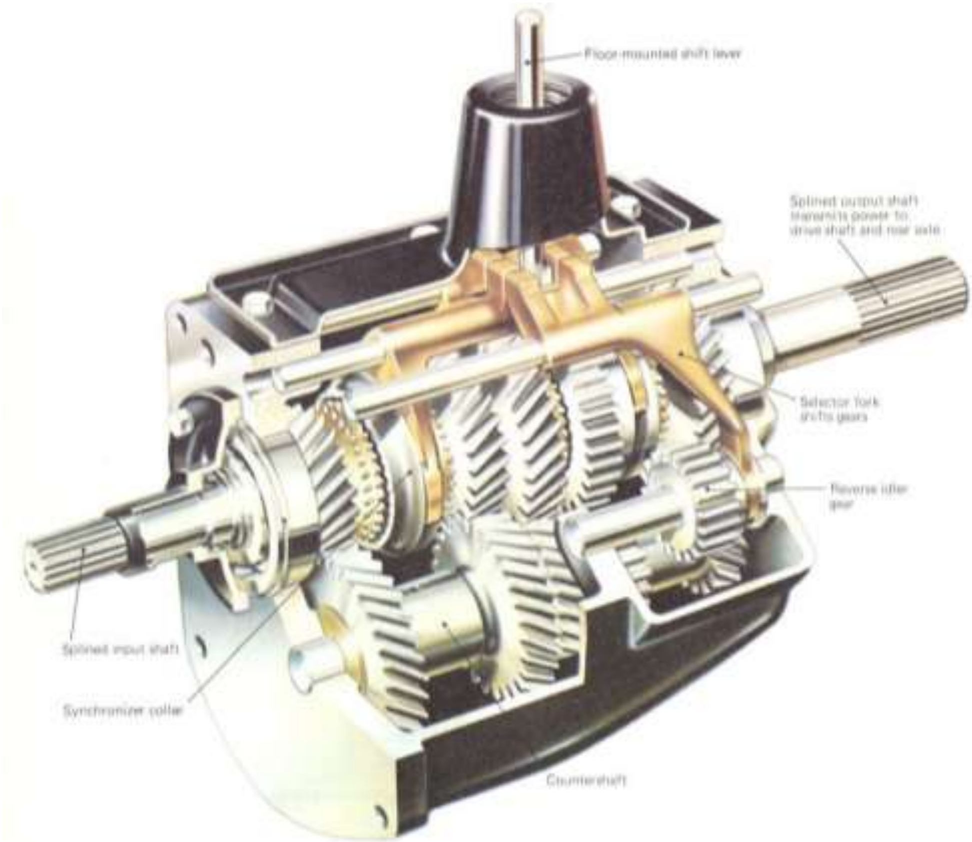
Indirect control





Direct control

Direct gear selection mechanisms are usually associated with rear wheel drive layouts. The transmission is mounted longitudinally enabling the extension housing to reach far enough back into the vehicle for driver to make gear selection

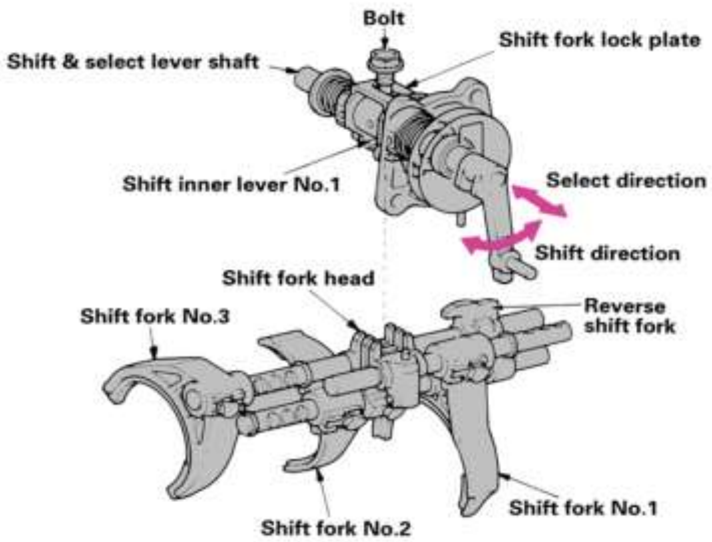


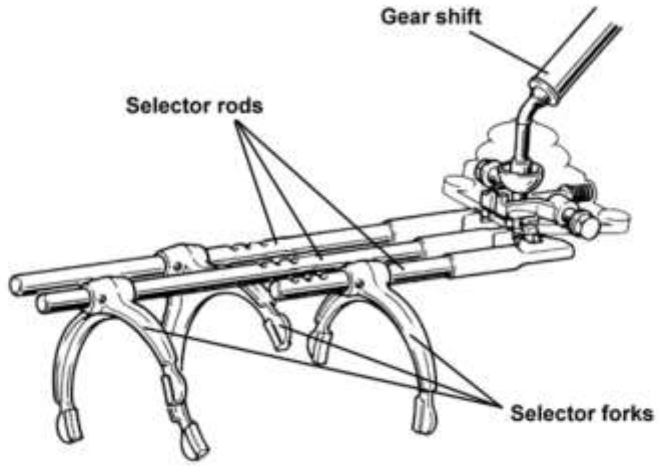
Every gearbox selector must be fitted with the following:

- An interlock mechanism that prevents two gears from being selected at the same time.
- A selector detent, this will hold the gears and selectors in position and will prevent unintentional gear selection.

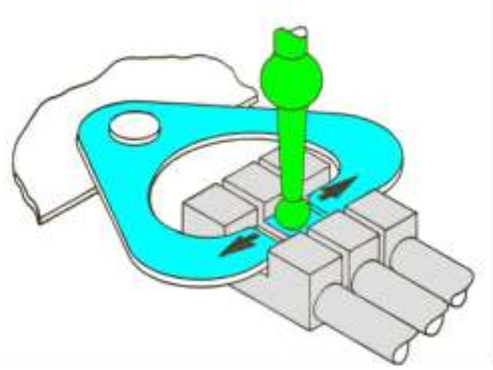
Interlock mechanisms

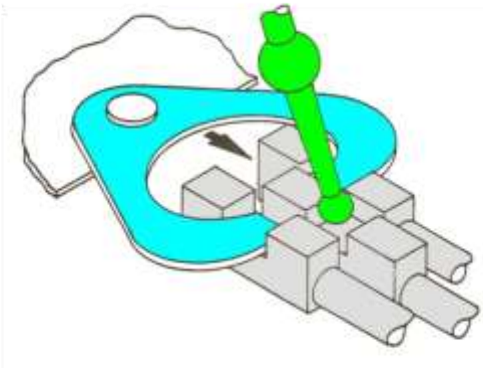
The double meshing prevention mechanism is essential to prevent the section of two gears at the same time and severe damage to the transmission. The shift fork lock plate fits into two of the three shift fork head slots locking all shift forks except the one in use.

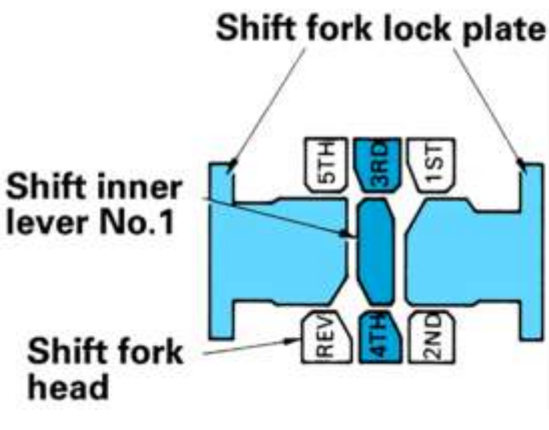


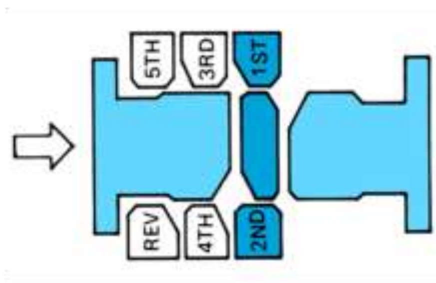


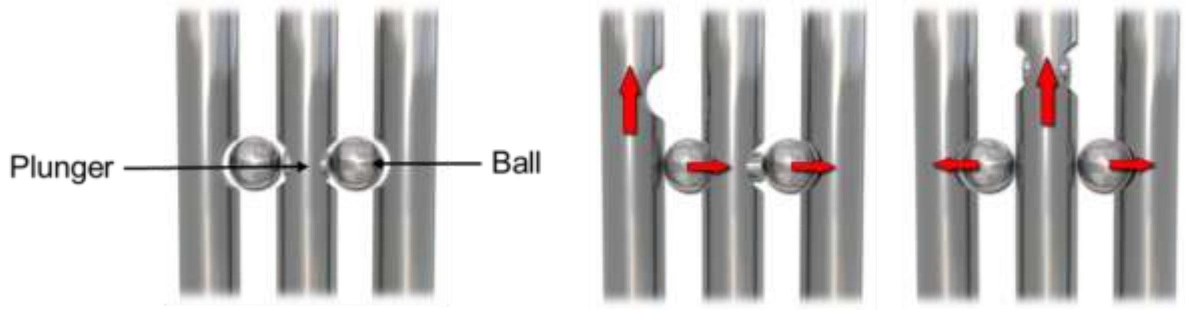
Indirect type Direct type





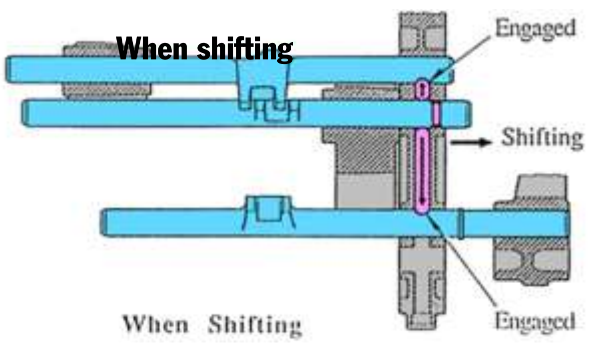


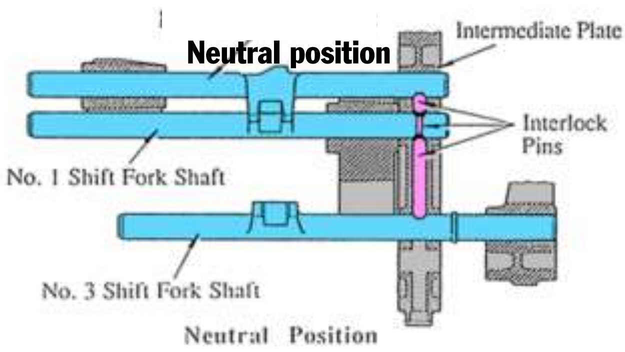




The mechanism is made up of a plunger and two balls. The diameter of each ball is greater than the spaces between the rods. When one of the outside selector rods is moved to select a gear, the full diameter of the rod presses its adjacent ball into the groove around the centre rod. The action of the ball secures the centre rod in the neutral position, but it also pushes the plunger (located inside the centre rod) against the second ball, locking the other selector rod in the neural position.

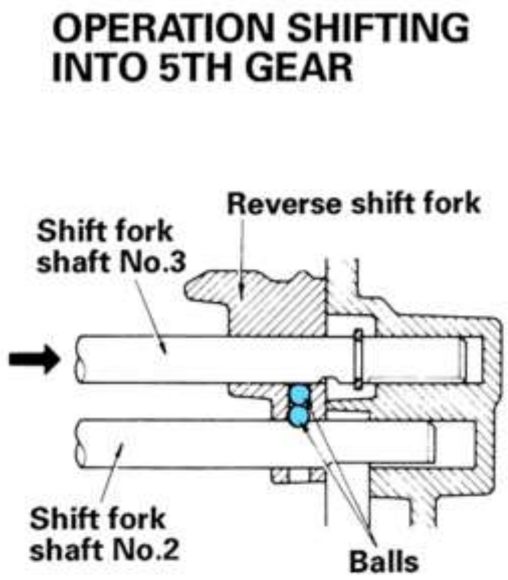
In this type of interlock mechanism the interlock pins fit into slots in the shift fork shafts. The movement of shift fork shaft No. 1 has pushed the interlock pins further into the shift fork shafts, locking them into position and preventing the selection of two gears at once

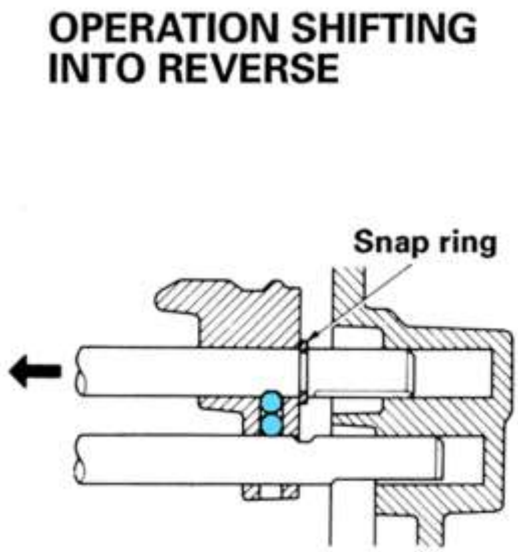




Reverse one way mechanism

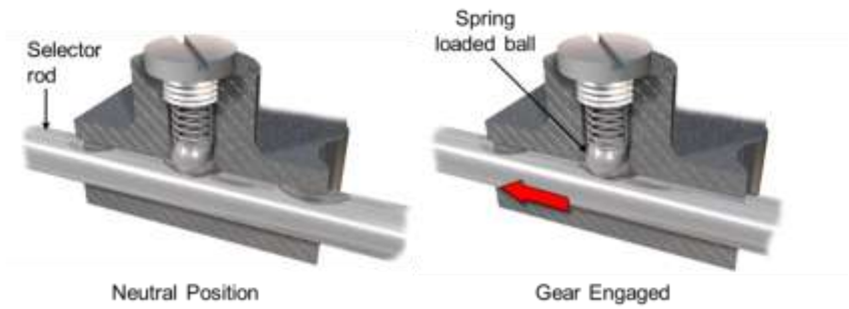
Shift fork number 3 moving to the right to select 5th gear forces the balls tighter into the groove on reverse shift fork, Number 2, preventing the reverse shift fork from moving. Selecting reverse causes the snap ring to move the reverse shift fork to the left

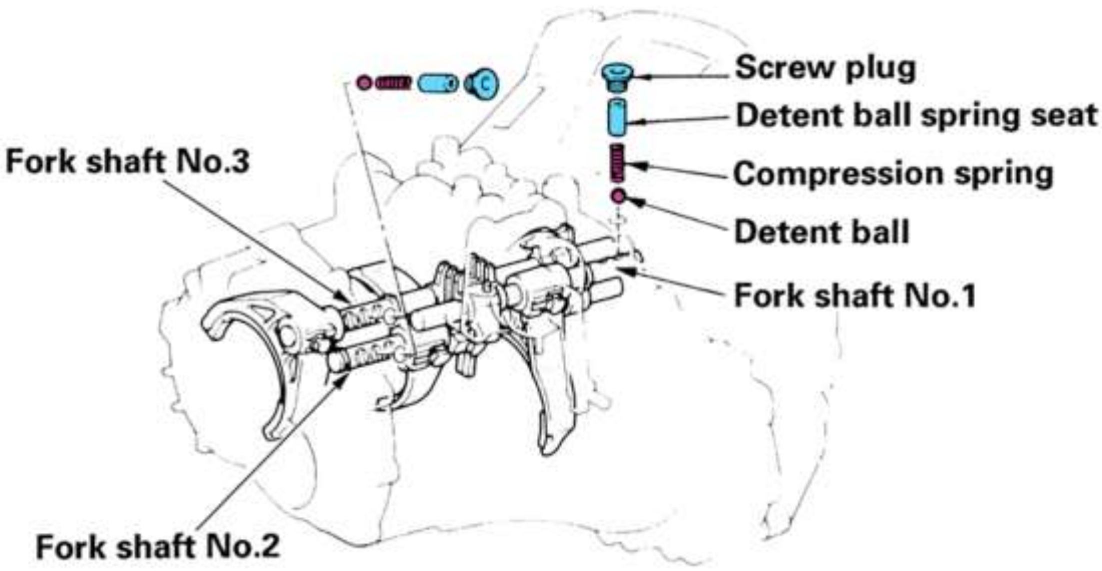




Selector detent

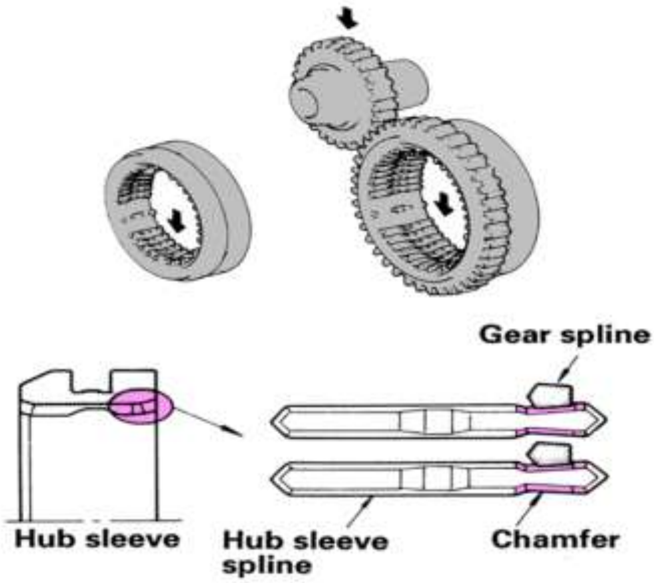
Each selector rod has a separate detent device. The detent consists of a ball and a spring. Machined into each selector rod are three grooves. These grooves correspond with the gears the rod is responsible for, i.e. 1^{st} – 2^{nd}. When the gear is selected the groove aligns with the ball and the spring maintains pressure. This effect stops the gear from jumping out of mesh and provides the driver with a positive feel.



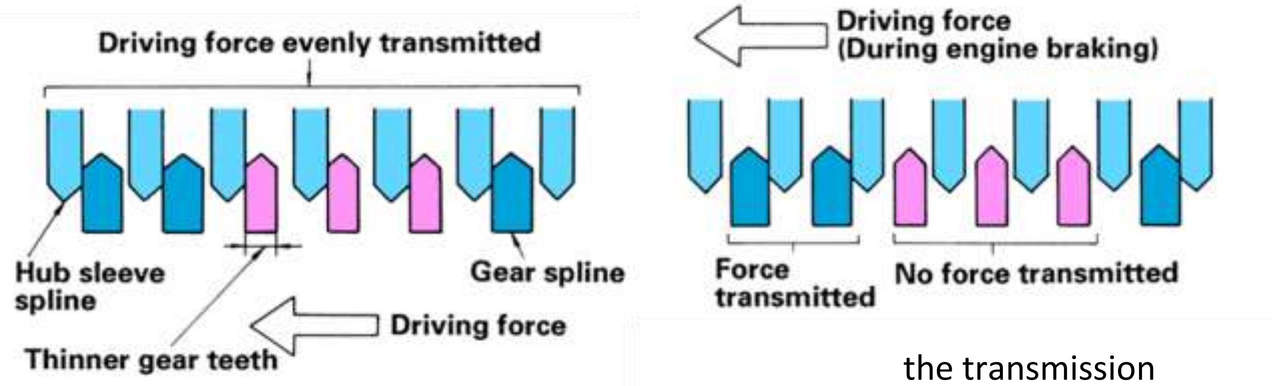


Shift detent mechanism – on hub

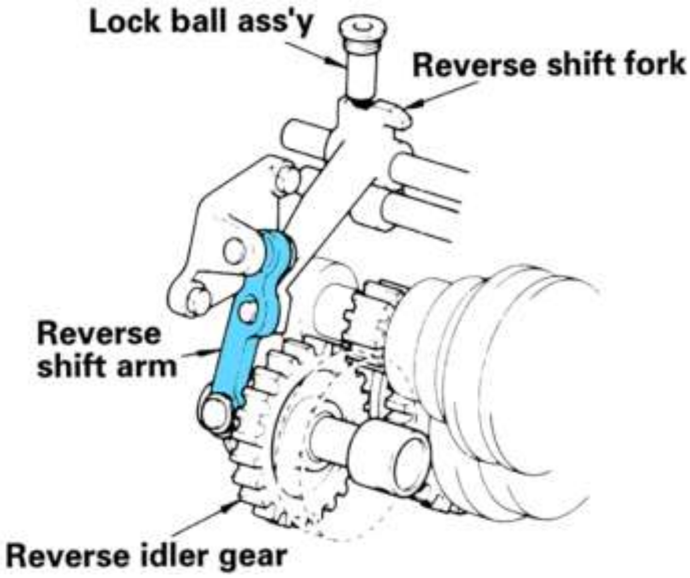
The hub sleeve splines have been chamfered on this reverse gear mechanism. A corresponding taper on the gear spline helps prevent the transmission from jumping out of gear.



Transmissions have a tendency to jump out of gear during engine braking or over run. Splines of different thickness are provided on the gear spline. During engine over run fewer splines are in contact increasing friction and preventing the transmission from jumping out of gear



Reverse gear detent



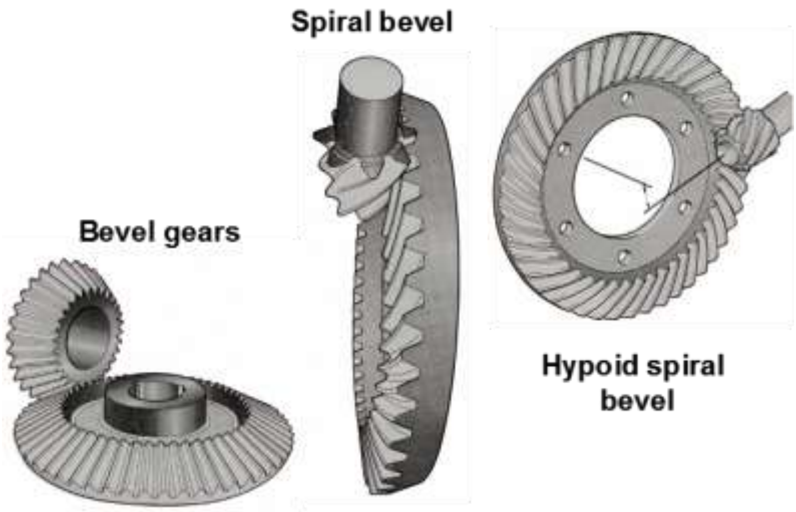
A locking ball is forced against the reverse shift fork to prevent the fork from moving when in forward gears or neutral and provide positive feedback to the driver when selecting reverse.

Final drive and differential

A vehicles final drive system is in effect two assemblies combined – the final drive gear set and the differential.

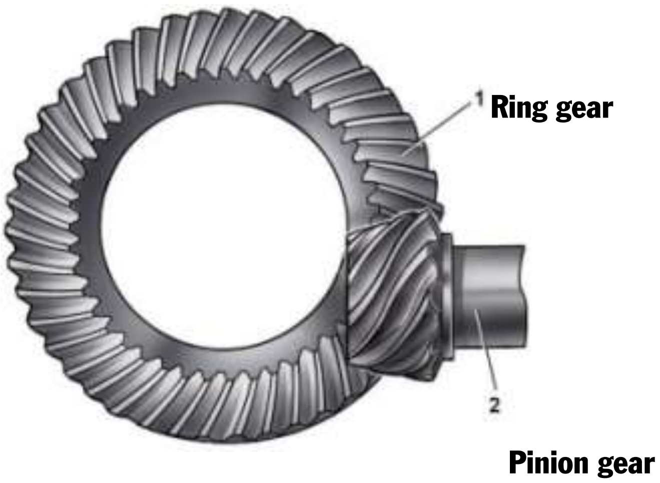
The final drive gears primary function is to further multiply torque (commonly approx. 4:1) received from the gearbox and direct this to the differential. The differential distributes this torque to the driven wheels but also allows a difference in wheel speed to occur between these during certain conditions (such as cornering.

Final drive



Final drives are of two distinct types – bevel gear and helical gear. The type used is very much dictated by the vehicles drive configuration. A front engine rear wheel drive vehicle will use a bevel gear type (as long as the engine is longitudinally mounted) as the drive from the gearbox runs from front to rear on the vehicle, so there is a requirement to change the drive direction through 90 degrees out to the driven wheels. A bevel gear assembly lends itself to this task perfectly. If the vehicle is front engined front wheel drive or perhaps rear / mid engined rear wheel drive, it is most likely that a helical gear set will be used as there is no requirement to achieve a drive direction change (transversely mounted gearbox). The diagram above shows gear sets suitable for the former mentioned drive arrangements that are a variation on this theme.

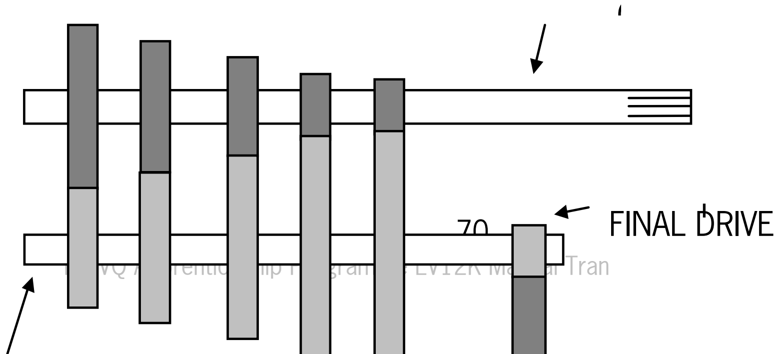
The spiral bevel gear assembly is a standard bevel gear arrangement whose teeth have been cut with a pronounced helix (spiral shape). This arrangement increases the area of tooth contact between the pinion and the ring gear (sometimes referred to as a crown wheel) therefore increasing its ability to transfer torque without risk of damage or excessive wear occurring. The rolling action of the teeth also reduces noise considerably. The hypoid spiral bevel gear assembly is now used almost universally where the drive layout dictates the need for drive direction change. It is identical to the spiral bevel with one exception – the pinion gear is lowered to a point beneath the centre line of the ring gear. This further increases tooth contact area with all of the advantages that we can now associate with this.



In both instances the final drive gear set compounds the selected gear ratio to further increase torque (and reduce driven speed). All drive from the gearbox has to pass through the final drive assembly, so it can be seen that every gear ratio available will be affected by the final drive ratio. Motor sport teams often exploit this fact to bring about a quick and relatively easy change of ratios throughout the vehicles transmission system to suit various conditions such as:

High speed tracks – smaller final drive ratio for increased top speed

Low speed tracks – higher final drive ratio for faster acceleration

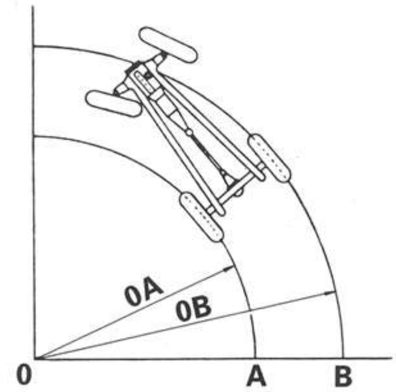


Helical gears

The diagram on the right shows a helical cut gear suitable for transversely mounted gearboxes. A helical gear is one whose teeth have been cut at an angle and this has the effect again of increasing tooth contact area and reducing noise. It does unfortunately produce end-thrust as a result of this angular cut (the gears try to force themselves out of mesh in the axial direction). This end thrust has to be contained by the gearbox casing and if the torque is considerable, this casing will have to be very strong and will therefore be heavy. A point is often reached where the torque (and end-thrust associated with this) is so large that straight cut gears (spur gears) have to be used. These are very noisy. However, the sort of torque figures that we are talking about are normally only found in the motorsport arena and on load carrying vehicles where noise isn't such an issue!

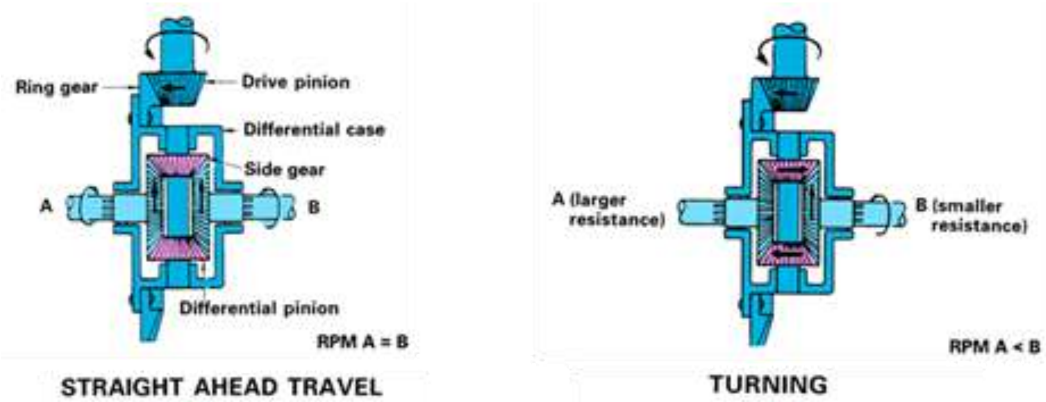
Differential

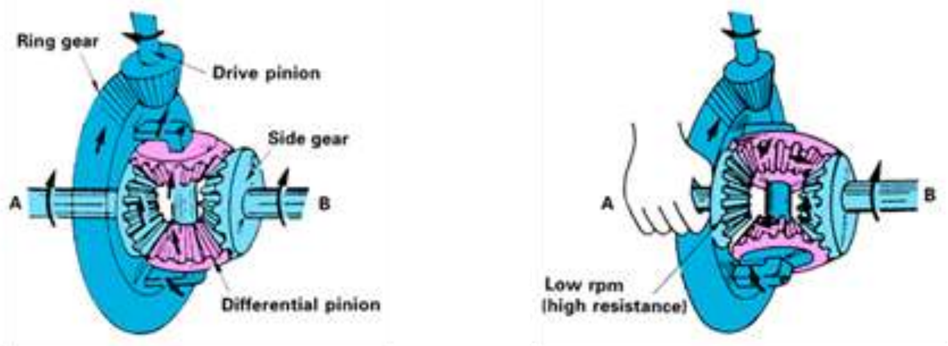
When a vehicle corners, the inside wheels rotate at a slower speed than the outside wheels. This is because the inside wheels effectively 'cut the corner' and therefore have less distance to travel (see diagram on right). All wheels are of course attached to the vehicle, therefore in order to keep up with the vehicle the outside wheels will have to turn at an increased speed because of the difference in distance. Imagine a line of people ice skating who decide to join hands and rotate around the first person using them as a pivot. The further towards the end of the line of people you are, the faster you have to go even though you are all part of the same overall body of people.

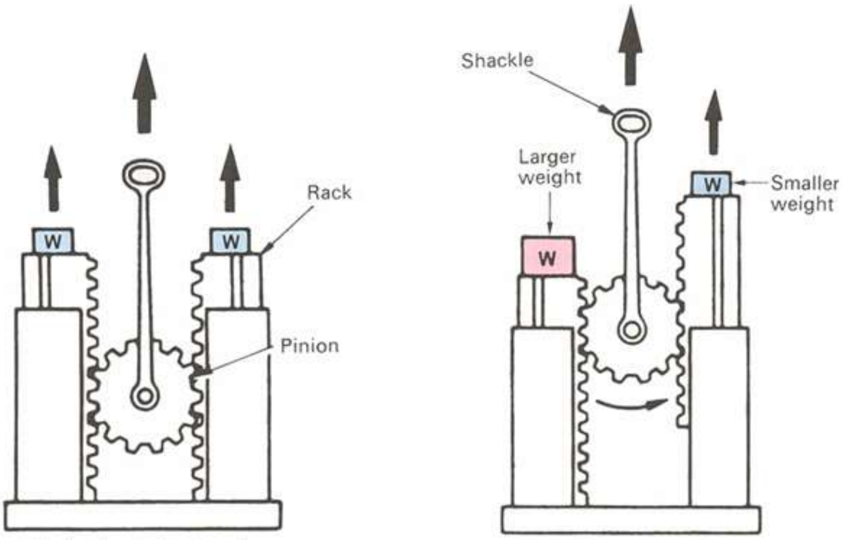


Distance A < Distance B
RPM of inside wheel < RPM of outside wheel

With non-driven wheels, this difference in speed is not a problem as these wheels are independent of one another. However, with driven wheels this is more of a problem as they are connected together courtesy of the drive shafts and final drive assembly. The differential allows for this difference in speed with no loss of drive. It should be noted that differences in rotational speed have to be accommodated in instances other than cornering. Uneven tyre wear / tyre pressures across the driven axle will result in differences in rolling radii; imperfect road surfaces and road camber – these will all result in differences in rotational speed.



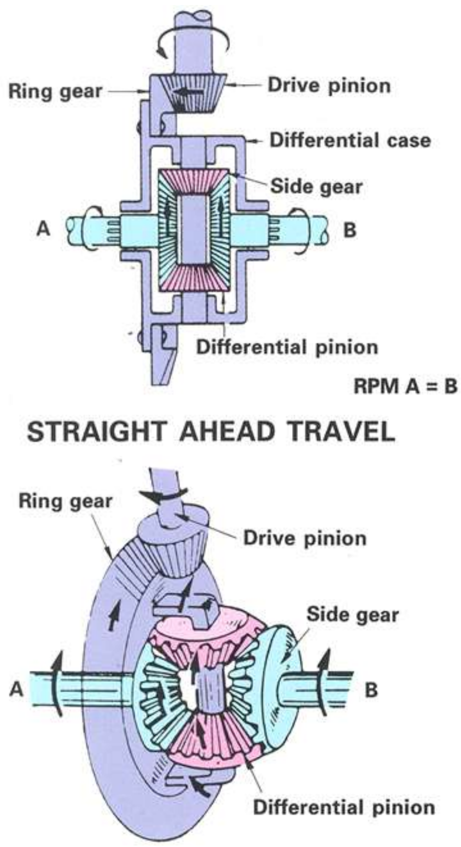




(a) Both racks travel the same distance.

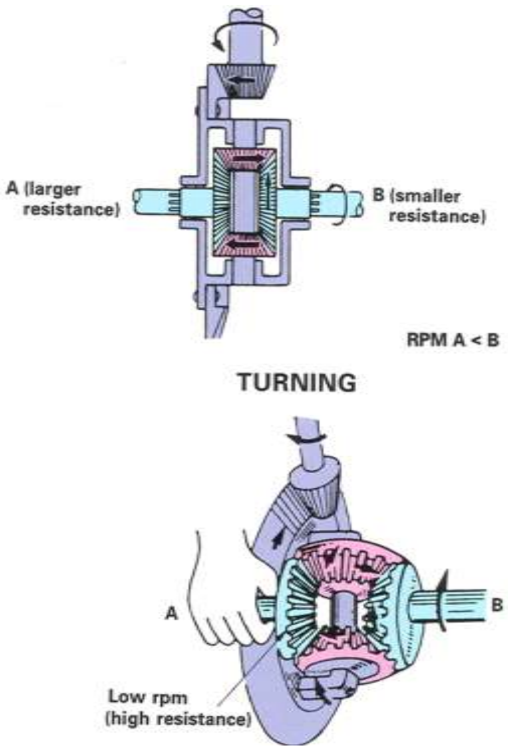
(b) The rack subject to the smaller resistance travels further.

The diagram above shows the principle of differential action. The central gear is meshed to two gear racks. These racks are free to slide up and down in their respective runners. The diagram to the left shows the racks with equal mass acting upon them. As the central gear is pulled up, this upwards motion is transferred directly and evenly to each rack and each rack moves a distance equal to each other and the central gear. The diagram on the right of figure 10 shows the racks with unequal mass acting on them. The rack on the left has a far greater mass acting on it. When the shackle is now pulled the central gear will rotate to enable the rack on the right to lift further (and more quickly) than the rack on the left. The course of least resistance is taken. A vehicles differential works in a very similar fashion. As the vehicle corners, the resistance to rotation of the inside wheel increases (the equivalent of a greater mass acting on it) and the resistance to rotation of the outside wheel reduces (the equivalent of less mass acting on it). The differential takes the course of least resistance and sends more of the drive (speed) to the outside wheel. This drive split is directly proportionate. The speed of the outer wheel will increase by the same amount that the speed of the inside wheel reduces.



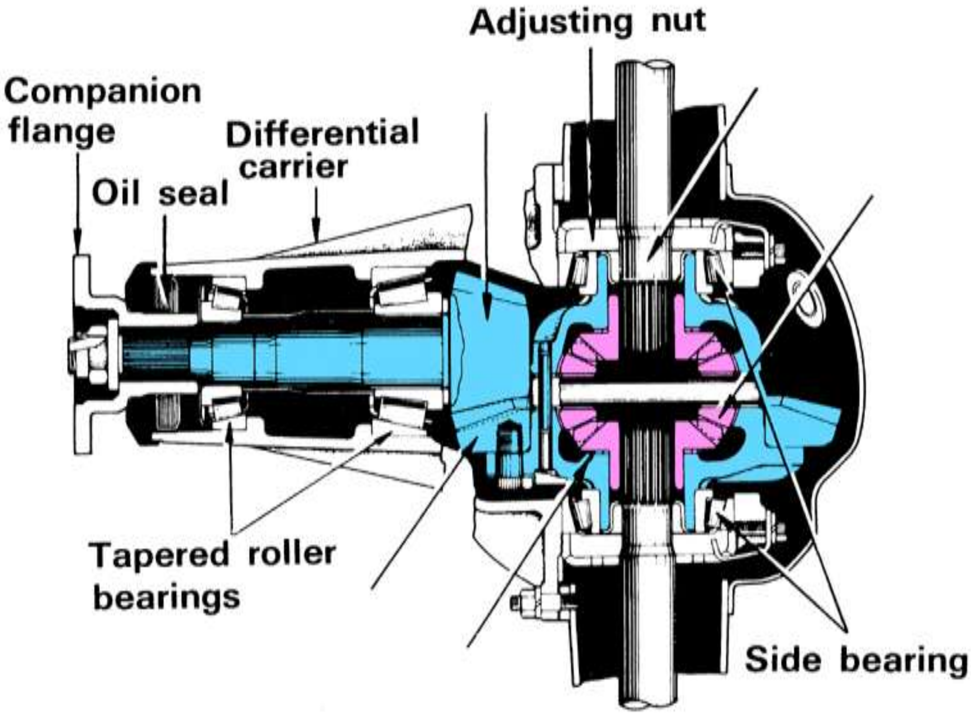
The diagram to the right shows a final drive differential assembly as used on a front engine rear wheel drive vehicle. It shows this assembly in a condition of 'no difference in rotational speed'. Drive flow through the assembly will be as follows: Drive from the gearbox is received via the prop shaft onto the drive pinion. The drive pinion transfers this drive to the ring gear (crown wheel). Mounted directly onto the ring gear is the differential case (cage) so as the ring gear rotates so does the differential case. The differential drive pin is mounted directly into the differential case and rotates with it, taking around the differential pinion gears. The differential side gears are directly meshed to these pinions and therefore rotate with them. The side gears are splined to the drive shafts / half shafts and therefore the drive is sent directly to the road wheels. With equal resistance to rotation at both of these wheels, the differential pinions will rotate with the differential case but not about their own axis (the drive pin).

The diagram on the right shows the differential compensating for a difference in required driven wheel speed. The flow of drive is identical up to the differential drive pin. The differential pinions rotate with this drive pin but as the differential finds it difficult to rotate the left hand wheel (in this example) due to the larger resistance experienced during a left hand corner manoeuvre, the differential pinions now start to rotate about their own axis and in the process increase the speed of the right hand wheel proportionately.



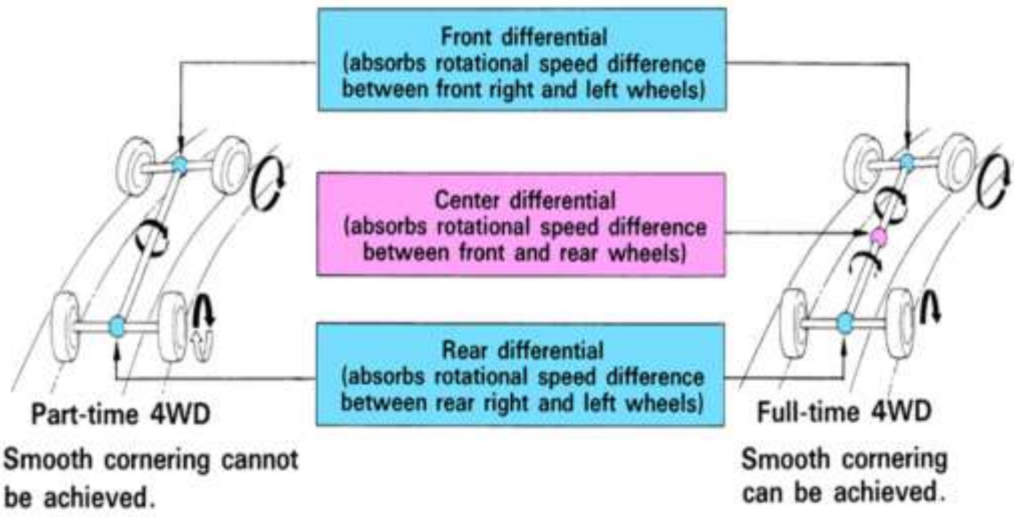
Exercise 10

Complete the labels by naming the parts correctly on the diagram below:

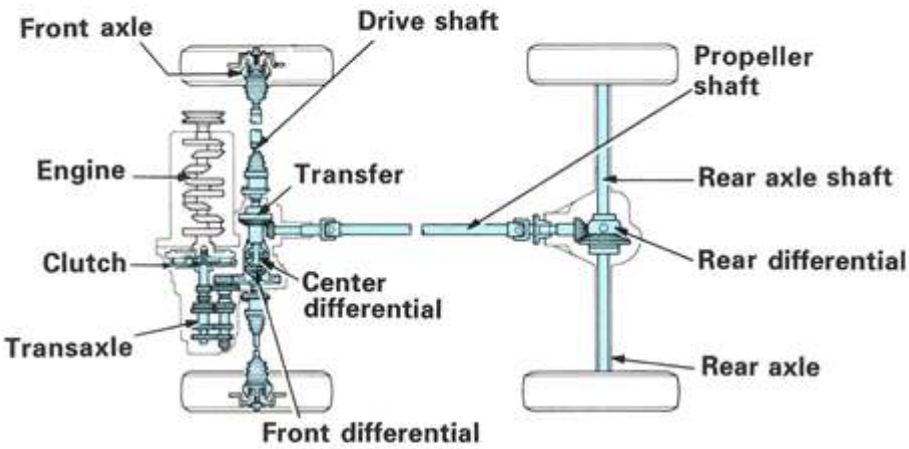


All-wheel drive

All-wheel drive vehicles require a differential assembly for both axles as both are driven. We no longer have a ‘dead axle’ that is able to absorb differences in rotational speed. In addition to this requirement, a third differential is required to allow for a difference in speed between the two axles

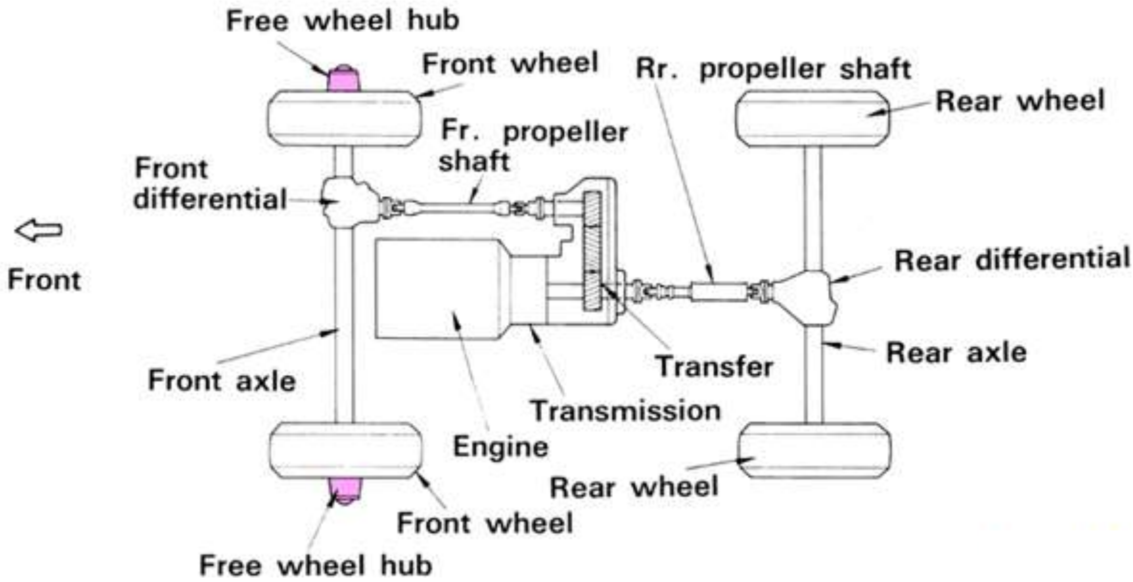


The third differential is also known as the centre differential. The diagram below shows a typical layout. The centre differential relays the drive to the transfer gear set whose primary role is to turn the drive through 90 degrees in order for that drive to be sent to the rear of the vehicle.



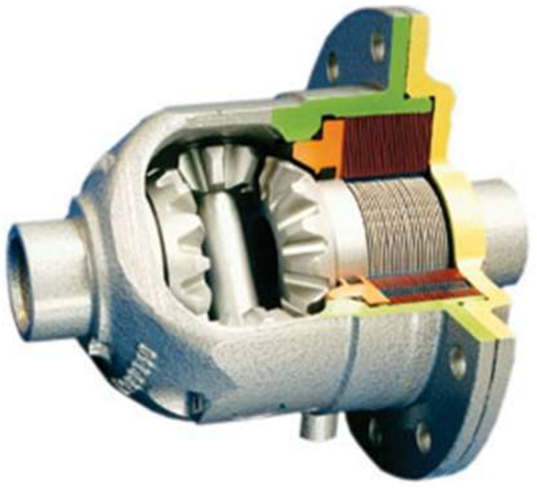
4WD TYPE (Full-time 4WD)

Part time 4 wheel drive



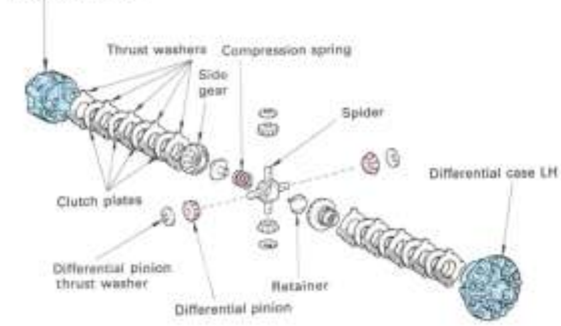
The diagram above shows a part time four wheel drive vehicle. These vehicles provide a four wheel drive option when the vehicle is to be used off-road. As these conditions would suggest that the vehicle is on slippy ground, a centre differential is seldom provided as any difference in rotational speed can be absorbed through natural slippage of the driven wheels on such ground. These vehicles should not be driven on hard standing (such as metaled roads) with four wheel drive engaged as the tyres will struggle to slip with the large amounts of grip that they will now have and this will result in transmission 'wind-up'. Wind-up is a condition where the transmission shafts absorb the difference in rotational speed at the road wheels by twisting. This can damage transmission components and also make the vehicle very difficult to steer. On a point of safety, these vehicles should never be jacked up without first checking that the four wheel drive is disengaged – wind up will cause the first wheel that is lifted clear of the ground to whip violently.

Limited slip differential

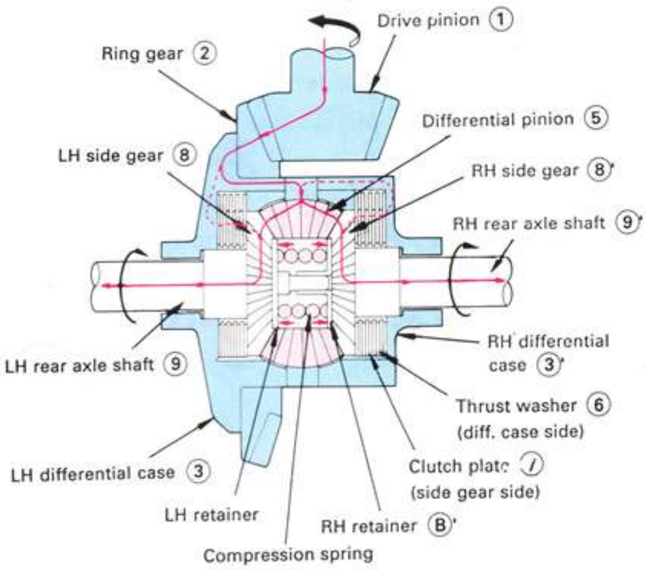


On vehicles fitted with a normal differential driven power will be lost when a vehicle makes a sharp corner or drives over a slippery surface such mud or ice, additionally if one of the driven wheels slips into a ditch and completely loses traction all drive will be lost. This is as all of the torque will flow to the wheel with least resistance and the wheel still in contact with the ground won't turn at all. Whenever this drive is lost driving performance will be reduced, and possibly disappear altogether. The limited slip diff (LSD) is designed to stop this happening. The LSD still provides the standard function of the standard diff except it incorporates the additional function of allowing the wheel with grip to still be driven even if the other wheel loses traction.

In between the side gears and the differential casing, thrust washers and clutch plates are mounted. The clutch plates are internally splined and fit onto flanges coming out of the side of the side gears. The thrust washers are fitted into recesses in the differential casing. See diagram below. A spring is fitted to press the clutch plates and the thrust washers against each other, via the retainer and the side gears in the centre of the construction. This means, in effect, the side gears are kept pressed against the differential case (via the thrust washers and clutch plates) by the spring.

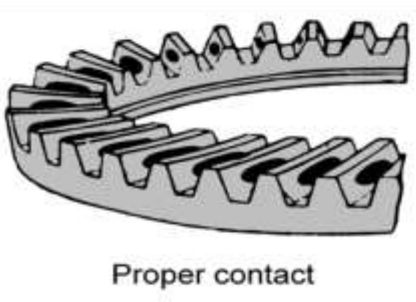


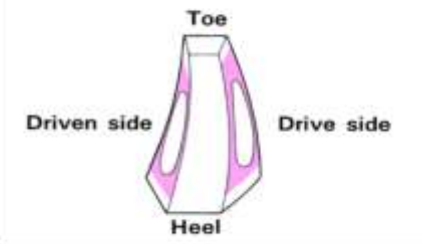
During straight ahead driving the left and right driven wheels are revolving at identical speeds. The differential case, side gears, pinion gears, thrust washers, clutch plates, retainers and compression spring are all revolving round in one unit as in a standard differential.



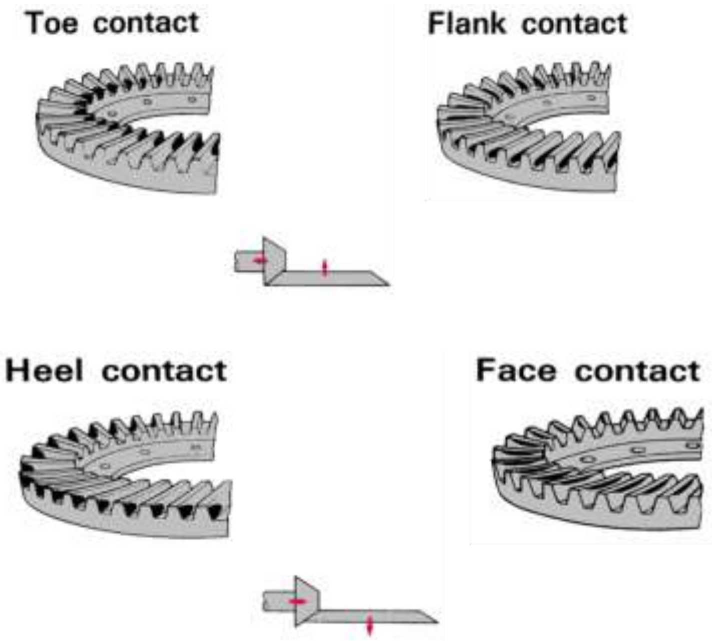
During cornering, if a large difference is produced in the amount at which the left and right driven wheels turn, the rates at which the side gears turn also varies. As they are attached together by the friction between the clutch plates and the thrust washers a frictional torque is created. (Frictional torque means the torque transmitted by the friction between two parts). The friction resists this variation in speed and tries to keep them both turning at the same rate. It is the amount of friction between the thrust washers and the clutch plates that attempt to keep the wheels revolving at the same speed. If the example of the one wheel going into a ditch and loses total traction is thought back to. It is the friction between the thrust washers and plates that drives the wheel along that still remains in contact with the ground.

Differential gear set up



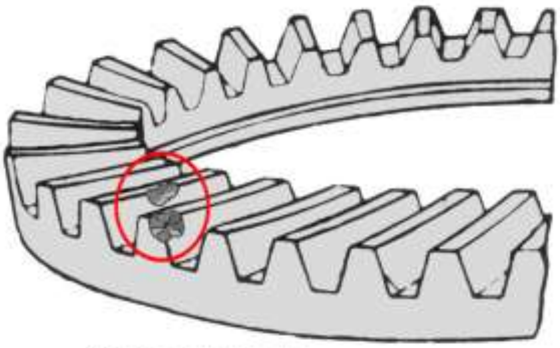


Improper tooth contact between ring gear and drive pinion can only be checked with the diff stripped down. A coloured paste such as yellow ochre oil paint should by brushed onto the teeth. The diff should be loaded (by hand) and the gears turned. As the gears act upon each other, the coloured paste will show where the contact patch is. The correct contact patch is in the middle height wise and middle width wise. Left shows the incorrect contact areas on the teeth. If any of these incorrect contact patch areas do occur. In the case of incorrect toe or flank contact the pinion needs to be moved further away from the ring gear, this needs to be carried out with a thinner adjusting shim. In the event of heel and face contact the pinion needs to be brought closer to the ring gear. This is carried out by fitting a wider adjusting shim on the pinion.



Damaged gear

This is again something that can only be diagnosed with the differential stripped down. If the oil is drained and the oil inspected, it may be possible to find the chunk of chipped tooth. This is a sure sign that the diff needs stripping. Once the damaged gear is found it must be replaced.


Chipped Teeth

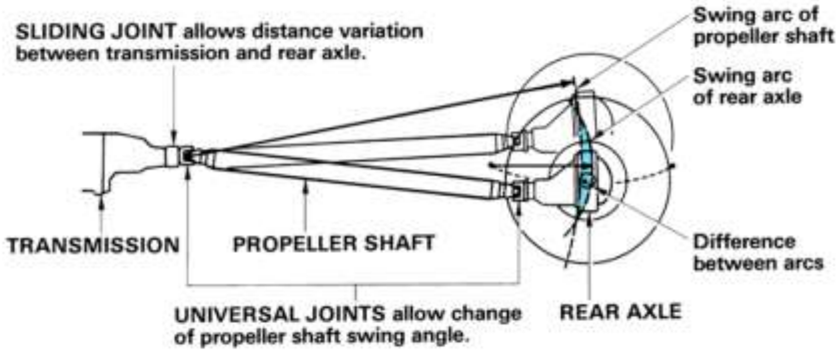
Drive line components

The drive line represents the components from the transmission to the wheels or differential in the case of 4WD. This consists of three main components:

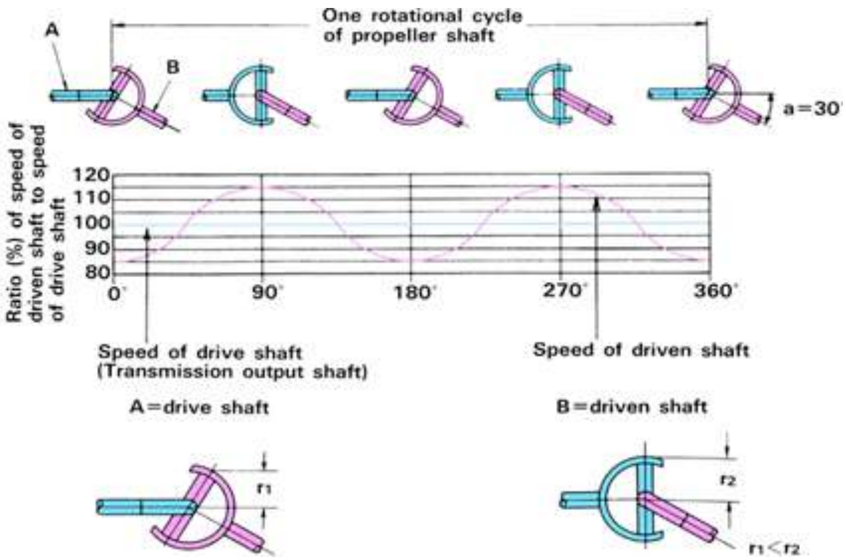
- Propeller shafts
- Drive shafts
- Wheel bearings

Propeller shaft (can also be known as a carden shaft)

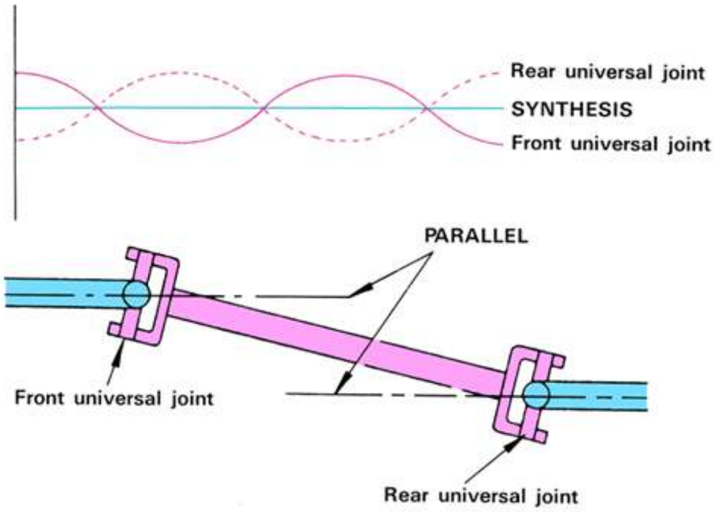
The transmission is normally fixed to the vehicle chassis by flexible rubber mountings. The rear differential and rear axle is usually supported by the rear suspension. Therefore suspension travel, due to vehicle loading and bumps in the road, causes the rear axle and differential to change position in relation to the transmission. The propeller shaft must therefore be designed to constantly change length and transmit power through a variety of angles. To allow changes in length the propeller shaft is usually connected to the transmission by a sliding splined shaft. Each end of the propeller shaft is fitted with a universal joint to enable it to absorb changes in drive angle.



In this illustration a simple universal joint, often referred to as a Hook's or Spider joint, can be seen to have a major drawback. Rotating at an angle of 30 degrees the speed of shaft B varies in relation to shaft A. This is often referred to as changing angular velocity. If action was not taken to overcome this problem vibration and surge at the wheels would be produced.

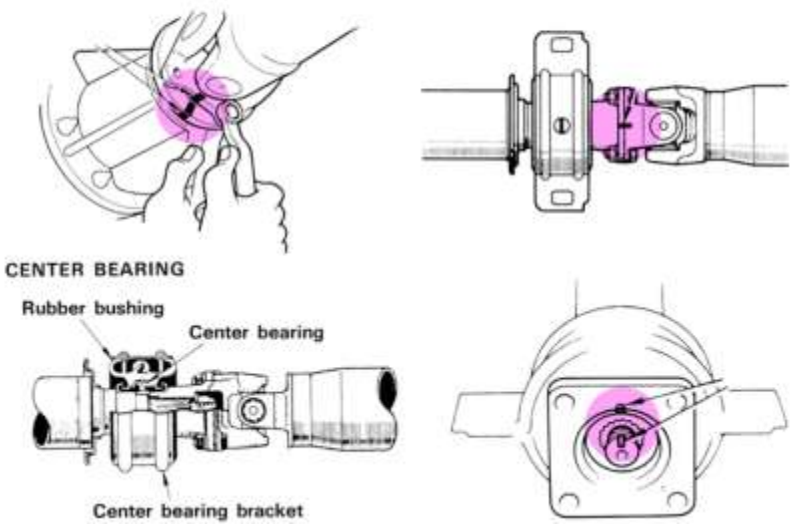


Variations in angular velocity are cancelled out by fitting a similar joint to the other end of the shaft. The drive and driven shafts are also fitted parallel to each other to smooth out variations in



rotating speeds and torque.

Because of this it is vital that propeller shafts are fitted correctly. Propeller shaft ends must be marked so that they can be refitted in exactly the same location. If this is ignored vibration and noise will be the result. In the above illustration the top shaft assembly is fitted correctly and the lower assembly is incorrect.

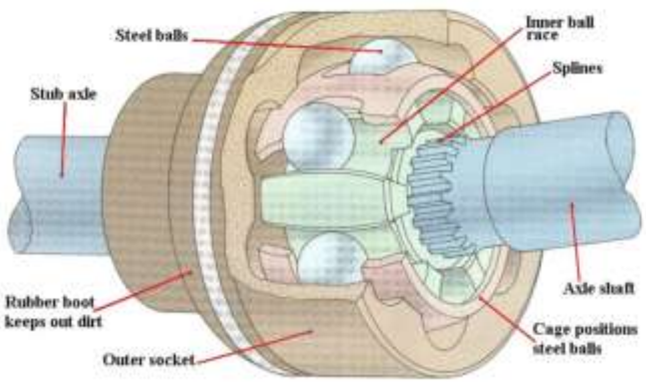


Drive shafts

The drive shafts transmit the power from the differential. During operation they must meet two requirements:

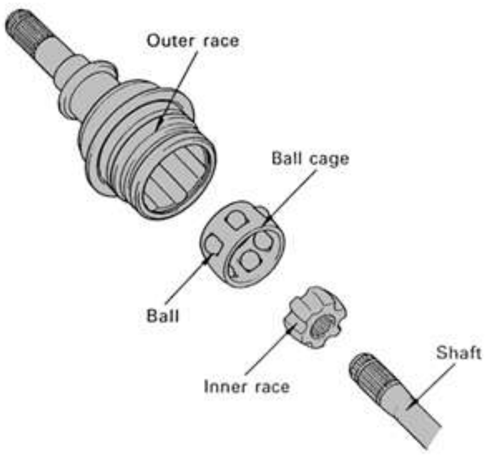
- The drive shaft should have some sort of mechanism to absorb changes in length during up and down suspension movements.
- The drive shafts should have some sort of mechanism to maintain the same operating angle during steering. They must also rotate at uniform speeds.

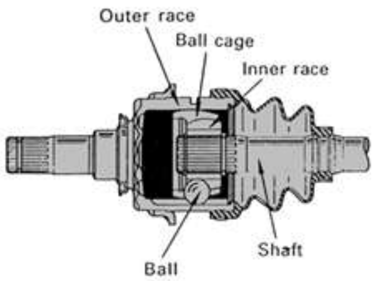
Constant velocity joint (outer joint)



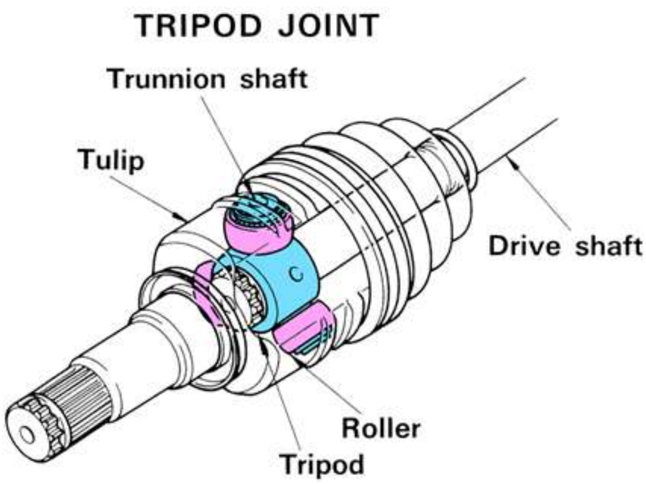
A Birfield joint, sometimes known as a Rzeppa joint, has an inner race fitted into an outer race between which steel balls are held in position by a steel cage. Simple construction and the ability to transmit large torque through a considerable angle means this joint is a common feature of drive shafts fitted to front wheel drive vehicles. Because the intersecting point (0 in the illustration) of the driving and driven shafts and the centre (P in the illustration) of each ball bearing is constant this is a constant velocity joint. The rotational speeds of the drive and driven shafts are identical. The expression constant velocity is commonly abbreviated as C.V. and a joint of this type often referred to as a C.V. Joint. The joint is encased in a flexible boot to retain the appropriate lubricating grease.

Constant velocity (inner joint)





In this constant velocity joint an inner race and an outer race have between them a ball cage. As can be seen from the illustration the outer race has a series of groves in which the ball bearings run, providing axial movement. The joint is encased in a flexible boot to retain the appropriate lubricating grease.

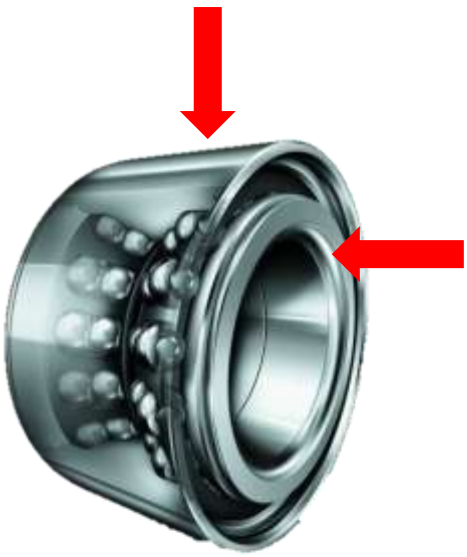


The Tripod joint has three trunnion shafts on which three rollers, which have roller bearings, run. An outer casing has a grove in which each of the rollers is located. The tripod joint is a relatively inexpensive joint which usually has axial movement. The joint is encased in a flexible boot to retain the appropriate lubricating grease. Failure of drive shaft joints are usually preceded by failure of the flexible boot allowing the loss of lubricant and the ingress of road dirt.

Wheel bearings

A modern vehicle will be equipped with various types of bearings. The bearings may look very similar but are very different due to the way in which they react to radial and axial loads.

Radial and axial loads



There are generally 4 main types of bearing used:

- Ball bearings
- Cylindrical roller bearings
- Spherical roller bearings
- Taper roller bearings

Ball bearings

This type of bearing is intended for carrying mainly radial loads, but can also support some axial load in both directions.

Double row bearings of this type are made capable of carrying heavier loads

Cylindrical roller bearings

This type of bearing is capable of carrying greater radial loads than ball bearings but can carry no axial loads

Spherical roller bearings

This type of bearing is self- aligning like a ball bearing. It is constructed on similar principles and is used as an alternative to ball bearings.

They have the advantage of being able to carry greater loads.

Taper roller bearings

This type of bearing is capable of dealing with large radial and axial loads in one direction so are often fitted in pairs in opposing directions. Different taper angles may be used depending upon the amount of axial load to be carried.

Wheel bearings

Most modern vehicle use angular ball bearings or unit type double row tapered bearings. The pre-load of the bearings is set by tightening the hub mounting lock nut to a specified torque.

This type of set up is common because it has the unique benefit of being able to bear radial loads as well as axial loads in one direction (this is why two bearings are arranged facing each other).

Bearing maintenance

Ball or roller bearings are lubricated with oil or grease depending on their use. The grease used is often a specialist type therefore the relevant technical data should be used.

During maintenance a taper roller bearing may require adjustment to reduce the axial movement. This should be done in accordance with the relevant technical data.

Caution

If these bearings are over tightened they may seize up and cause significant heat damage.

Testing methods

Road testing a vehicle is often the only way to evaluate the transmission

- Transmission operation
- Clutch slipping
- Smooth engagement of all the gears
- Bearing noise
- Knocking
- Gears jumping out
- C.V. join operation
- Drive shaft / prop shaft vibration