Unit IV
Clutches & Gear Box

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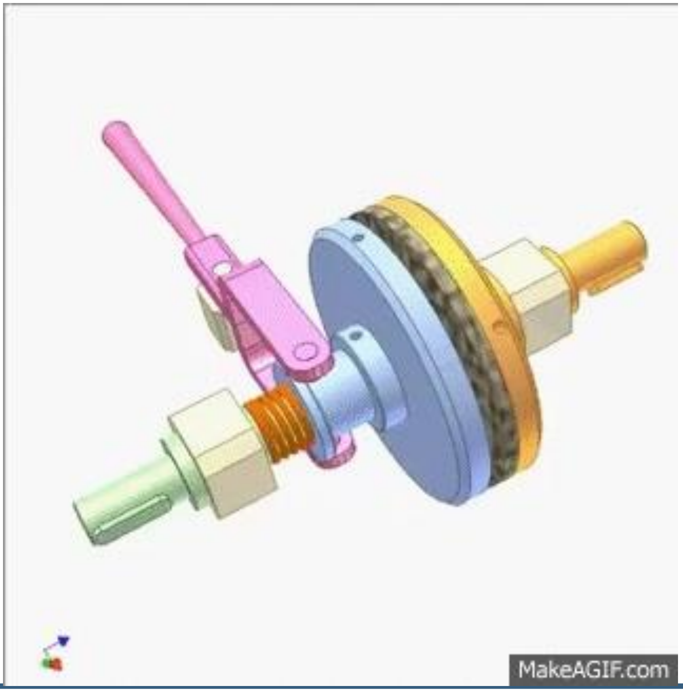
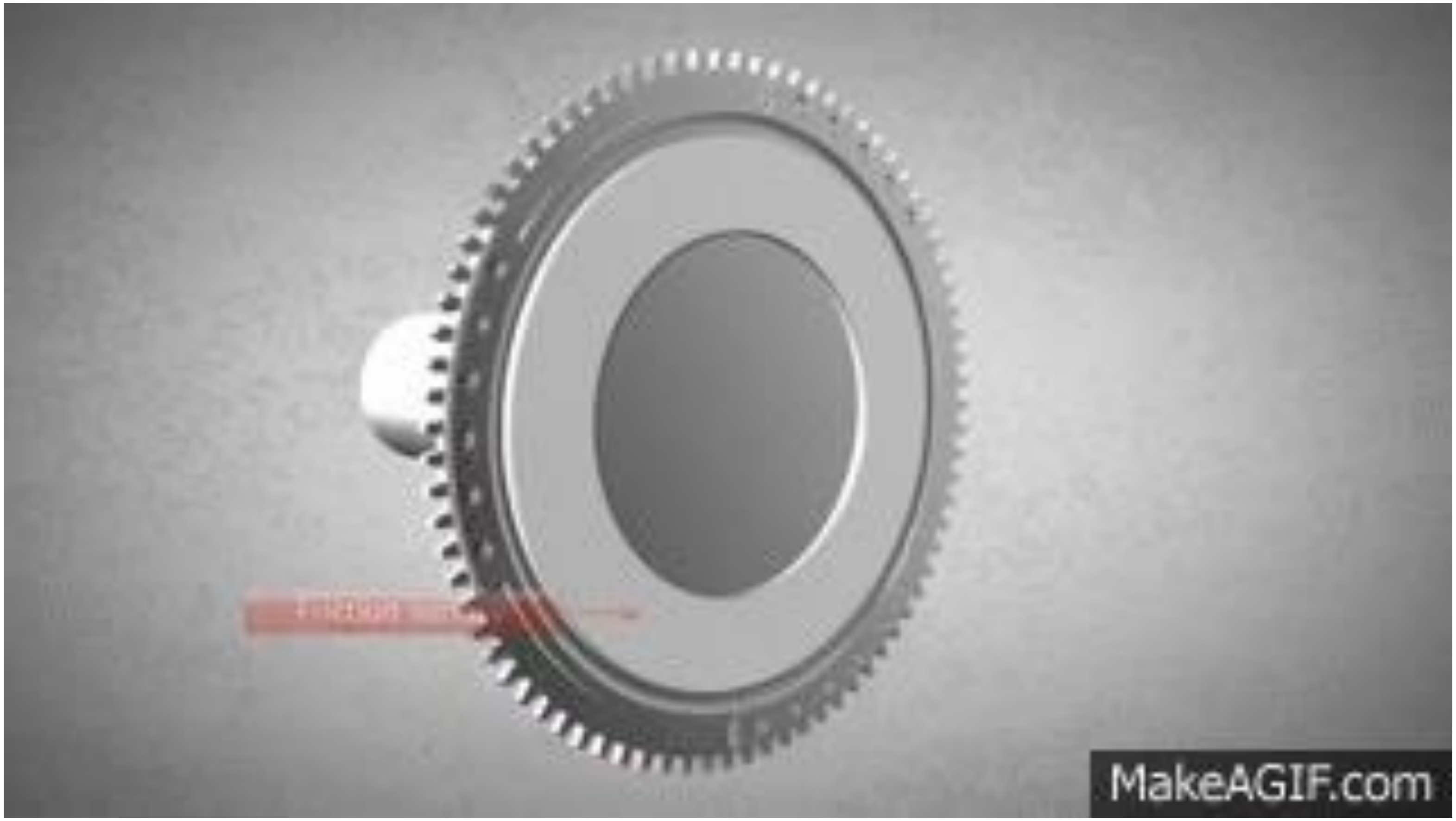
❖ Syllabus

- **Clutches:** Principle, Functions, General requirements, Torque capacity, Types of clutches, Cone clutch, Single-plate clutch, Diaphragm spring clutch, Multi-plate clutch, Centrifugal clutch, Electromagnetic clutch, Lining materials, Over-running clutch, Clutch control systems.
- **Gear Box:** Necessity of gear box, Resistance to motion of vehicle, Requirements of gear box, Functions of gear box, Types, Sliding mesh, Constant mesh, Synchromesh. Principle, construction and working of synchronizing unit, Requirements & applications of helical gears, Gear selector mechanism, Two wheeler gear box, Lubrication of gear box, Overdrive gears, Performance characteristics. (10 hrs.)

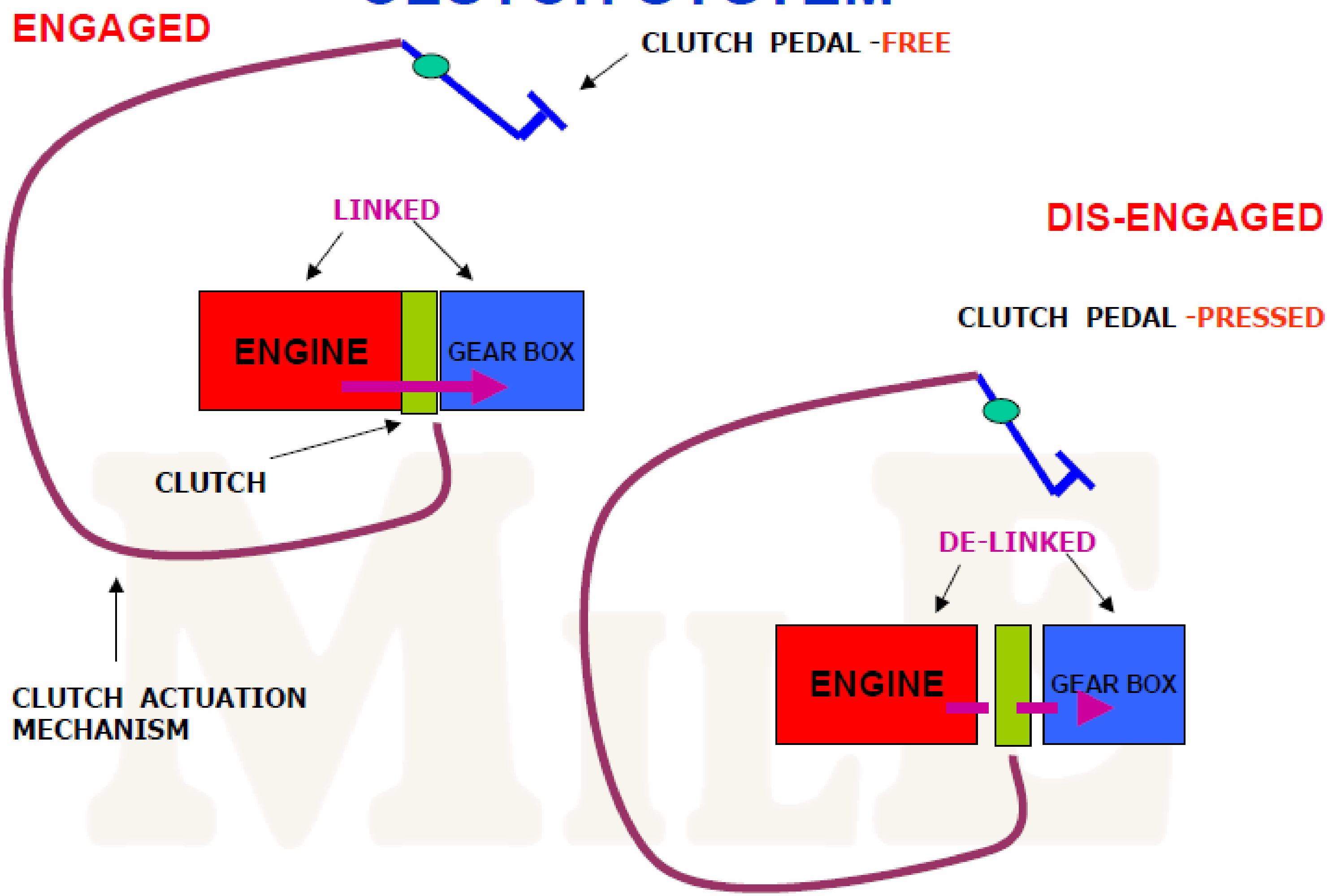
- **Clutch:-**
- **Principle:**
- A **clutch** is a mechanical device that engages and disengages the power transmission, especially from driving shaft to driven shaft.
- It operates on the **principle of friction**. When two surfaces are brought in contact and are held against each other due to friction between them, they can be used to transmit power.
- If one is rotated, then other also rotates.



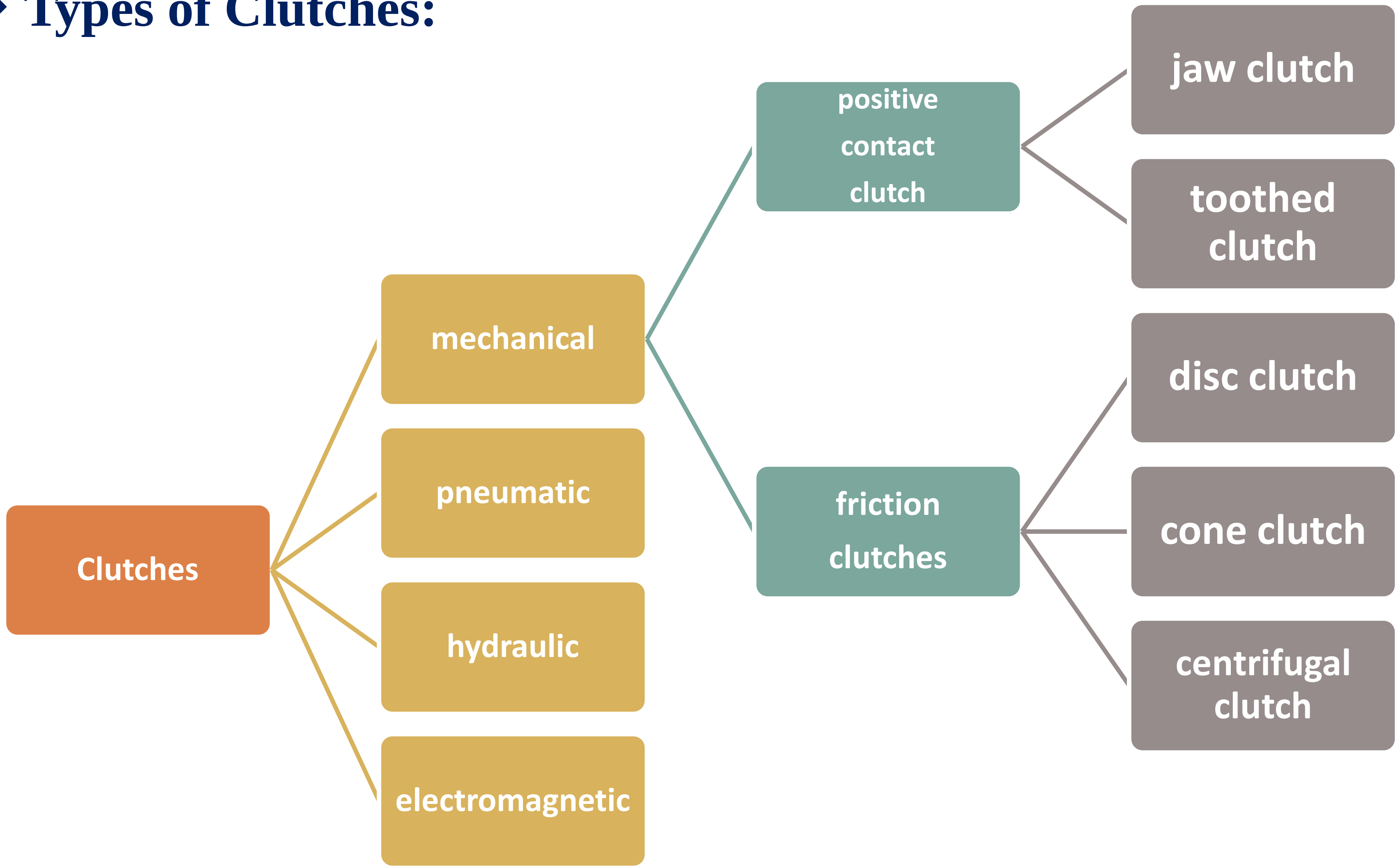
❖ Clutch Operation:



CLUTCH SYSTEM



❖ Types of Clutches:



❖ Positive contact clutches

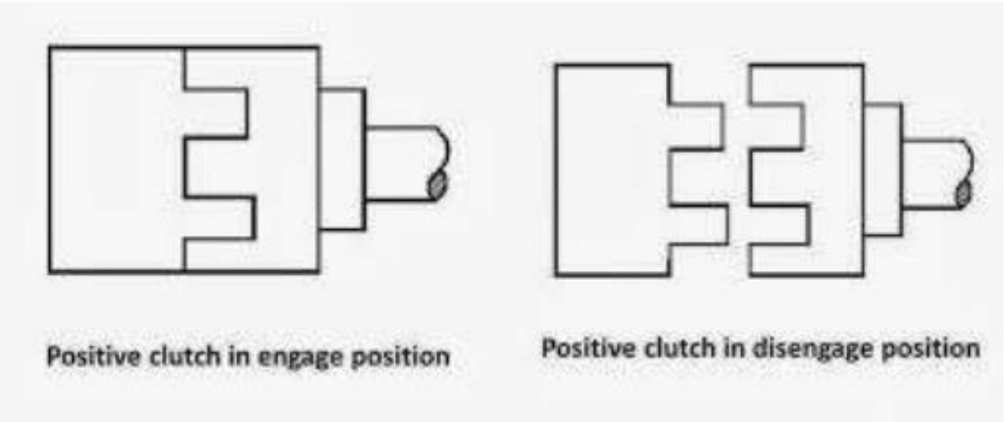
➢ *Transmit power from the driving shaft to the driven shaft by means of jaws or teeth*

+ Transmit large torque with no slip
+ Develop very little heat, because they do not depend upon friction.
+ Generally lighter.
+ Less costly than a friction clutches of similar torque capacity.

-Can not be engaged at high speeds, max 60 rpm for jaw clutches, and 300 rpm for toothed clutches

-Shock accompanies engagement at any speed

-Require some relative motion in order to engage when both driving and driven shafts are at rest



Square Jaw Clutch

❖ Friction clutches

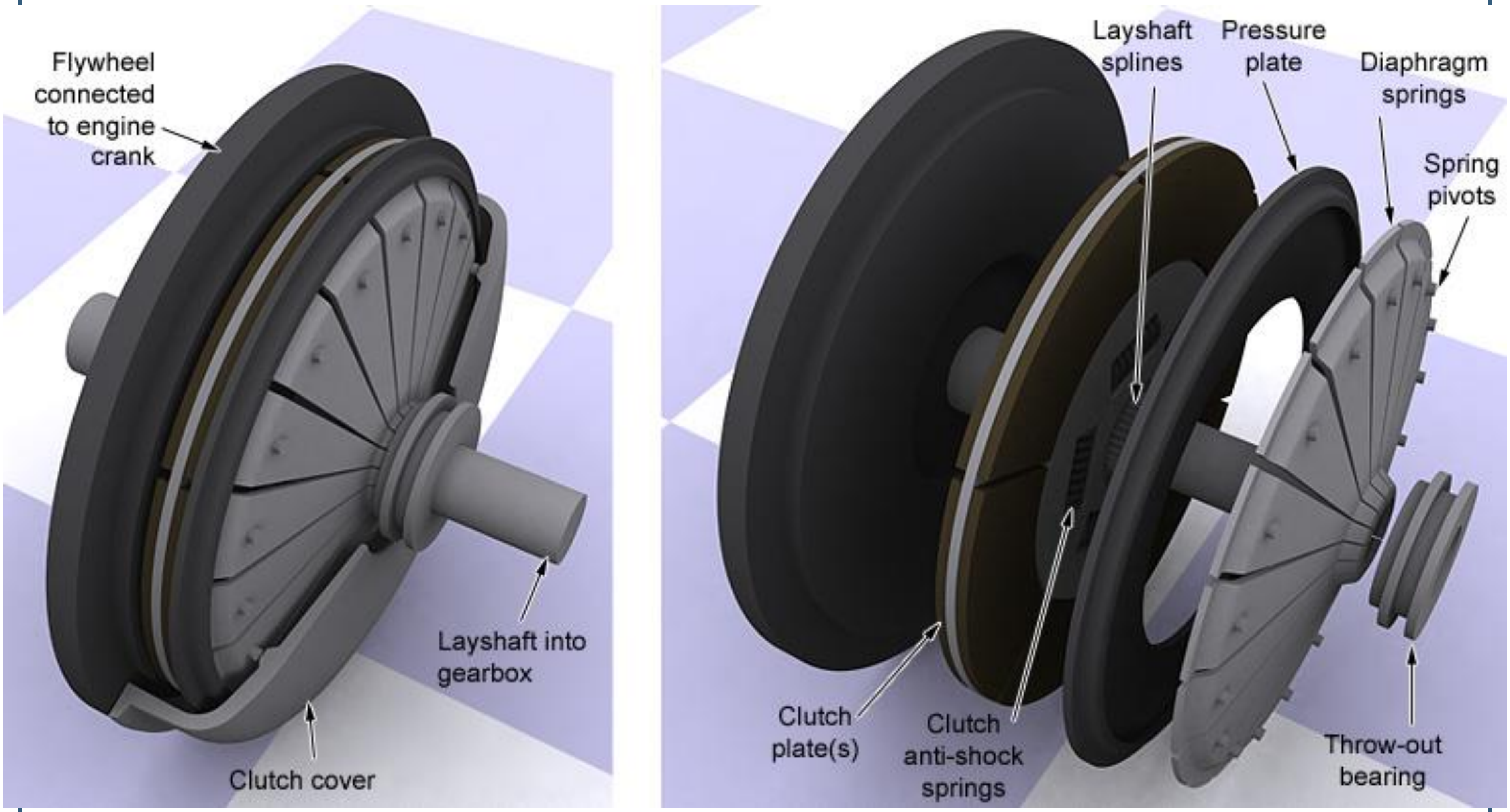
➢ *Transmit power from the driving shaft to the driven shaft by means of plates, disks or cones*

+ Because they can slip relative to each other, there is very little shock during engagement.
+ Can be used for high speed engagement applications.

-Do slip

-Do wear out (requiring replacement of friction material)

-Heat is developed (might require external cooling)


Flywheel connected to engine crank
Layshaft into gearbox
Clutch cover
Layshaft splines
Pressure plate
Diaphragm springs
Spring pivots
Clutch plate(s)
Clutch anti-shock springs
Throw-out bearing

❖ Requirements of the clutch :

1. Torque transmission – Low/High
2. Clutch engagement – Gradual/Sudden
3. Heat dissipation – High/Low
4. Dynamic balancing – High/Low
5. Vibration damping – High/Low
6. Inertia – High/Low
7. Size- Big/Small
8. Operation- Easy/difficult

❖ Torque capacity of the clutch depends on :

1. Coefficient of friction- High/Low
2. The diameter of the driven plate – Big/Small
3. Spring thrust applied by the pressure plate- High/Low

❖ Limitations of capacity :

1. Max available μ is 0.35, higher than these clutch becomes unstable
2. Increasing diameter increases its inertia & it will continue to spin after disengagement
3. There is a limit to clamping pressure to which friction lining material subjected if it is to maintain friction properties over a long period of time.

❖ Torque Transmitted by the clutch :

Torque transmitted $T = n * F * R$

F –frictional force = $\mu * P$

μ - coefficient of friction

P –Axial load

n –number of plates

R –effective mean radius of frictional surface

-Torque transmitted depends on the radius of the friction material.

-A limit on the spring force is set by the magnitude of the effort a driver may be expected to exert on a clutch pedal .

-μ is constant for a given material .

-n can be increased to transmit more torque.

❖ Clutch

➢ Types of Clutches :

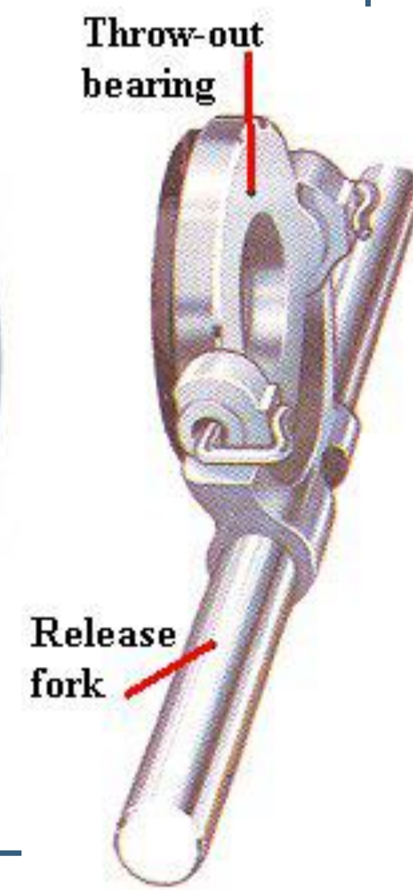
1. Single plate clutch
2. Multiple plate clutch
3. Cone clutch
4. Diaphragm clutch
5. Semi-centrifugal clutch
6. Centrifugal clutch

➢ Method of clutch actuation :

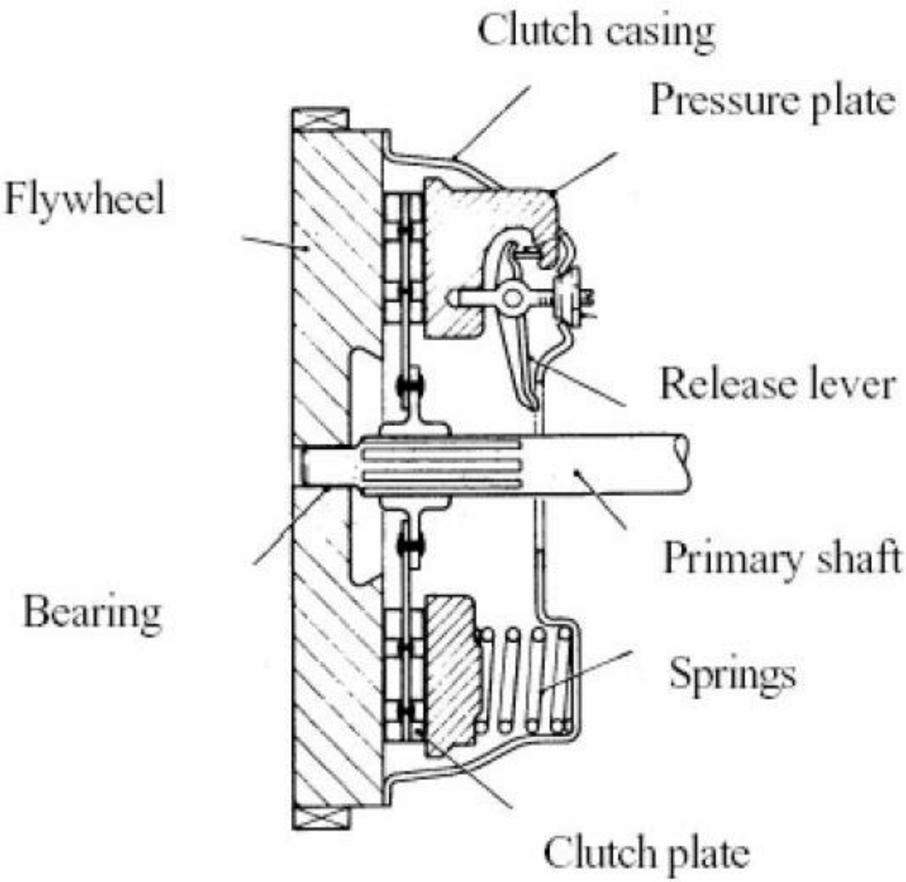
1. Mechanical
2. Hydraulic
3. Vacuum
4. Electro magnetic

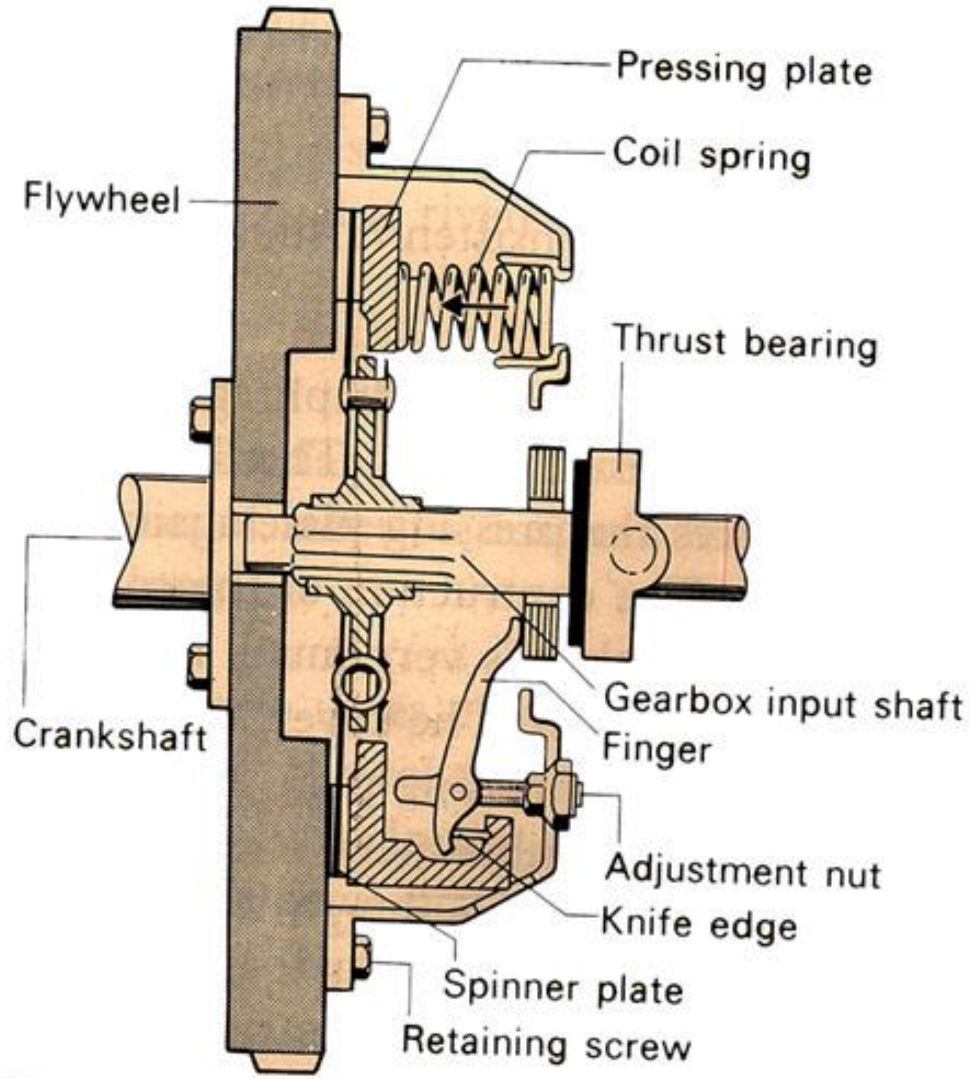
Components of the clutch

Flywheel Friction plates Pressure plate cover

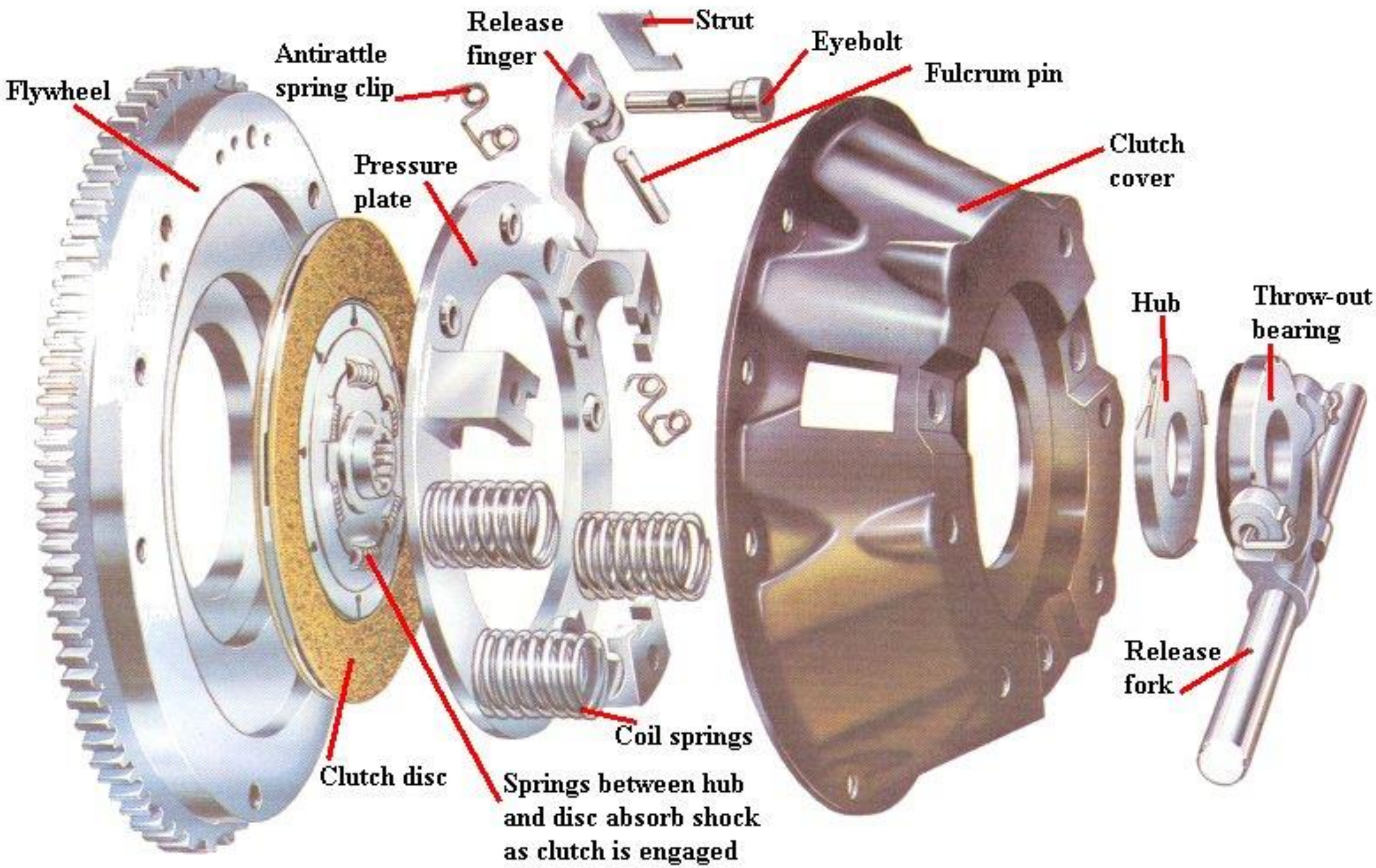


❖ Single plate clutch



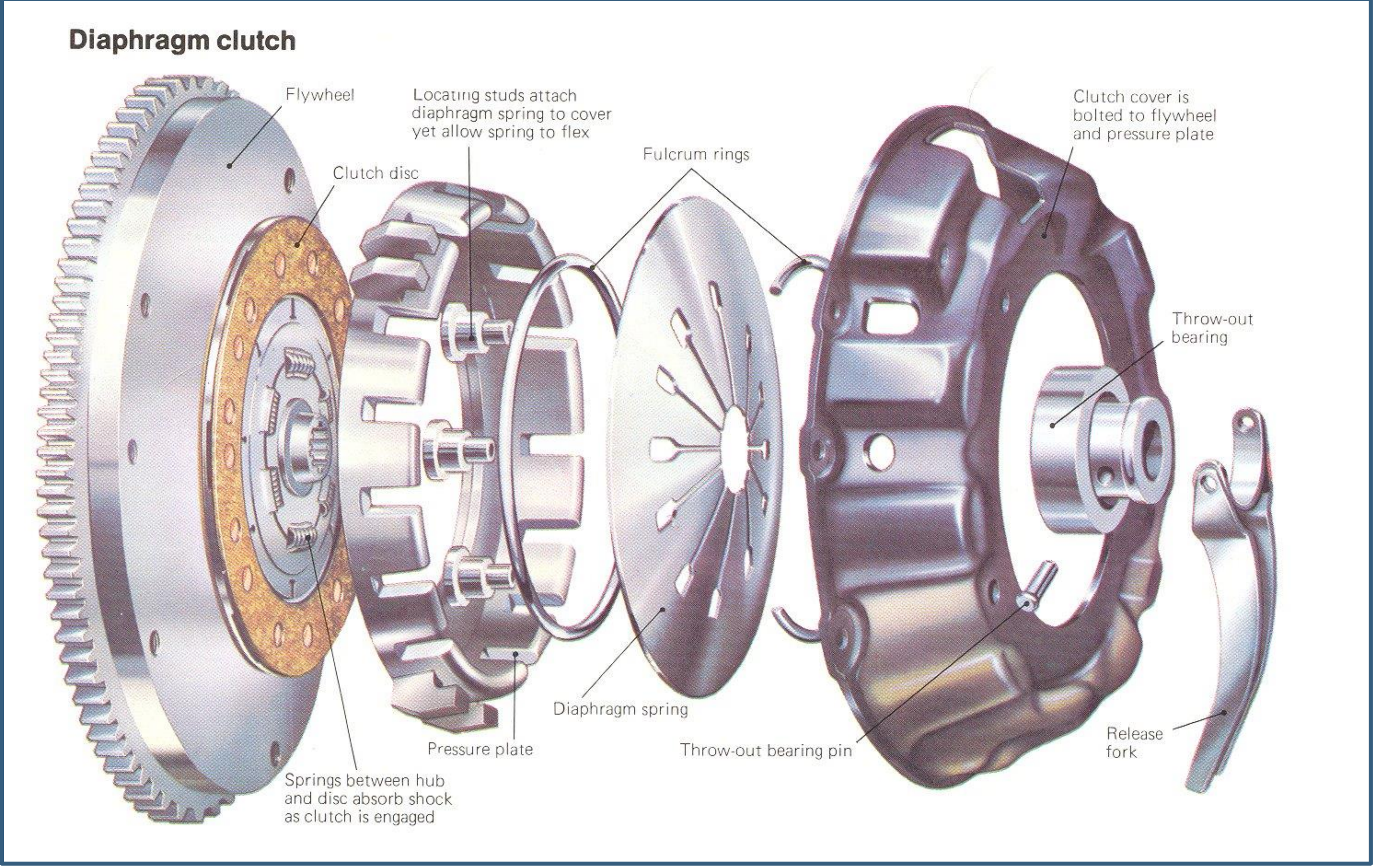


1. Coil Spring Clutch

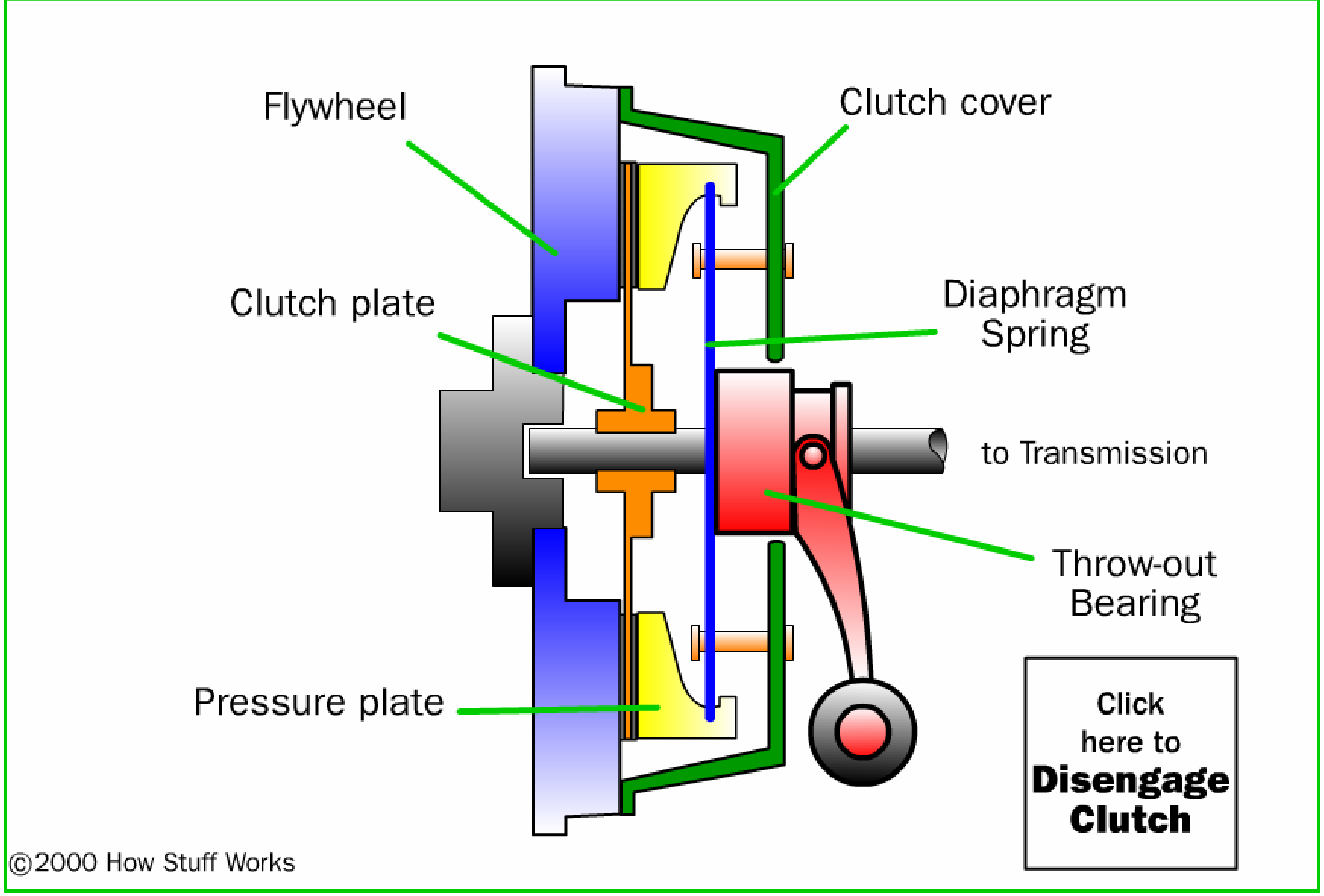


❖ Working of the clutch

- When the pressure is applied to the foot pedal, the pressure is transmitted through the release finger, fork and release bearing. Then the springs are compressed and its moves back the pressure disc thus releasing the clutch plate. Now the clutch is said to be disengaged.
- At this stage the pressure plate and flywheel are free to rotate with with the clutch plate stationary.
- Similarly, when the clutch pedal is released, spring pressure is fully applied on the clutch plate. The plate is held between the flywheel and the pressure plate rotates as a single unit.
- Typical friction disc travels about 0.06 inch(1.5 mm).
- Sometimes a clutch with greater holding power is needed. When limited space prevents making the clutch larger, the a clutch with the two friction disc can be used.
- Use of second disc adds area, thereby providing greater torque carrying capacity (used in medium and heavy trucks).


Diaphragm clutch
Flywheel
Locating studs attach diaphragm spring to cover yet allow spring to flex
Fulcrum rings
Clutch cover is bolted to flywheel and pressure plate
Clutch disc
Throw-out bearing
Diaphragm spring
Pressure plate
Throw-out bearing pin
Release fork
Springs between hub and disc absorb shock as clutch is engaged

Diaphragm Clutch



Working of Diaphragm spring clutch

- Used with most manual transaxles and in many rear manual wheel drive vehicles.
- A beleville(diaphragm) spring supplies the force that holds (the friction disc against the flywheel.
- The spring has tapered fingers pointing inwards from a solid ring. These act as release levers to take up the spring action as the clutch disengages.
- As the clutch pedal is pressed, the release bearing pushes against the fingers, which cause the diaphragm to pivot about the inner pivot ring, and outer section moves outwards, and pushes the pressure plates away from friction disc.
- Spring force varies according to the size and thickness of diaphragm spring.

❖ Merits of the Diaphragm Spring over Multi-coil Spring.

(a) The diaphragm spring is compact permitting the use of a shallow clutch bell-housing to enclose the clutch unit.

(b) Due to fewer moving parts squeaks, rattles, and wear are eliminated in diaphragm spring.

(c) This system does not require initial adjustment of the pressure-plate unit unlike the multi-coil spring clutch units, where a small clearance is necessary between the release-lever plate and the thrust bearing.

(d) In this design accurate balance of the clutch assembly is maintained under all operating conditions.

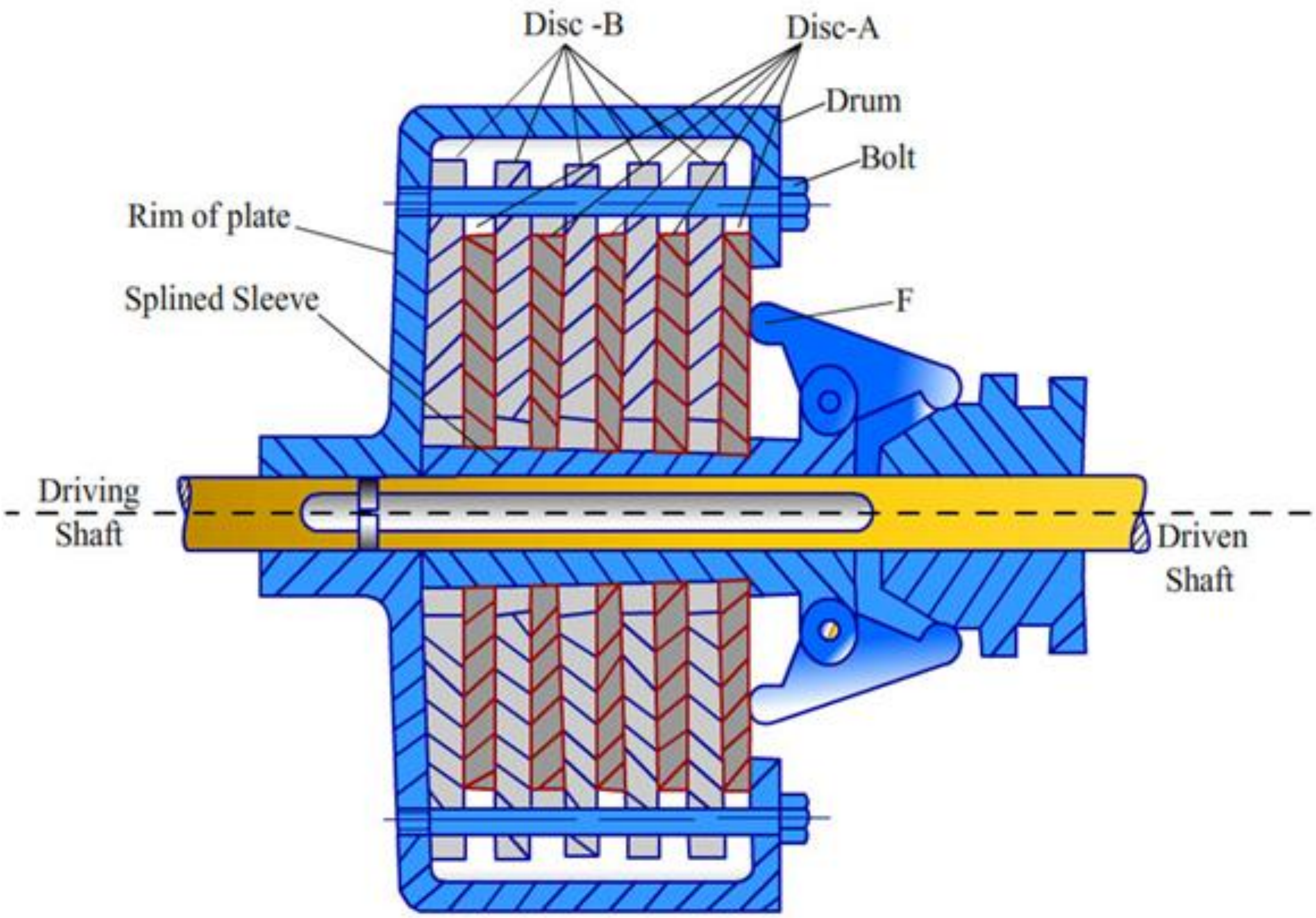
(e) The diaphragm acts as both clamping spring and release-finger.

(f) As the driven-plate wears, the spring axial load self-compensates in this clutch.

(g) Clamping load in diaphragm-spring is independent of the engine speed whereas coil springs tend to bend along their length and loose their thrust at high speeds.

(h) In this clutch disengagement pressures reduce with increase in pedal movement.

❖ Multi-plate Clutch:



Multi-plate clutch

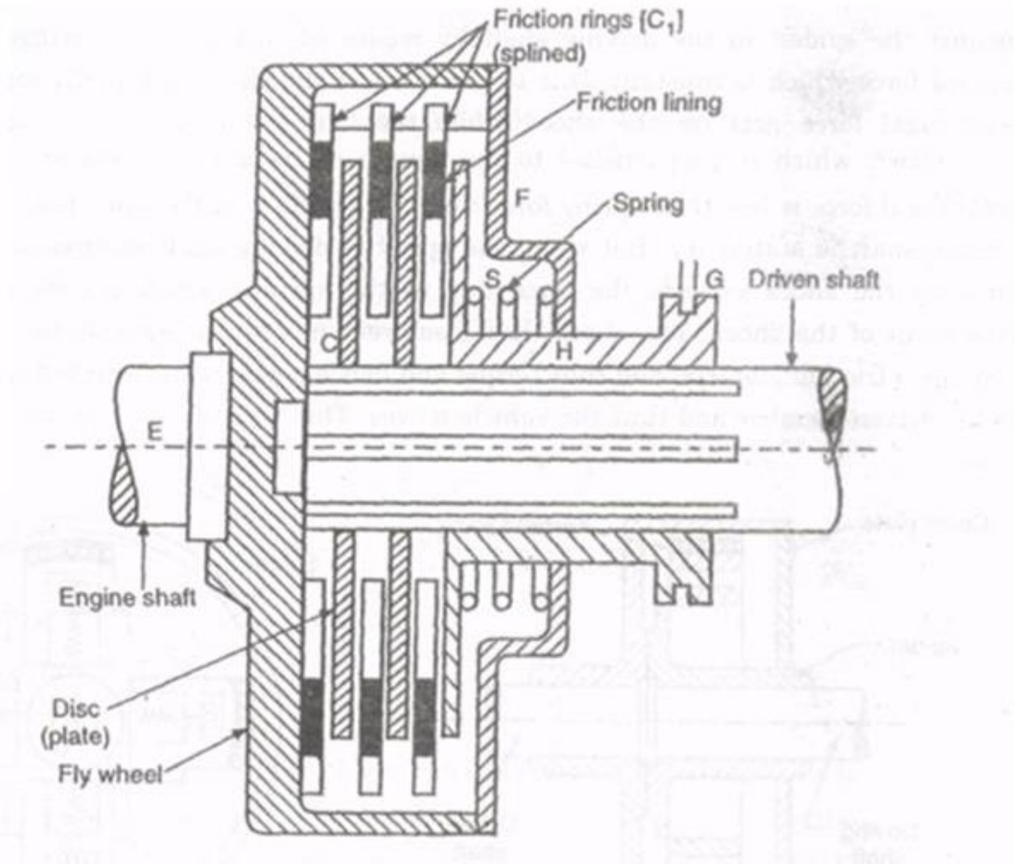
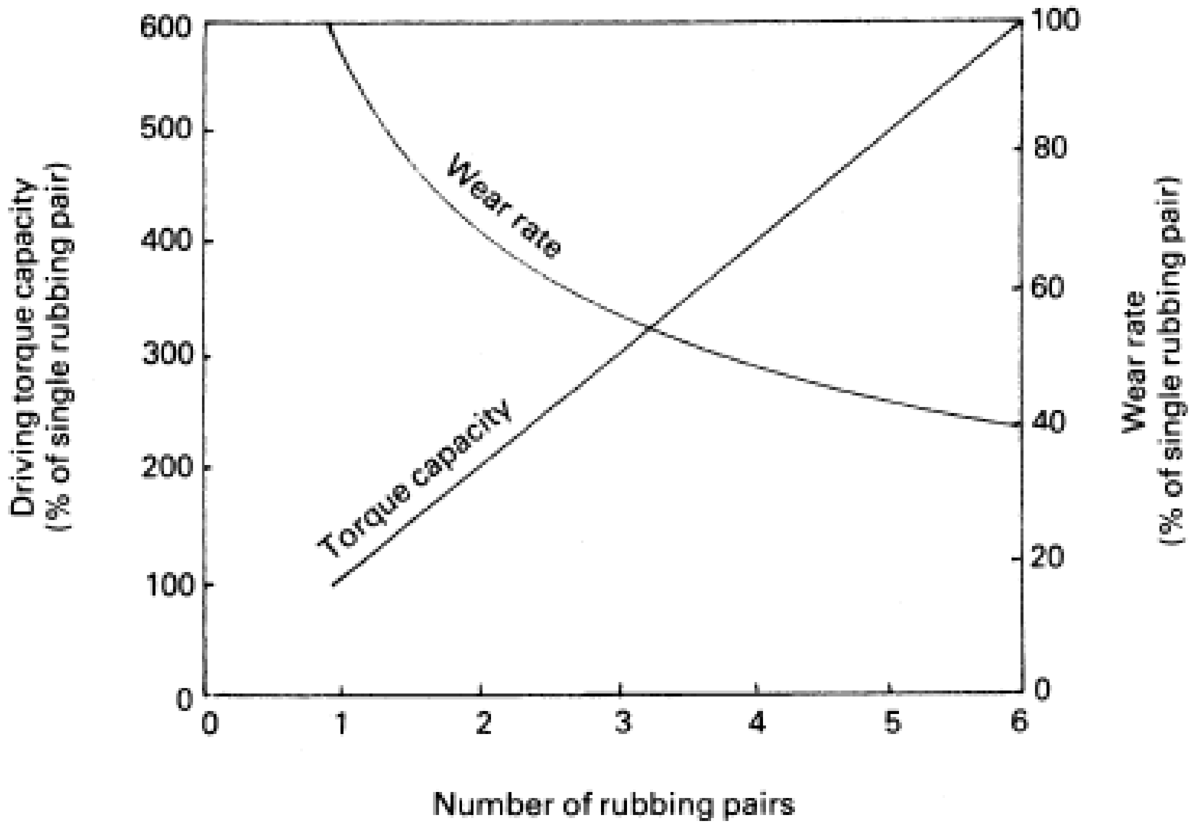


Fig. 6.31 : Multiple Plate Clutch

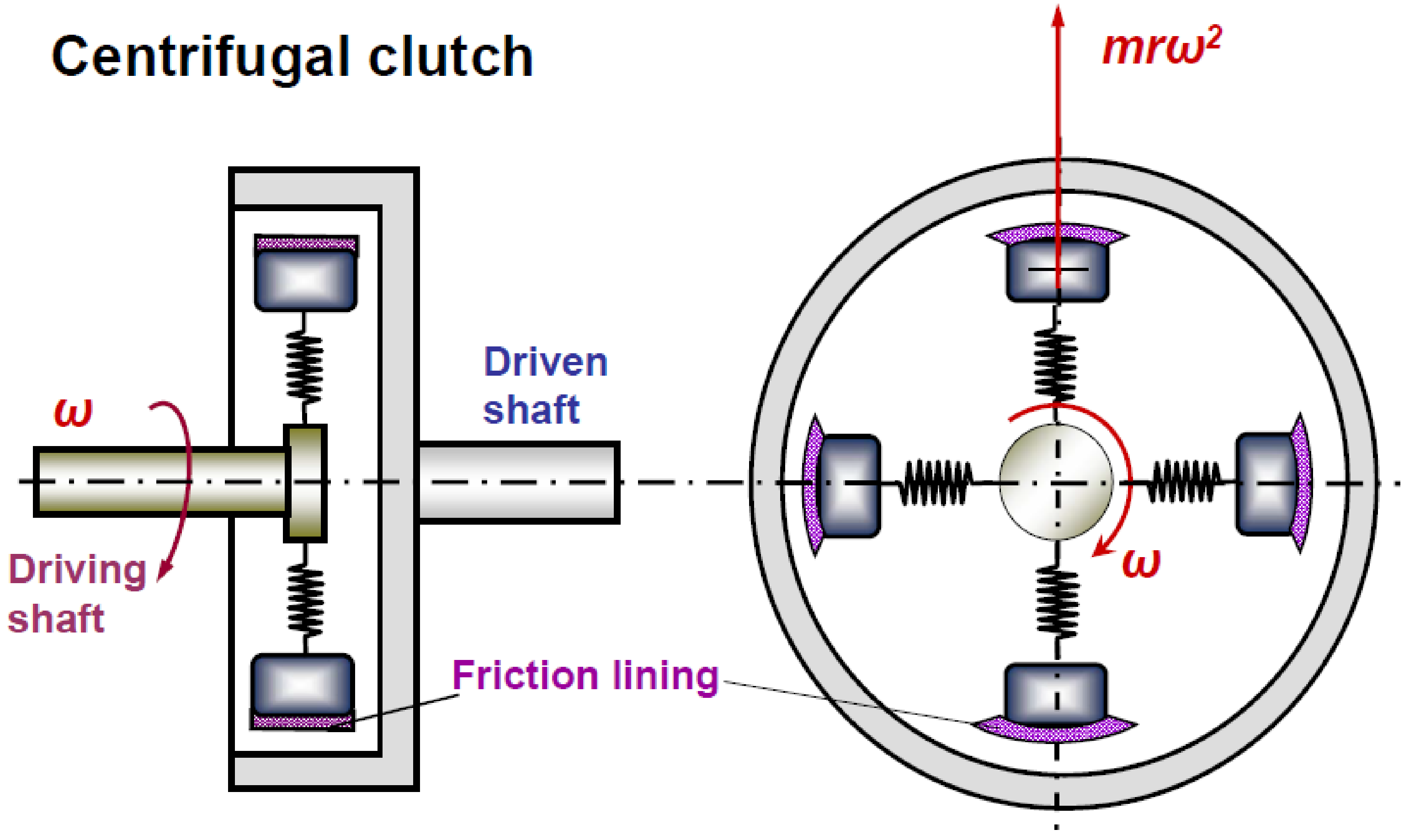
❖ Multi-Plate Clutch

- Multi-plate clutch consists of a number of clutch plates, instead of only one clutch plate as in the case of single plate clutch.
- As the number of clutch plates are increased, the friction surface also increase.
- The increased number of friction surfaces obviously increases the capacity of the clutch to transmit torque.
- The plates are alternately fitted to the engine shaft and the gear box shaft.
- They are firmly pressed by strong coil spring and assembled in a drum. Each of the alternate plate slides in grooves on the flywheel and the other slides on splines on the pressure plate.
- Thus, each alternate plate has inner and outer splines.

- The multiple clutch works in the same way as the single plate clutch, by operating the clutch pedal.
- The multiplate clutches are used in heavy commercial vehicles, racing cars and motor cycles for transmitting high torque.
- The multiple clutches may be dry or wet.
- When the clutch is operated in an oil bath, it is called a wet clutch.
- When the clutch is operated dry, it is called dry clutch.
- The wet clutch are generally used in conjunction with, or as a part of the automatic transmission.
- It is used in racing cars and heavy motor vehicles which have high engine power.

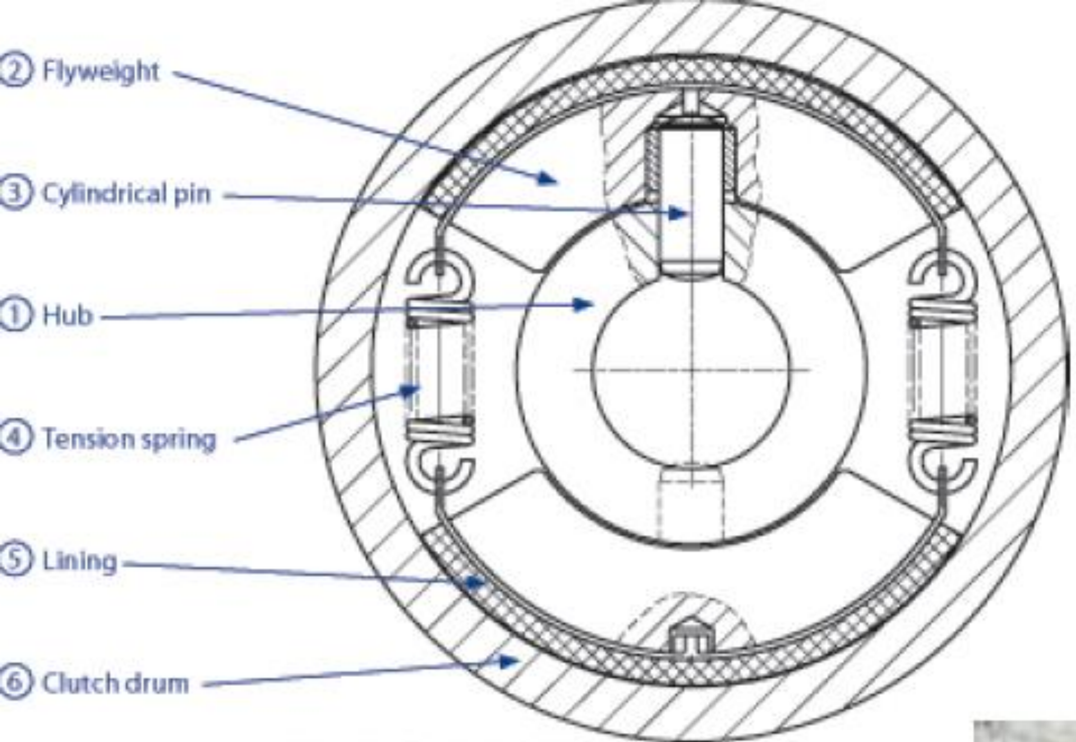

600
500
400
300
200
100
0
100
80
60
40
20
0
0
1
2
3
4
5
6
Driving torque capacity
(% of single rubbing pair)
Wear rate
(% of single rubbing pair)
Wear rate
Torque capacity
Number of rubbing pairs

Centrifugal clutch



The maximum torque transmitted, $T = A\omega^2 - B$

where, ***A*** and ***B*** are constants for a given clutch.


② Flyweight
③ Cylindrical pin
① Hub
④ Tension spring
⑤ Lining
⑥ Clutch drum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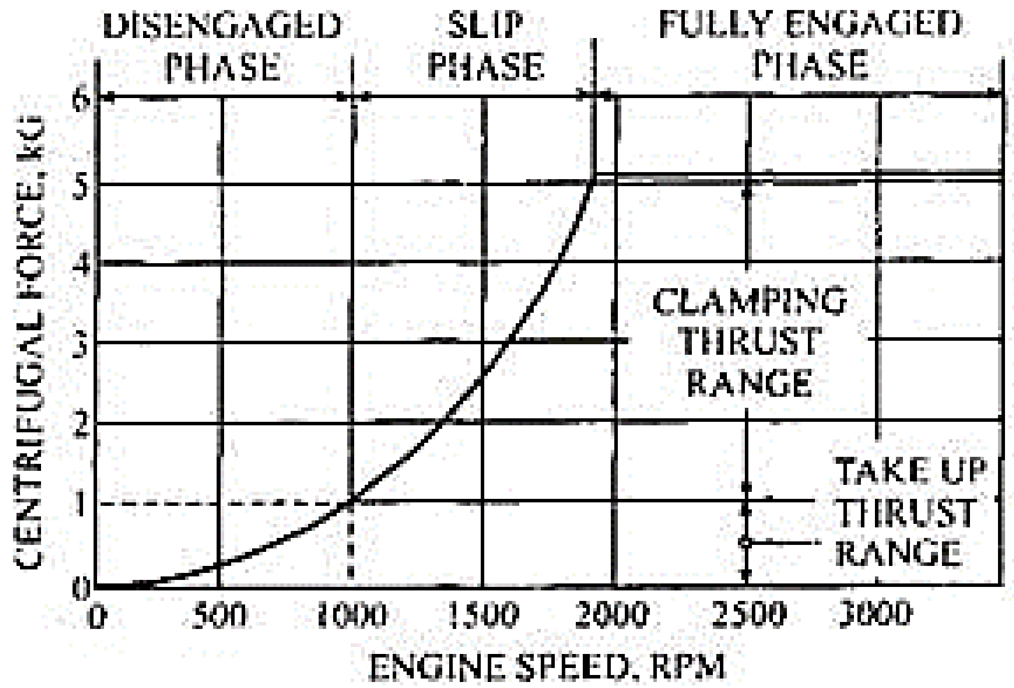
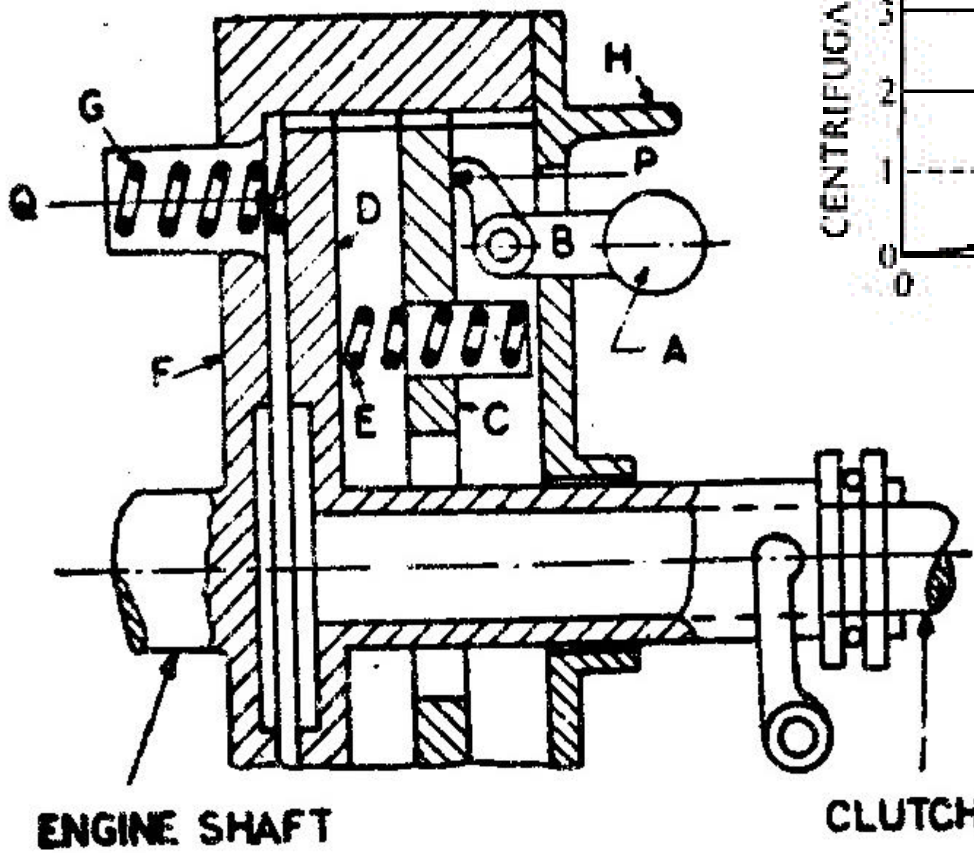
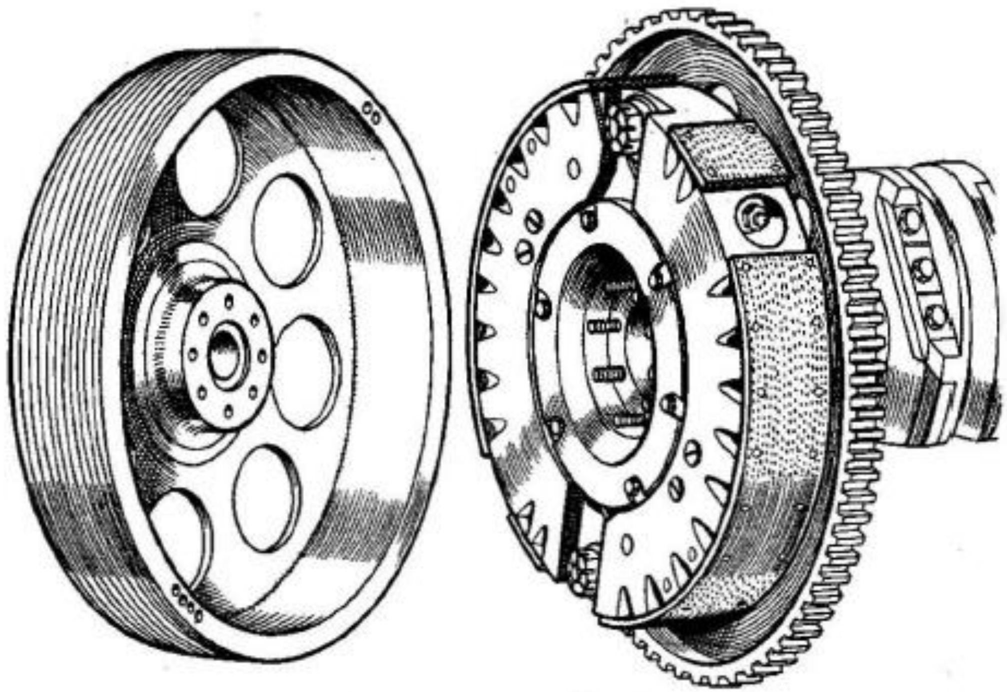
Centrifugal clutch characteristics:



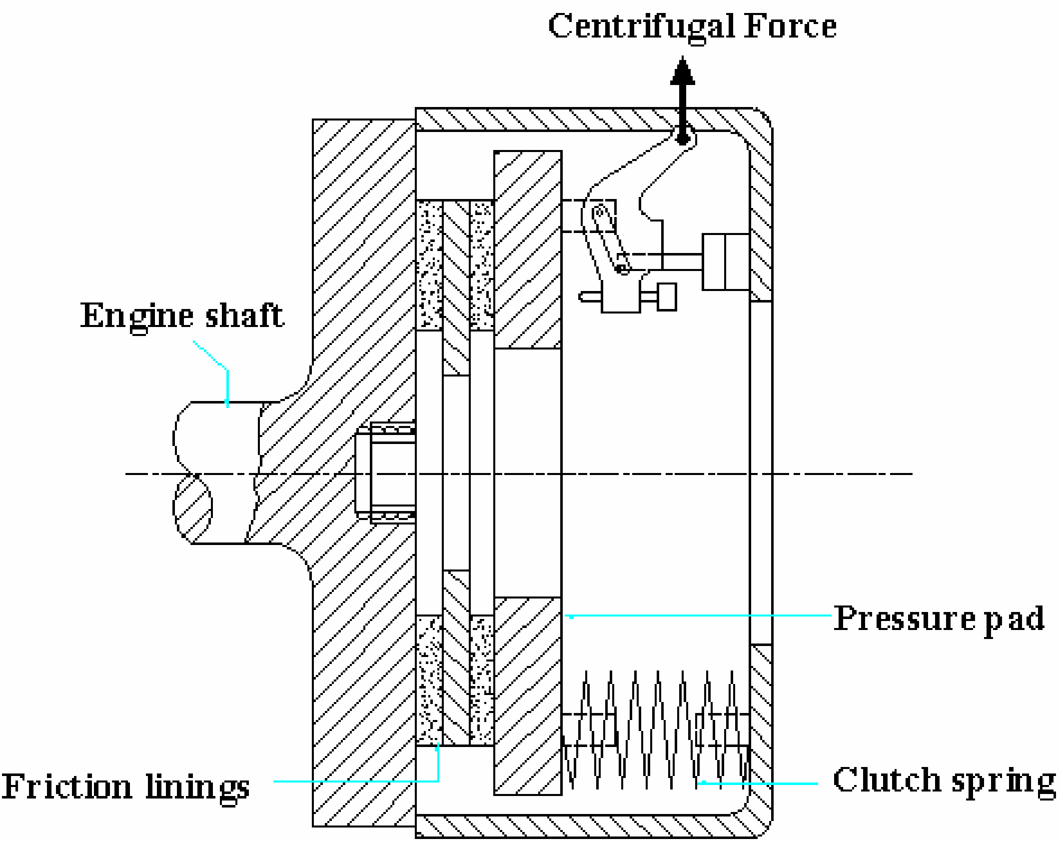


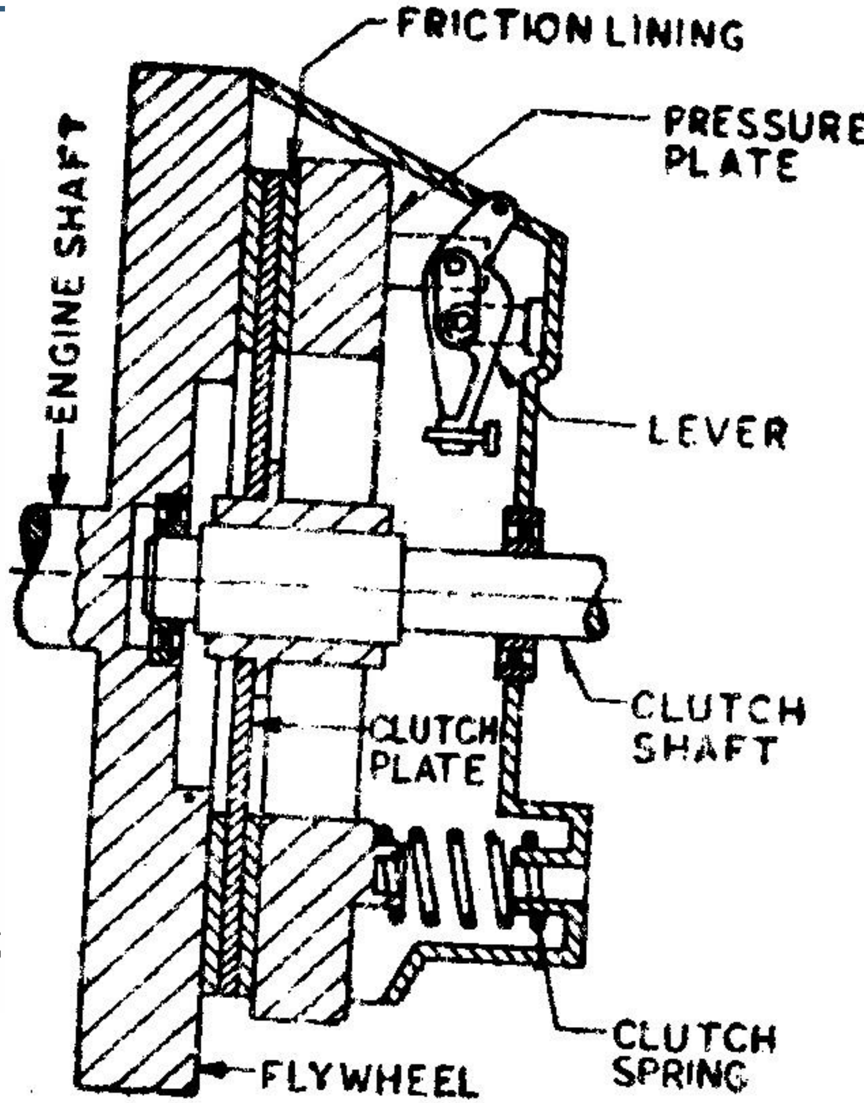
The faster the RPM, more is the force on clutch disk



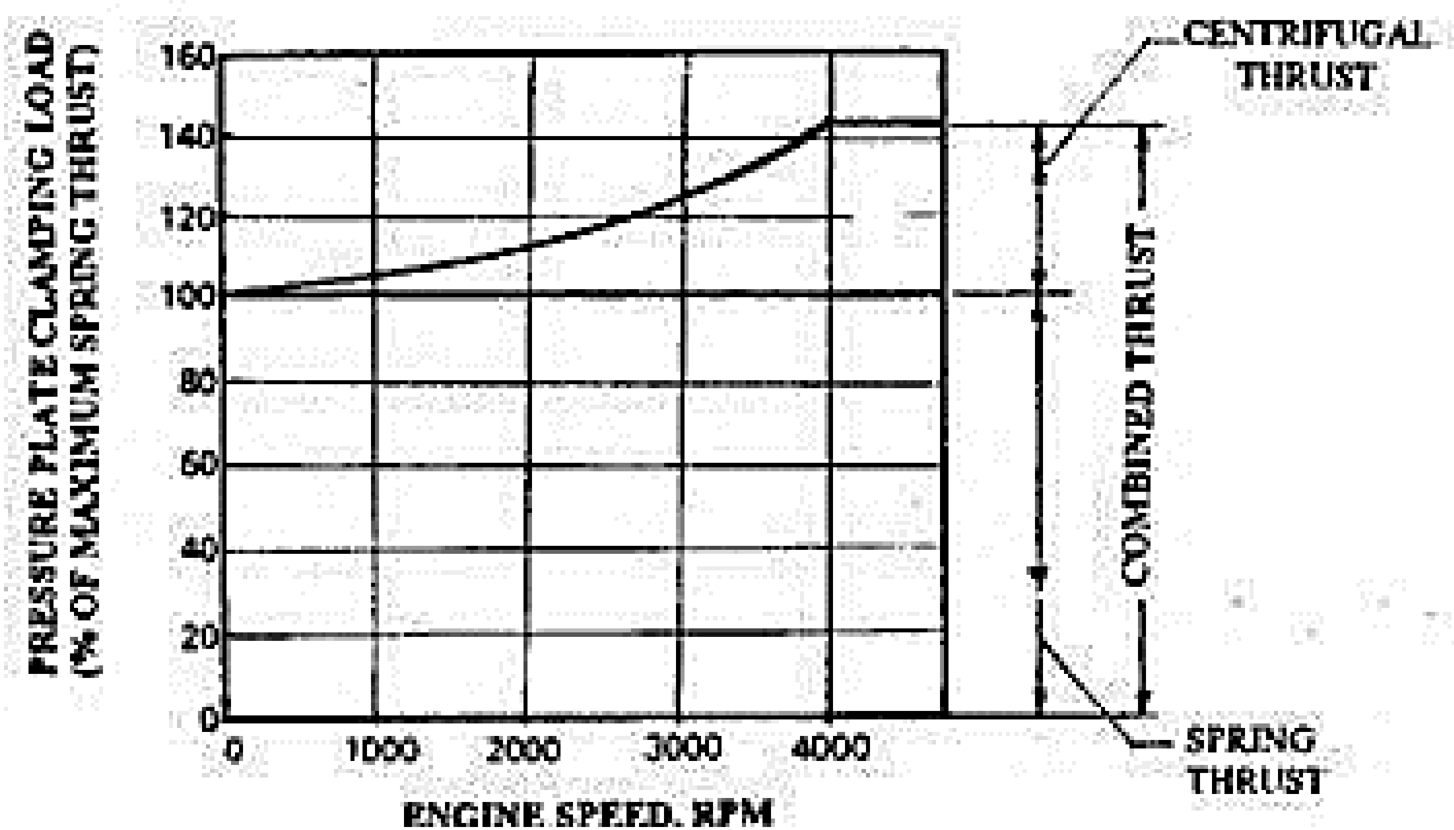
- Functioning of the clutch is automatic and depends upon the engine speed.
- As the speed increases, the flyweights move outwards due to the centrifugal force. This movement operates a bell crank lever and presses the floating plate.
- No need for specific operation to disengage the clutch.
- The vehicle can also be stopped with the gear load, without stalling the engine.
- The vehicle is controlled by the accelerator pressure and gear transmission at the starting only.
- This arrangement makes the driving operation very easy and convenient

Semi-centrifugal Clutch:

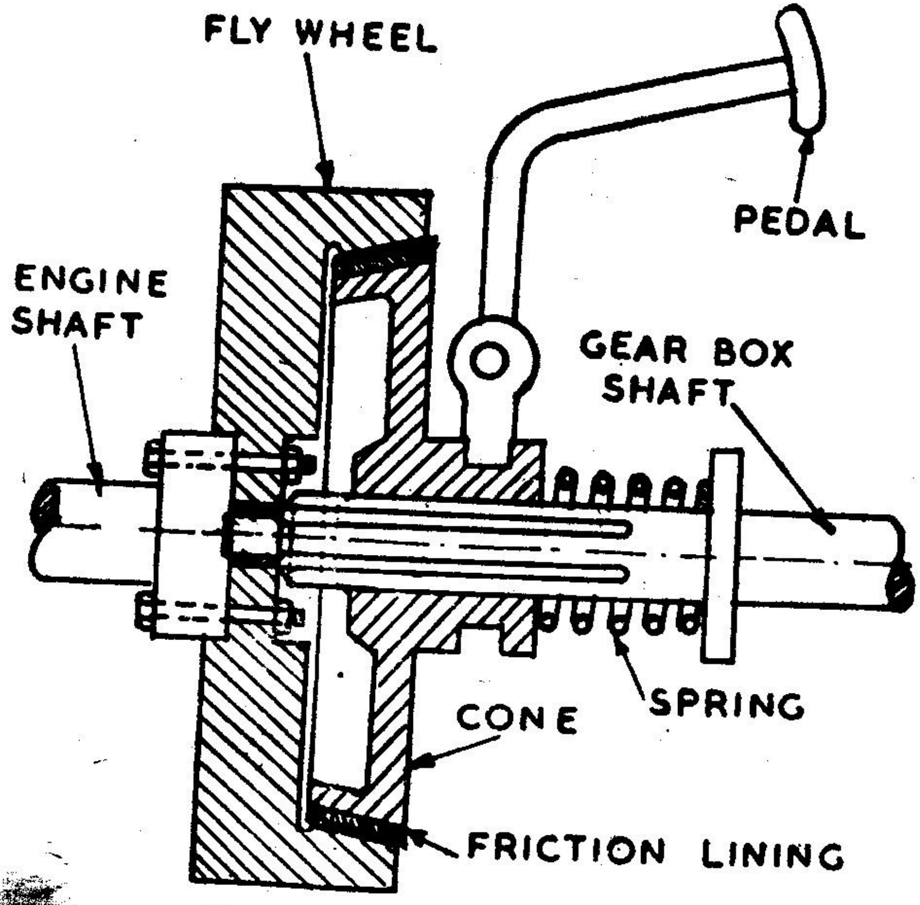


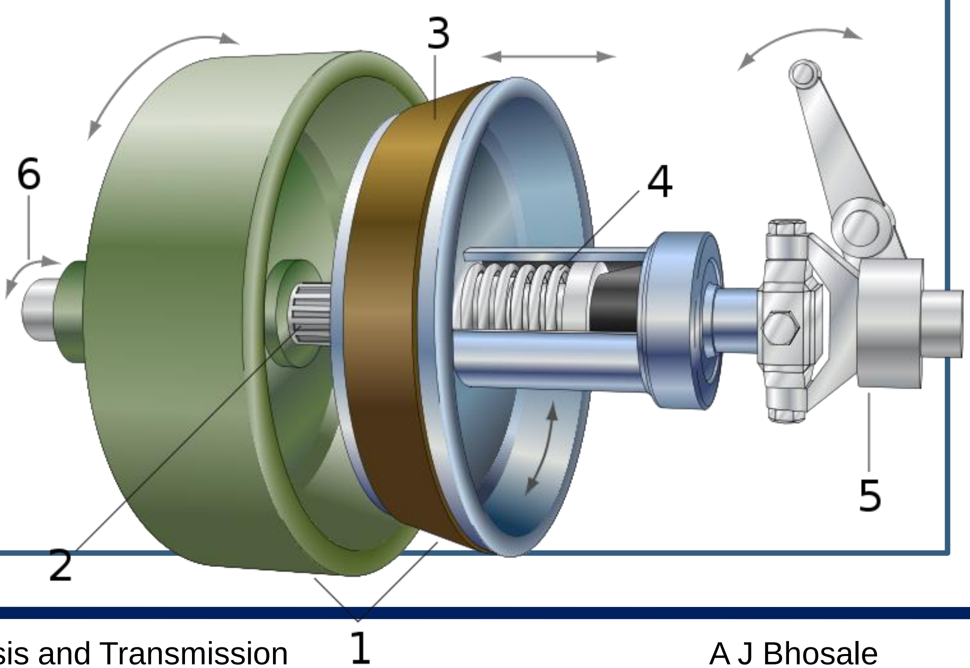


Semi-centrifugal clutch characteristics:



- This type of clutch uses lighter pressure plate springs for a given torque carrying capacity, so that the engagement of the clutch in the lower speed range becomes possible.
- The centrifugal force supplements the necessary extra clamping thrust at higher speeds.
- Offset bob weights are attached to the release levers at their outer ends, allowing levers to be centrifugally out of balance
- The centrifugal force causes the pressure plate to force against the driven plate, adding extra clamping load.
- Although the thrust due to the clamping springs is constant, the movement due to the centrifugal force varies as the square of the speed. Therefore, the reserve factor for the thrust spring can be reduced to 1.1 compared to 1.4-1.5 for a conventional helical coil spring clutch unit.
- Consequently, centrifugal clutch can be used for heavy duty applications requiring transmission of greater torque loads.


FLY WHEEL
PEDAL
ENGINE SHAFT
GEAR BOX SHAFT
SPRING
CONE
FRICTION LINING


3
6
4
5
2
1

Cone Clutch:

- They are wedge clutch provides a positive drive when the external face of the male cone member engages with the internal face of recessed conical member.
- The facing is usually fitted to the female or recessed member in order to improve heat dissipation and durability.
- Normally cone clutch are used with **epicyclic gear** trains for a higher torque transmission.
- The energy which a cone clutch can absorb during on engagement is less compared to the energy absorbed by a multiple clutch.
- But it is compact, cheaper and requires low clamping load due to the wedging action. The cone clutches are loaded by spring or hydraulic cylinders.
- .

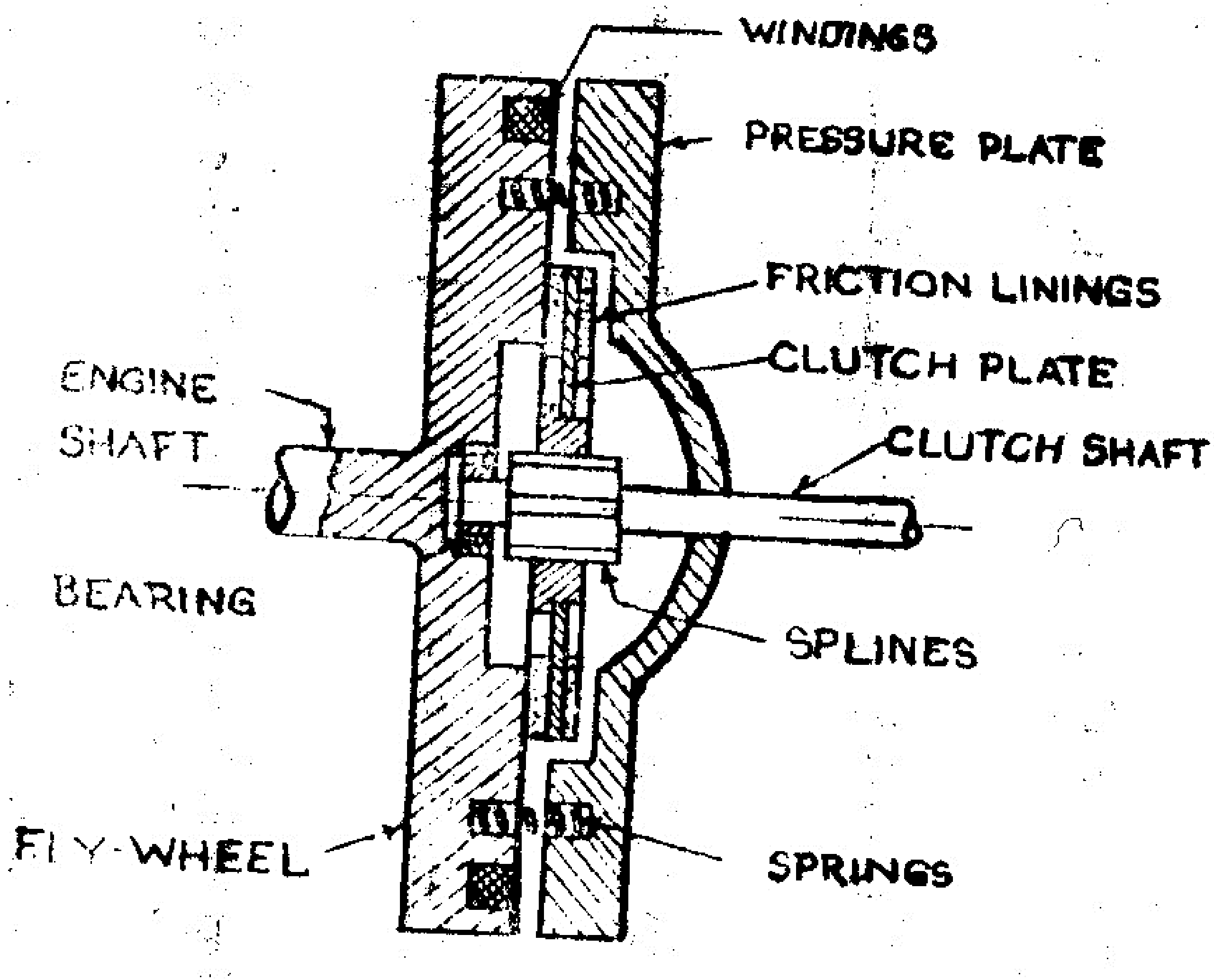
- **Wedge angle and accurate axial alignment** are the two important factors for good cone clutch performance.
- **If the wedge angle is very less, it results in excessive wedge action and fierce engagement. This in turn results in difficult operation for disengagement.**
- **If the wedge angle is too large it reduces torque transmission capacity of the clutch and make the clutches to skid.**
- **Semi-cone angle of 12-16** are commonly used for effective torque transmission.
- The torque transmitted by a cone clutch is given by,

$$T = \mu W (r_1 + r_2) / 2 \sin \alpha$$

Where, r_1 and r_2 are the radius of large and small cone (friction) in meters.

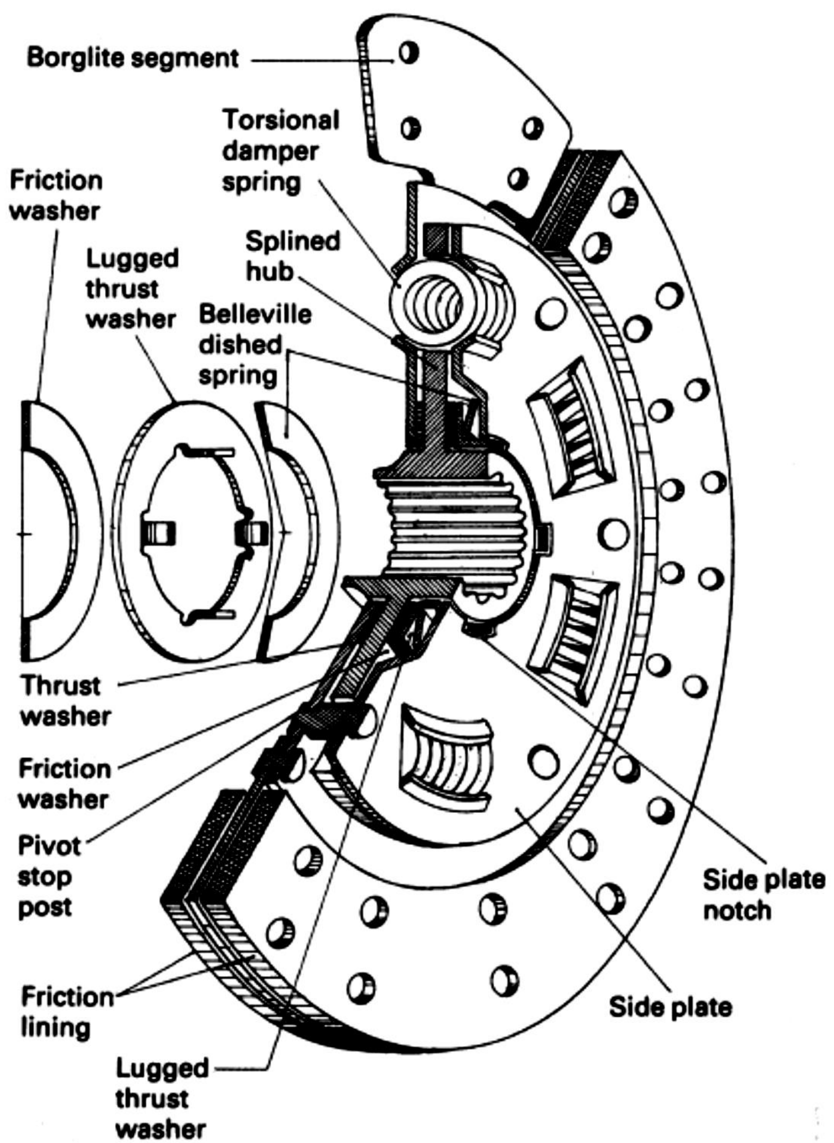
α is the semi – cone angle.

Electromagnetic Clutch:

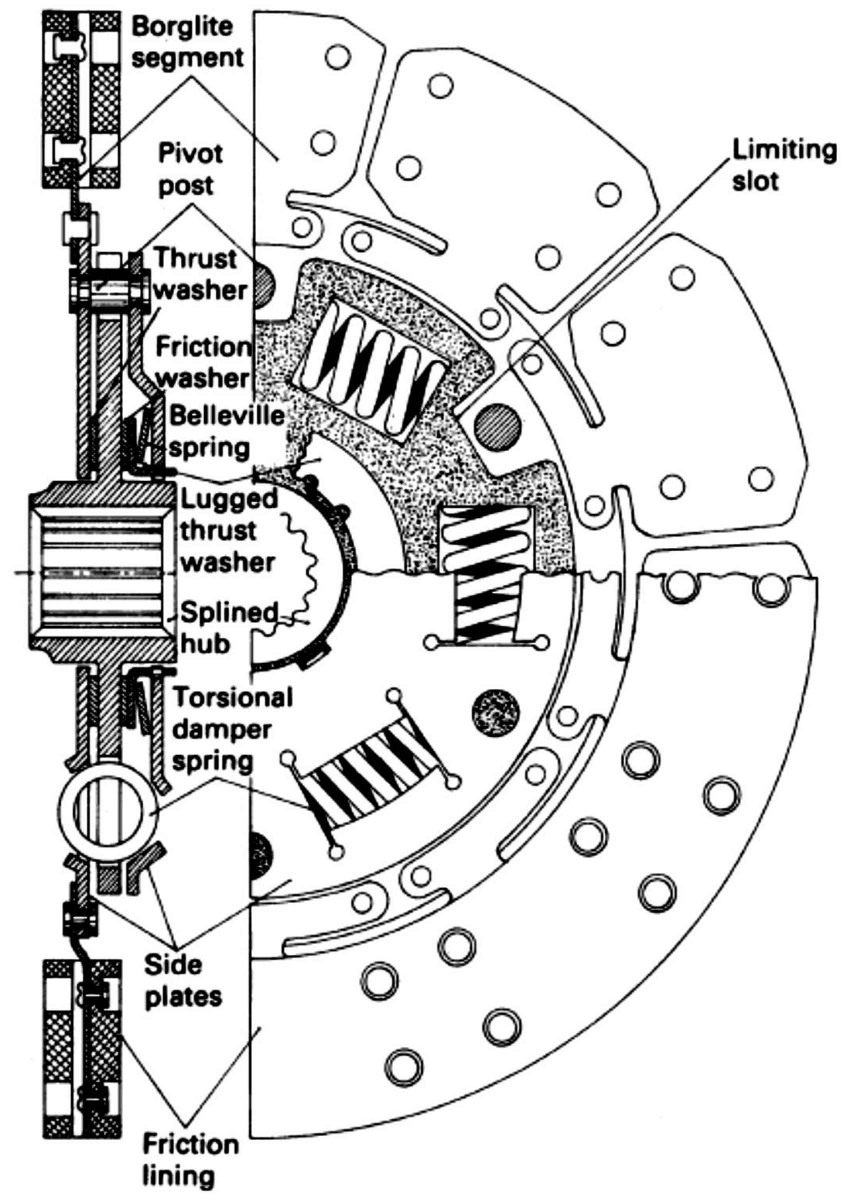


- **Electromagnetic Clutch**
- In this system the clutch is controlled by means electric current supplied to the field windings in the flywheel.
- The fly wheel is attached with the field winding, which is given electric current by means of battery, dynamo or alternator.
- The construction feature of main components is almost similar to the single plate clutch.
- When electric current is supplied to the windings the flywheel will attract the pressure plate and clutch plate is forced between pressure plate and flywheel resulting in engagement.
- When the supply to the winding is cut off the clutch is disengaged by releasing the pressure plate due to the force exerted by the helical springs or tension springs.
- Electromagnetic clutch consists of a clutch release switch.
- When then driver holds the gear lever to change the gear, the switch is operated cutting off the current to the winding which causes the clutch disengaged.

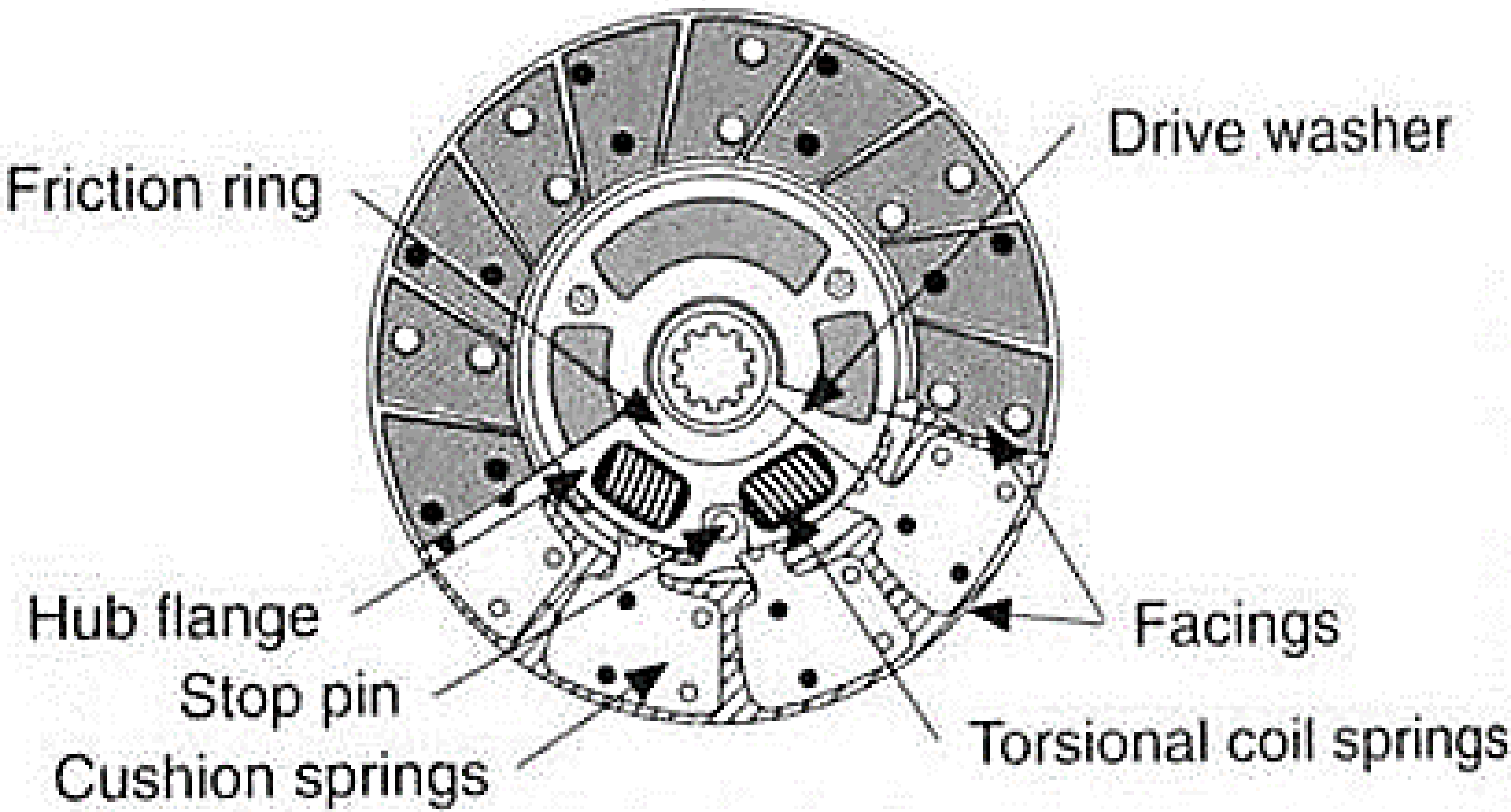
- When the vehicle is stalling, the engine speed is lower & the dynamo output is low, the clutch is not firmly engaged. Therefore, three springs are also provided on the pressure plate which helps the clutch disengaged at low speed.
- The forces of the electromagnet can be regulated by means of an electrical resistance provided with acceleration system and controlled by the accelerator pedal.
- When the speed is increased, the accelerator pedal is pressed and the resistance is gradually cut off and thus in this way, force of electromagnet is increased and clutch transmission becomes more rigid.
- Slippage should occur only during acceleration. When the clutch is fully engaged, there is no relative slip (if the clutch is sized properly). Torque transfer is 100% efficient.



Borglite segment
Torsional damper spring
Friction washer
Lugged thrust washer
Splined hub
Belleville dished spring
Thrust washer
Friction washer
Pivot stop post
Friction lining
Lugged thrust washer
Side plate notch
Side plate

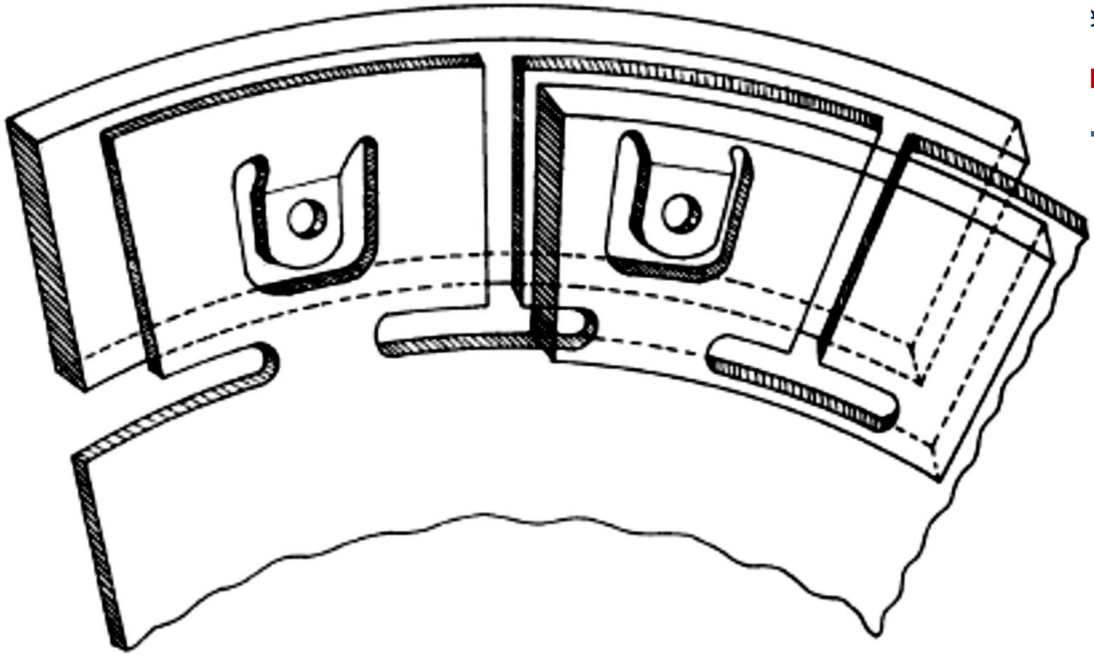


Borglite segment
Pivot post
Thrust washer
Friction washer
Belleville spring
Lugged thrust washer
Splined hub
Torsional damper spring
Side plates
Friction lining
Limiting slot

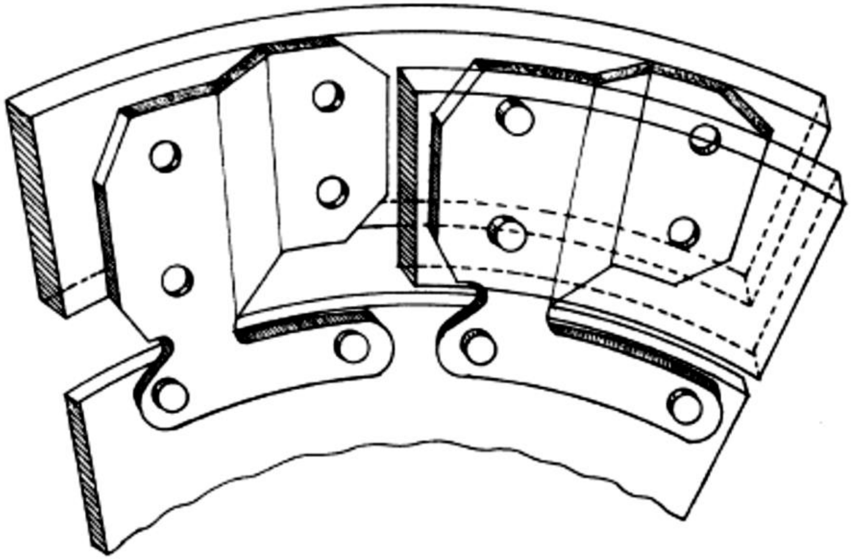


Parts of a clutch disc.

Crimp Spring



(a) Arcuate horseshoe spring



(b) Borglite segment spring

- Both forms of crimped steel spring segment situated between the friction linings provide progressive take up over the greater pedal travel and prevent snatch
- The separately attached spring segments are thinner than segments formed out of the single piece driven plate, because of that squeeze take up is generally softer and the spin inertia of the thinner segments is noticeably reduced.
- Ensures satisfactory bedding of the facing material and even distribution of the work load.
- Cooling between friction lining occurs when the clutch is disengaged which helps to regain the frictional properties of the facing material.
    - **Better clutch engagement control.**
    - **Improved distribution of the friction work over the lining faces reduces the peak operating temperature.**

When the clutch is initially engaged the segments are progressively Flattened so that the rate of increase In clamping load is provided by the rate of reaction offered by the crimp springs

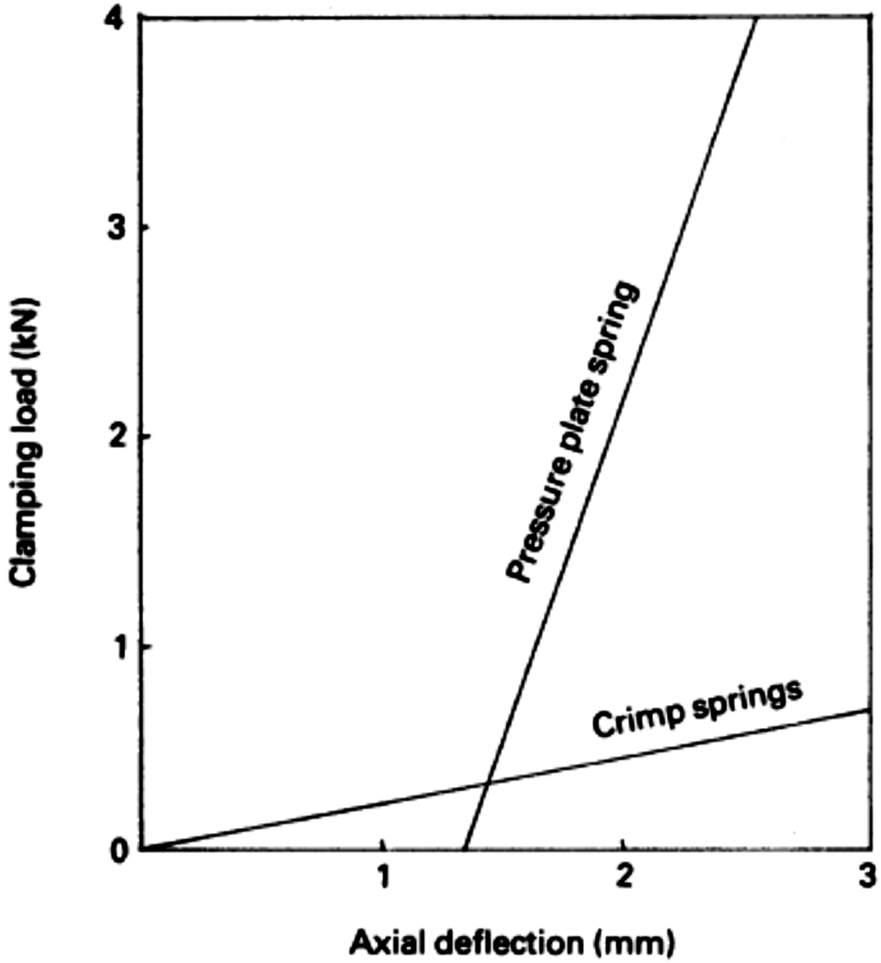
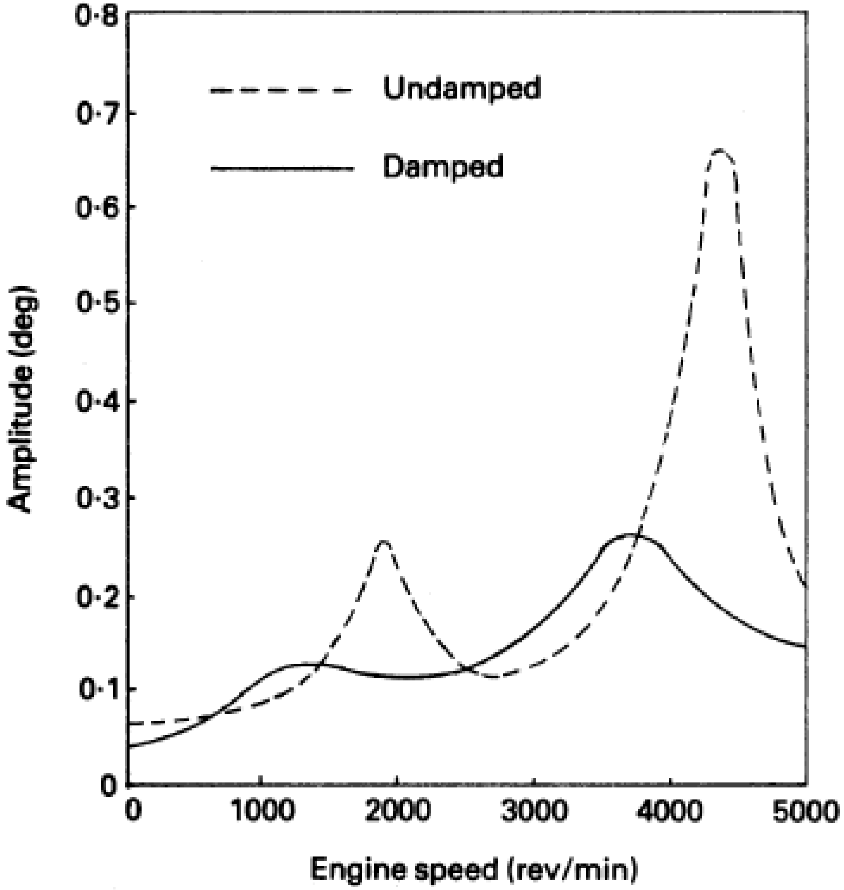


Fig. 2.5 Characteristics of driven plate axial clamping load to deflection take-up

Torsional Damper Spring:



Crankshaft Torsional Vibrations

❖ Torsional Damper Spring:

- To overcome the effects of crankshaft torsional vibrations a torsion damping device is normally incorporated within the drive plate hub assembly.
- To transmit torque more smoothly and progressively during take up of normal driving and to reduce the torsional oscillations being transmitted from the crankshaft to the transmission, compressed spring are arranged circumferentially around the hub of the driven plate.

❖ Clutch Material:

Components	Material	Components	Material
Cover plate	Mild steel	Damper spring	Spring steel
Diaphragm spring	Spring steel	Clutch hub	Mild steel
Coil spring	Spring steel	Bolts to fasten flywheel and cover plate	Steel
Pressure plate	Cast iron	Rivets on cushion spring	Brass
Clutch disc	Mild steel	Retainer spring	Spring steel
Friction facing	Asbestos base	Damper spring retainer plate	Mild steel
Rivets on facing	Aluminum brass	Cushion spring	Mild steel

Requirements of Friction Lining:

1. Relatively high coefficient of friction under operating conditions,
2. Capability to maintain the frictional properties over its working life,
3. Relatively high energy absorption for short periods,
4. Capability to withstand high pressure plate compressive loads,
5. Withstanding high impacts of centrifugal force during gear changing.
6. Adequate shear strength to transmit engine torque.
7. High level of endurance in cyclic working without effecting friction properties.
8. Good compatibility with cast iron facings over the entire range of operating temperature.
9. A high degree of tolerance against interface contamination without affecting its friction take-up and grip characteristics.

❖ Friction lining:

- Linings are riveted or bonded to the clutch plates .
- Rivet heads are seated in counter bores in the friction material, and it is made of copper or aluminum, with this only thickness of the lining down to the rivet heads can be used and remainder has to be scrapped .
- Bonded lining can utilize large portion of the total volume of the friction material .
- Friction materials are woven or molded.

Asbestos-based Linings

- Asbestos-based linings are, generally, of the woven type. These woven linings are made from asbestos fibre spun around lengths of brass or zinc wire of make lengths of threads, which are both heat resistant and strong.
- Advancement in weaving techniques has also eliminated the use of wire coring. This has enabled to offer asbestos woven lining as either non- or semi-metallic to suit a variety of working conditions.
- The woven cloth can be processed in one of two ways :
- In one method, the fiber wire thread is woven into a cloth, which is then pressed into discs of the required diameter. Several of these discs are stitched together to obtain the desired thickness.

- The final disc is dipped into resin solution so that the woven asbestos threads are bonded together.
- In the other method, the asbestos fiber wire is woven in three dimensions in the form of a disc to obtain the desired thickness in a single stage.
- It is then pressed into required shape and bonded together by again dipping it into a resin solution. Finally the rigid lining is machined and drilled for reverting to the driven plate.

- These asbestos linings operate satisfactorily below **533K** providing a reasonable life span and uniform coefficient of friction between **0.32 and 0.38.**
- However, most manufacturers of asbestos-based linings quote a maximum safe temperature of **633 K**.
- As a substitute to asbestos lining material, the DuPont Company has developed a friction material with the trade name **Kevlar aramid** derived from automatic polyamide fibers belonging to the nylon family of polymers.

- It possesses **high endurance** over its normal working pressure and temperature range.
- Since it is lighter in weight than asbestos material, the time required for gear changing is less due to a reduction in driven plate spin. It **exhibits good take-up characteristics.**
- It has **good centrifugal strength** to withstand lining disintegration due to sudden acceleration caused during the changing of gears. It has **stable rubbing properties** at high operating temperatures.
- At a temperature of 698 K it begins to break down steadily changing to carbon, and the disintegration process is completed at about 773 K.

Metallic Friction Materials

- The metallic linings are normally made from either **sintered iron or copper-based sintered bronze**. The semi-metallic linings are made from a mixture of organic and metallic materials.
- Metallic lining materials in a powder form are compressed and heated in moulds until sufficient adhesion and densification take place.
- This process is known as **sintering**.
- The metallic rings are then ground flat and are then riveted back to back onto the driven plate.

- When compared to the organic asbestos based linings, the metallic and semi-metallic linings -generally have a higher coefficient of friction, can operate at higher working temperatures, have greater torque capacity and have extended life.
- The metallic materials have relatively high inertia, making it difficult to obtain rapid gear changes, and these facings are more expensive than organic materials.
- Therefore, metallic and semi-metallic linings have been only moderately successful.

Cerametallic Friction Materials

- Cerametallic button friction linings are becoming popular for heavy duty clutches. Instead of a full annular shaped lining, like organic friction materials, **four or six cerametallic trapezoidal-shaped buttons** are evenly spaced on both sides around the driven plate.
- The cerametallic material in a powder form containing mainly of **ceramic and copper**, is compressed into buttons and heated.
- This causes the copper to melt and flow around each particle of solid ceramic. Once solidified, the copper forms a strong **metaceramic interface bond**. These buttons are then riveted to the clutch driven plate and then finally ground flat.

- The cerametallic lined driven plates offer the following advantages.

(a) They have a **very low inertia** (about 10% lower than the organic disc and 45% lower than a comparable sintered iron disc). Therefore it results in quicker gear changes.

(b) They have a **relatively high and stable coefficient of friction** with an average value of **0.4** so that the torque capacity of clutches is increased.

(c) These can satisfactorily operate at **high working temperatures of up to 713 K** for relatively long periods without causing fade.

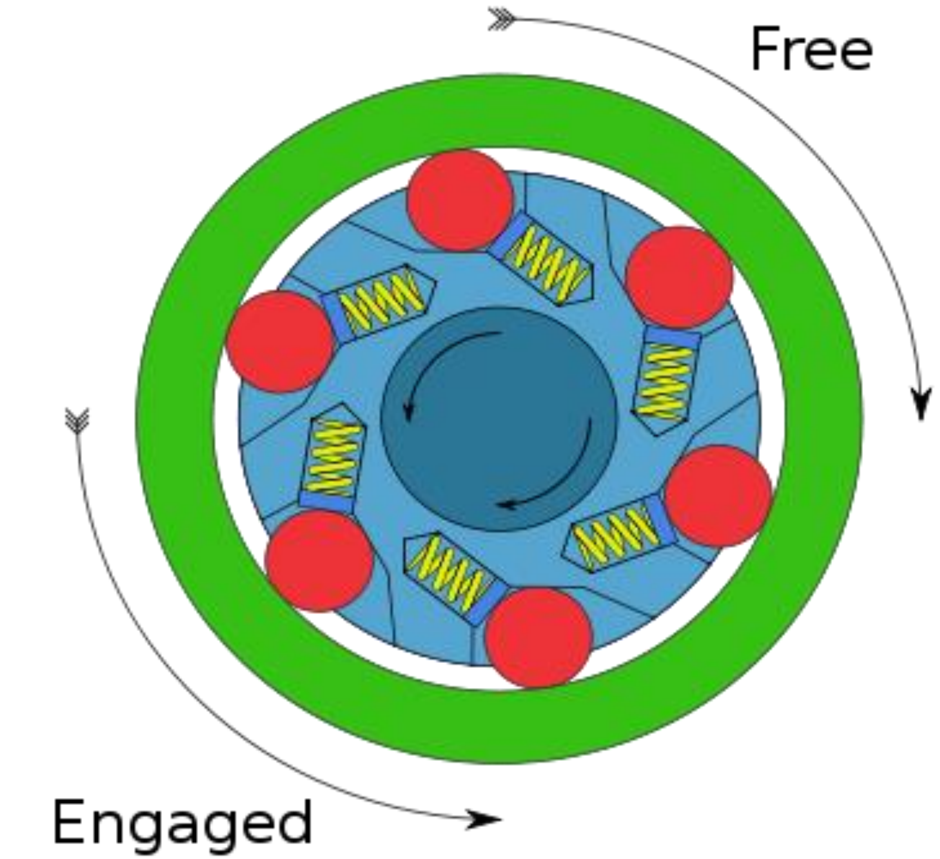
(d) Button type driven plates **use only about 50% of the flywheel** and pressure plate surfaces during clutch engagement. This **improves convective heat transfer** to the surrounding by as much as 100%.

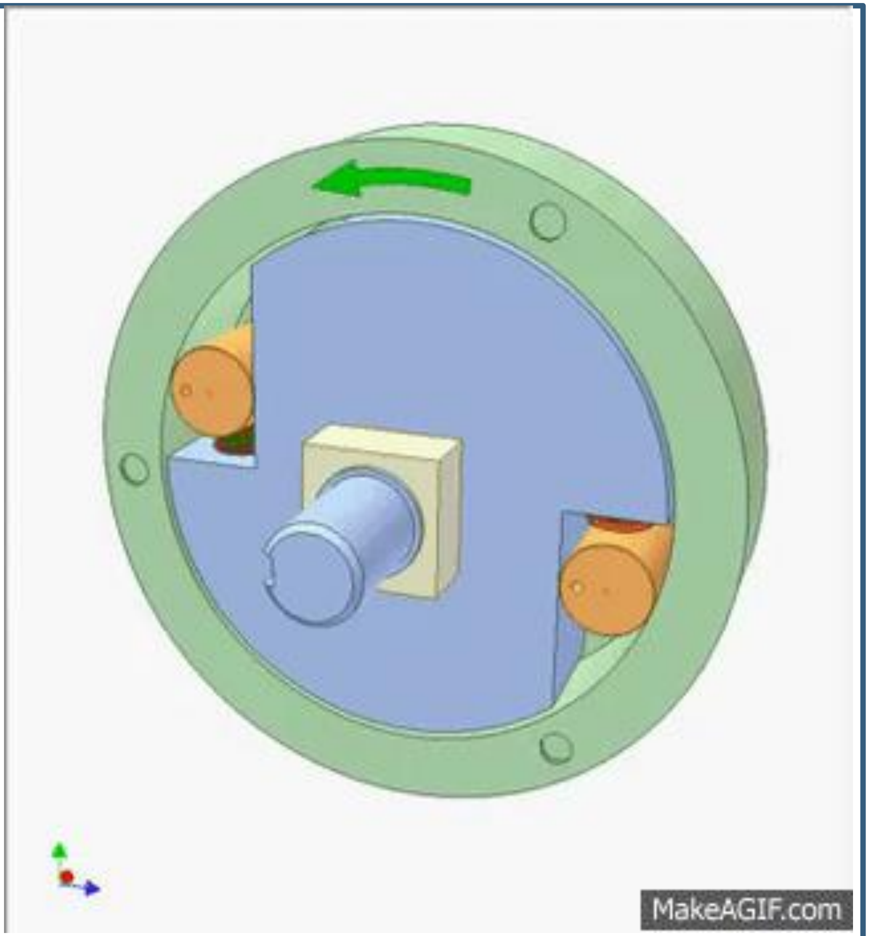
(e) Button type friction pads **do not warp** during use unlike full ring metallic or organic linings.

(f) Button type friction pads **prevent scoring of the friction faces**, as they permit the dust worn from the friction surfaces to be thrown clear of the clutch areas.

g) Cerametallic materials are **less sensitive to grease and oil** contamination than organic asbestos based linings. Also present time ceramic-metallic friction buttons do not wear tracks in flywheel and pressure plate facings, which was a problem is early days of application.

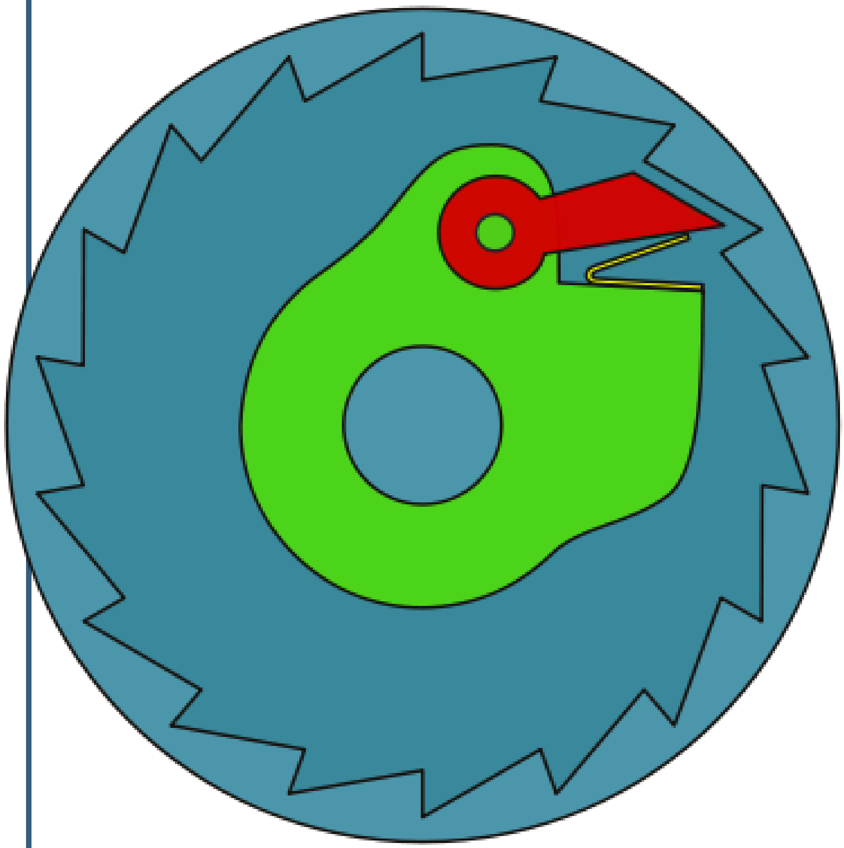
Overrunning Clutch:

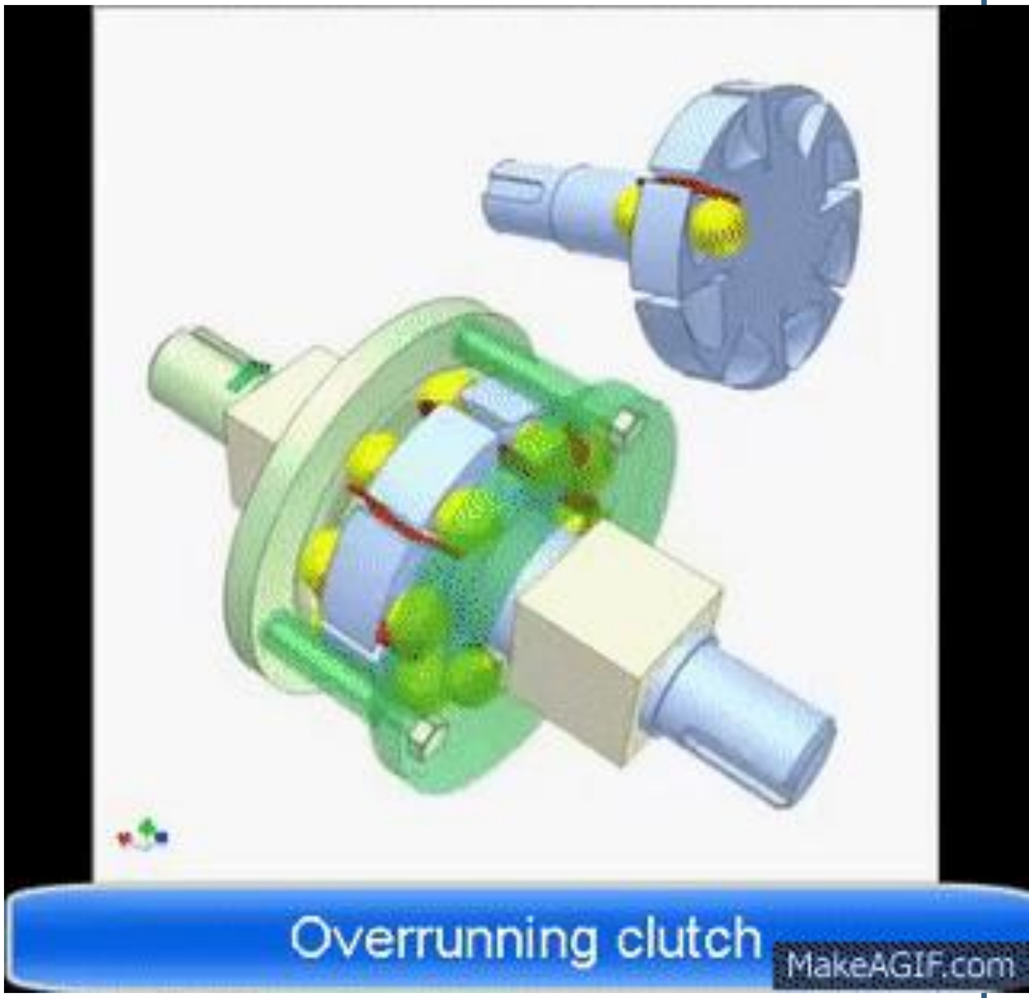




- In 1869, **William Van Anden** invented the freewheel for the bicycle.
- ..\..\VId\Nowfer's explanation How does a free wheel clutch work.mp4

..\..\VId\Overrunning clutch animations.mp4





- **A freewheel** or **overrunning clutch** is a device in a transmission that disengages the driveshaft from the driven shaft when the driven rotates faster than the driveshaft.
- The condition of a driven shaft spinning faster than its driveshaft exists in most bicycles when the rider holds his or her feet still, no longer pushing the pedals.
- In a fixed-gear bicycle, without a freewheel, the rear wheel would drive the pedals around.
- Applications:
  - Bicycles
  - Agricultural Units
  - Vehicle Transmissions (Automatic)
  - Helicopters
  - Engine Starters

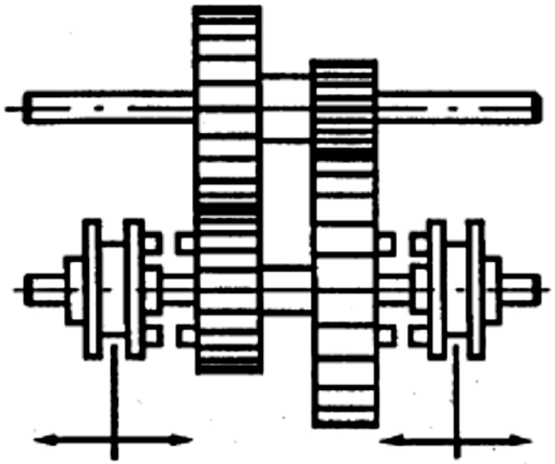
..\..\VId\Overrunning clutch animations.mp4

❖ Gearbox:-

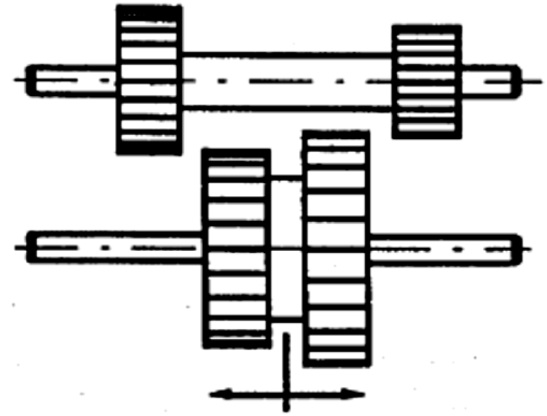
- Most modern **gearboxes** are used to increase torque while reducing the speed of a prime mover output shaft (e.g. a motor crankshaft).
- This means that the output shaft of a **gearbox** rotates at a slower rate than the input shaft, and this reduction in speed produces a mechanical advantage, increasing torque.
- **Types of Gearboxes**

1. Selector Gearbox
2. Industrial Gearbox
3. Steering Gearbox
4. Machine Gearbox
5. Transfer Case Gearbox
6. Final Drive Gearbox

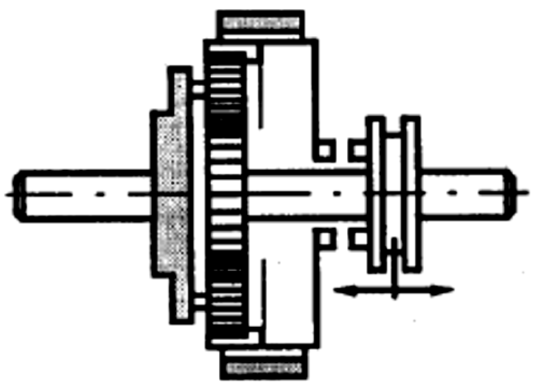
History:



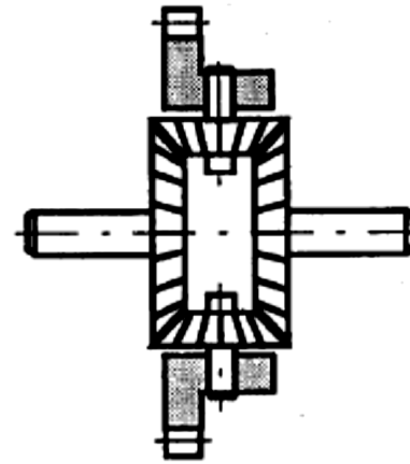
1784 *Watt* patent
2-speed gearbox with dog clutch engagement



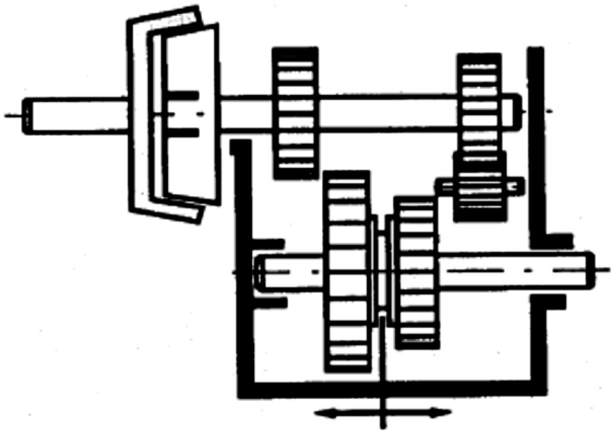
1821 *Griffith*
2-speed gearbox with sliding gears



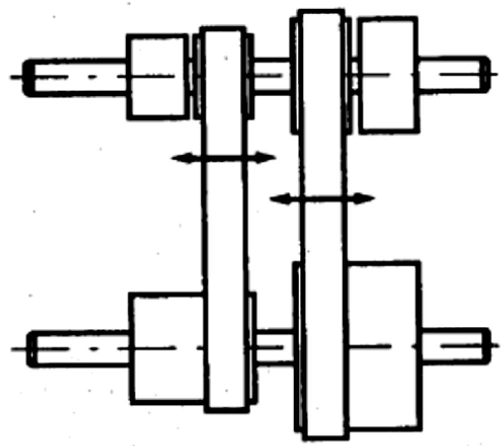
1834 *Bodmer*
Shiftable planetary gear



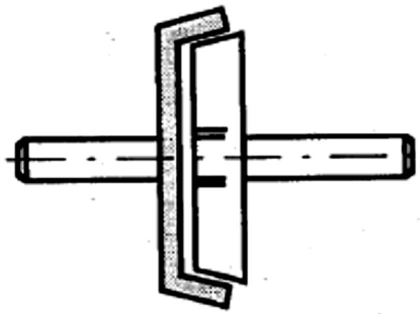
1827 *Pecqueur*
Differential gear



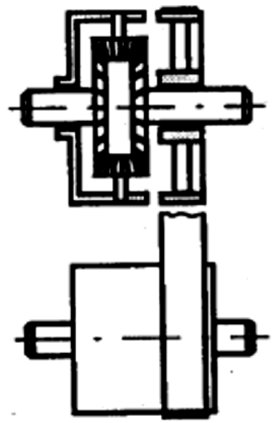
1879 *Selden*
Complete vehicle transmission with clutch, R gear and housing



1849 *Anderson*
Shiftable belt transmission

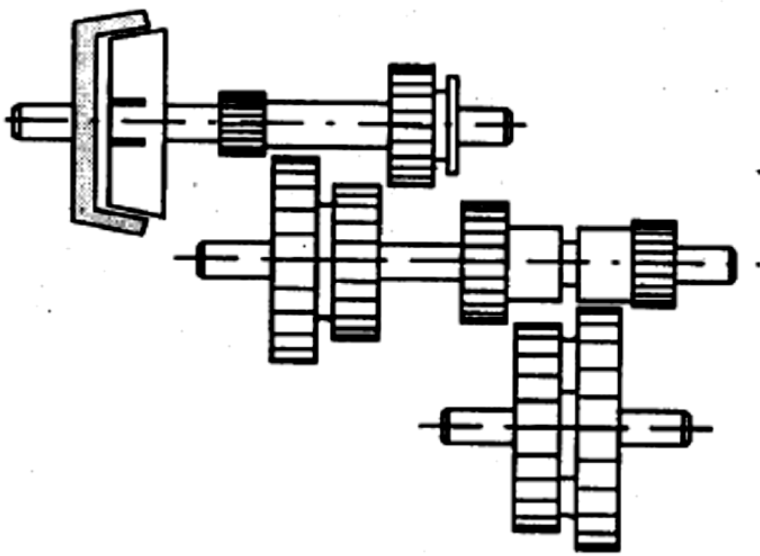


Around 1885 *Marcus*
Engaging cone clutch

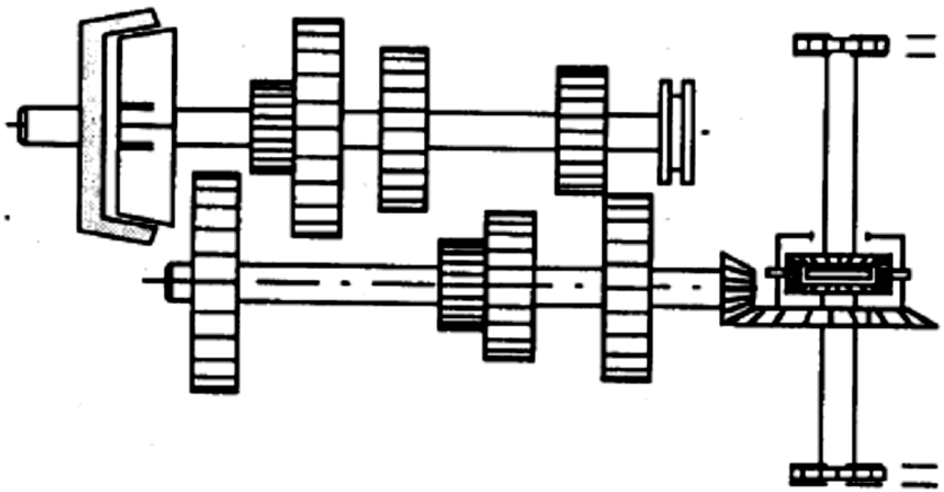


1886 *Benz*
Belt-driven bevel gear differential

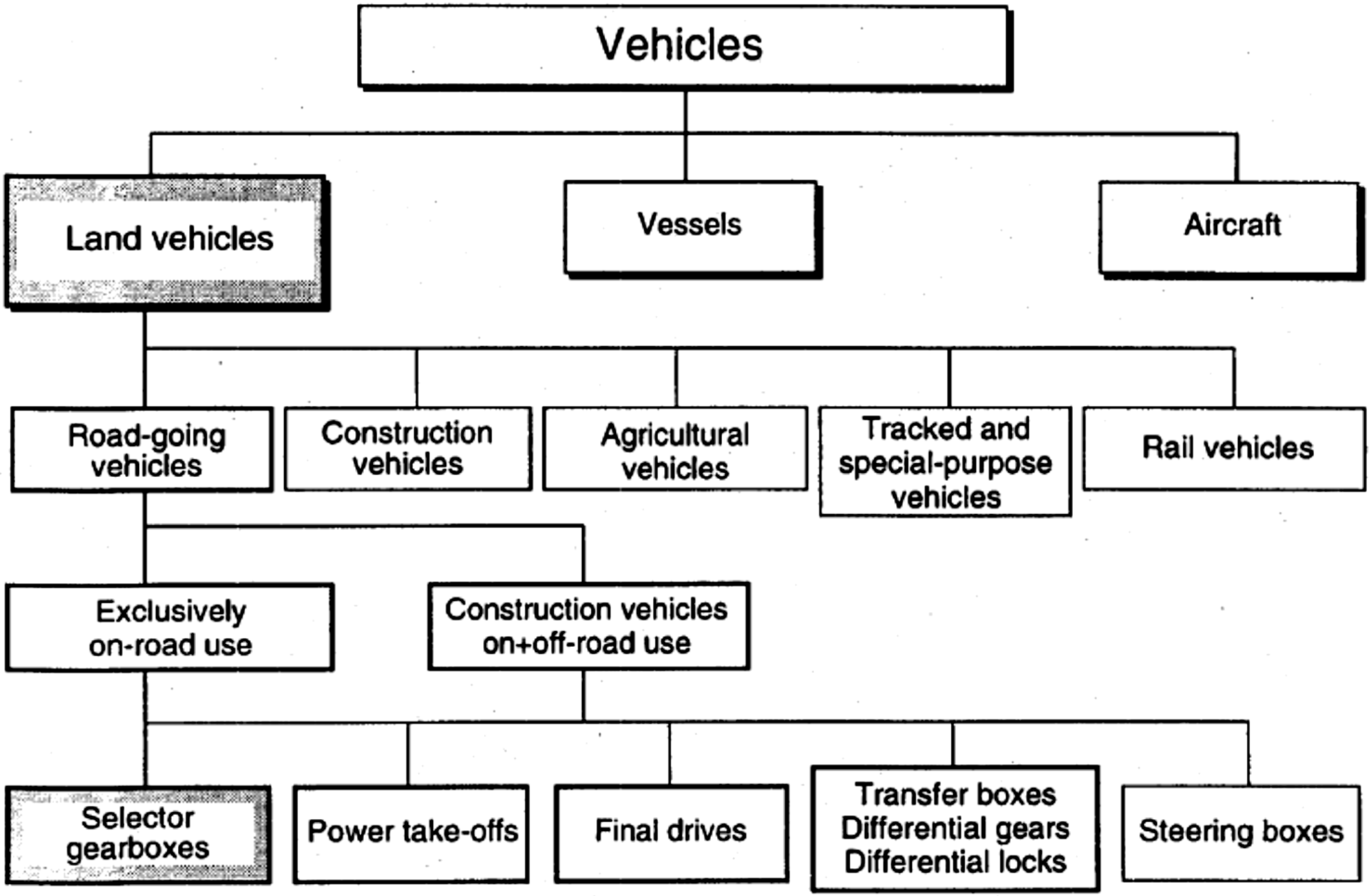
❖ Early Vehicle Transmission:



1889 *Maybach-Daimler* gearbox



1890 *Peugeot* driveline


Vehicles
Land vehicles
Vessels
Aircraft
Road-going vehicles
Construction vehicles
Agricultural vehicles
Tracked and special-purpose vehicles
Rail vehicles
Exclusively on-road use
Construction vehicles on+off-road use
Selector gearboxes
Power take-offs
Final drives
Transfer boxes Differential gears Differential locks
Steering boxes

<table>
<tr><th colspan="10">Transmission types</th></tr>
<tr><td colspan="6">z-speed-transmissions
(geared transmissions with z speeds)</td><td colspan="4">Continuously variable transmissions</td></tr>
<tr><td>Constant-mesh transmission</td><td>Synchromesh transmission</td><td>Semi-automatic constant-mesh or synchromesh transmission</td><td>Fully automatic constant-mesh or synchromesh transmission</td><td>Conventional automatic transm.</td><td>Twin-clutch transmission</td><td>Pulley transmission</td><td>Toroidal transmission (friction gear)</td><td>Hydrostatic transmission</td><td>Electric transmission</td></tr>
<tr><td colspan="3">With power interruption</td><td colspan="7">Without power interruption (powershift)</td></tr>
<tr><td colspan="3">Moving off and disengagement with foot-operated clutch</td><td colspan="7">Automatic continuously variable moving off</td></tr>
<tr><td colspan="2">Manual gearshift</td><td>Semi-automatic gearshift</td><td colspan="3">Automatic gearshift</td><td colspan="4">Automatic torque and speed conversion</td></tr>
</table>

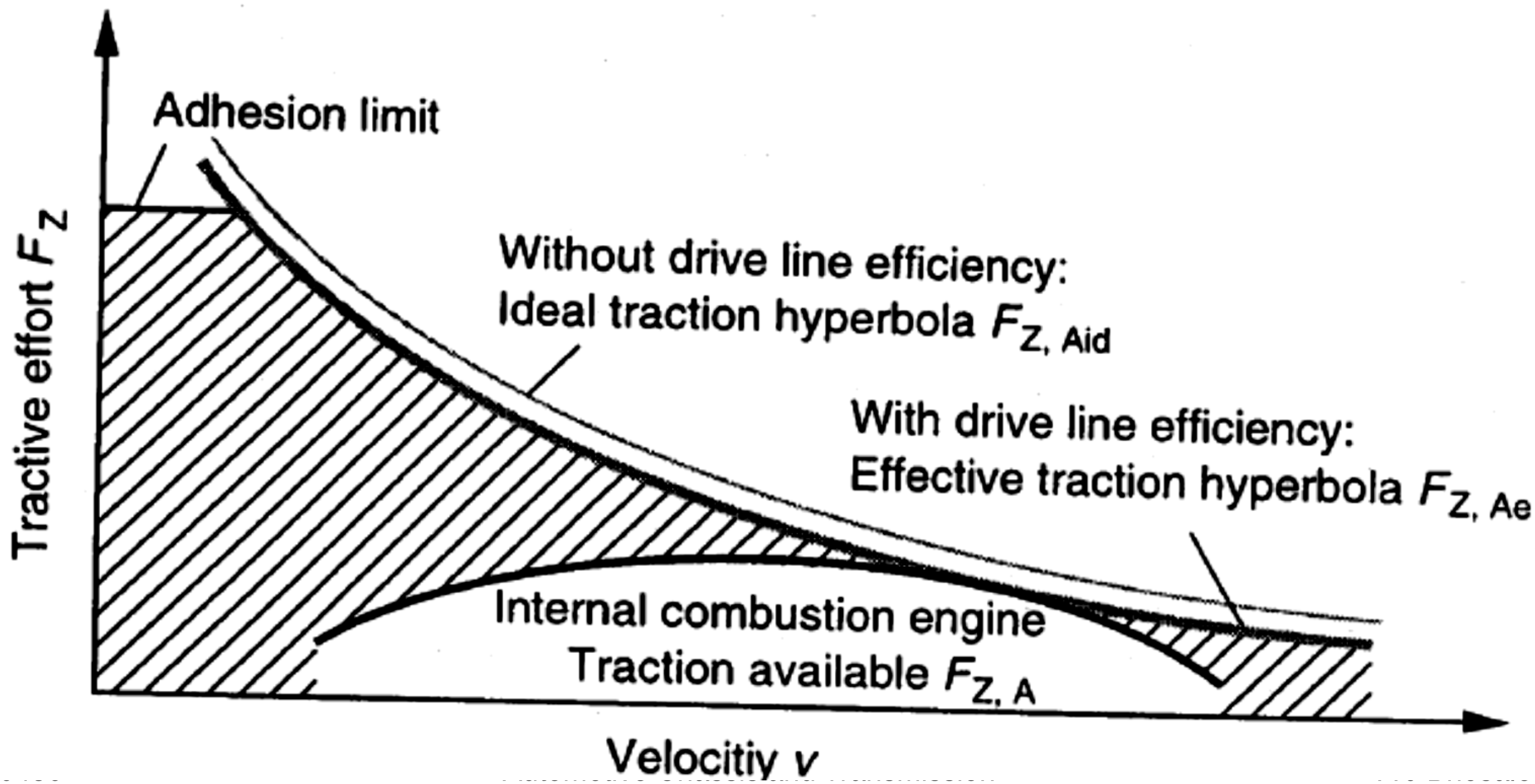
- **Necessity of gear box:**

- Variation of resistance to the vehicle motion at various speeds.
- Variation of tractive effort of the vehicle available at various speeds.
- IC Engines are having very high power to weight ratio, relatively good efficiency and relatively compact energy storage but it has three distinct disadvantages,
  - Unlike electric motor the combustion engine is incapable of producing torque from rest (zero engine speed).
  - An I.C. engine produces maximum power only at certain engine speed.
  - The efficiency of the engine i.e. its fuel consumption , is very much dependent on the operating point in the engine's performance map.
- Vehicle transmission mediate between the engine and drive wheels.

$$F_{Z,\,Aid} = \frac{P_{max}}{v} \quad \text{or} \quad F_{Z,\,Ae} = \frac{P_{max}}{v}\eta_{tot} \;.$$

- Where, -P_{max} -engine power and v- road speed,

  η_{tot} – total efficiency



❖ Functions of Transmission –

- Torque produced by the engine varies with speed only within narrow limits. But under practical condition automobile demands a large variation of torque available at the wheels. Transmission provide a means to vary the torque ratio between engine and road wheels as required.
- Neutral position.
- Reversing the direction of rotation of the drive .

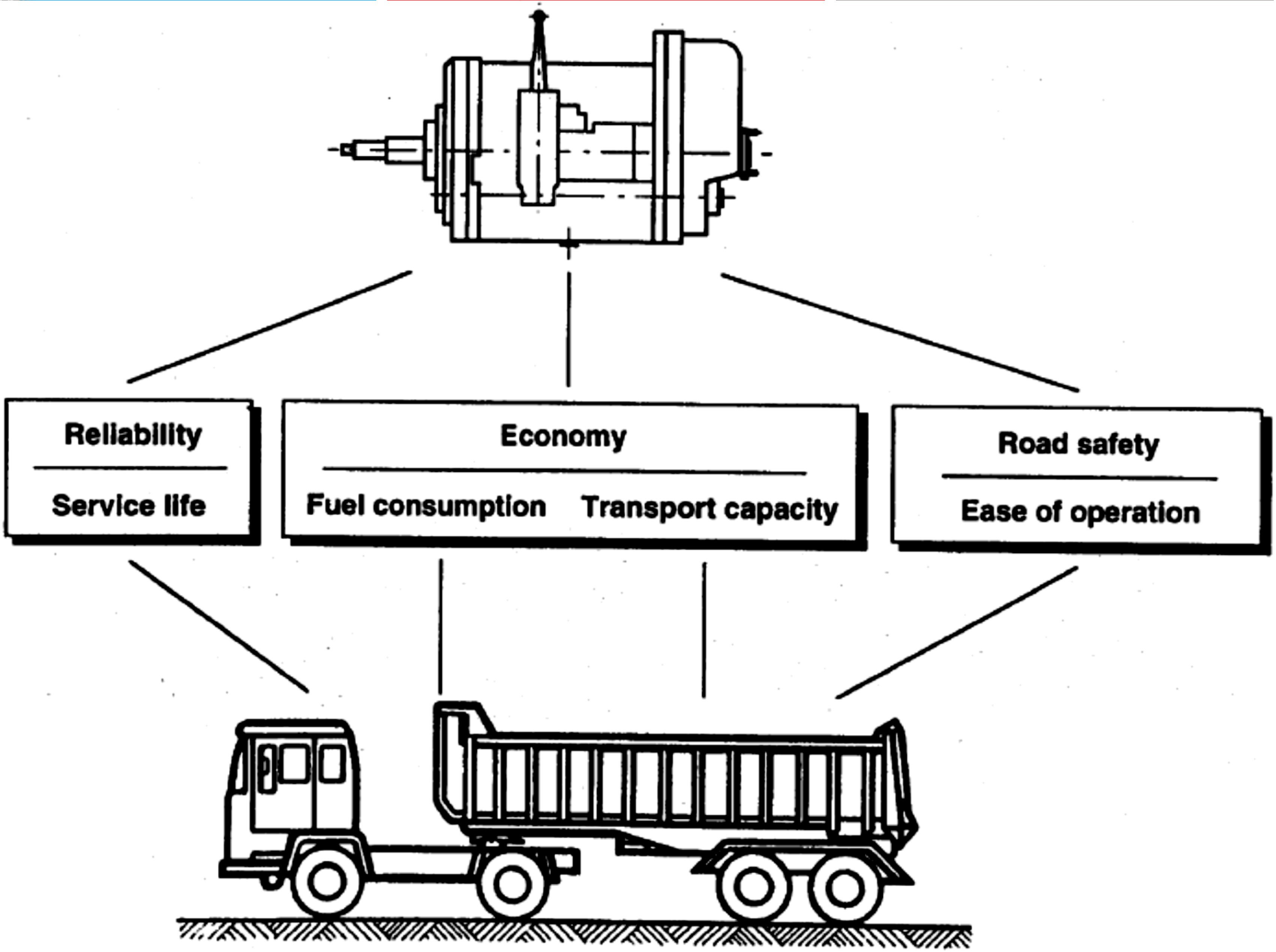
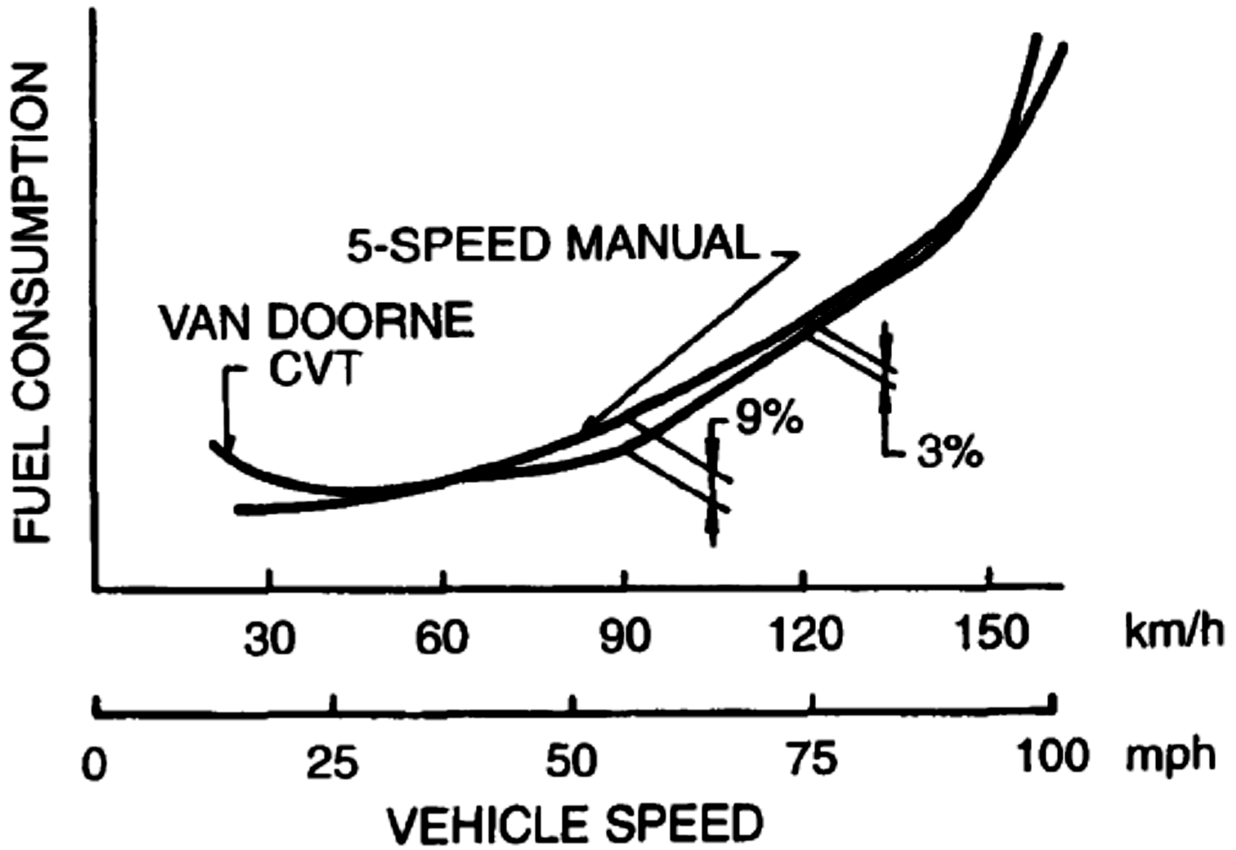


Figure 1.3. Effect of the transmission on key features of the vehicle

How Automotive Transmission is related to Fuel Consumption?

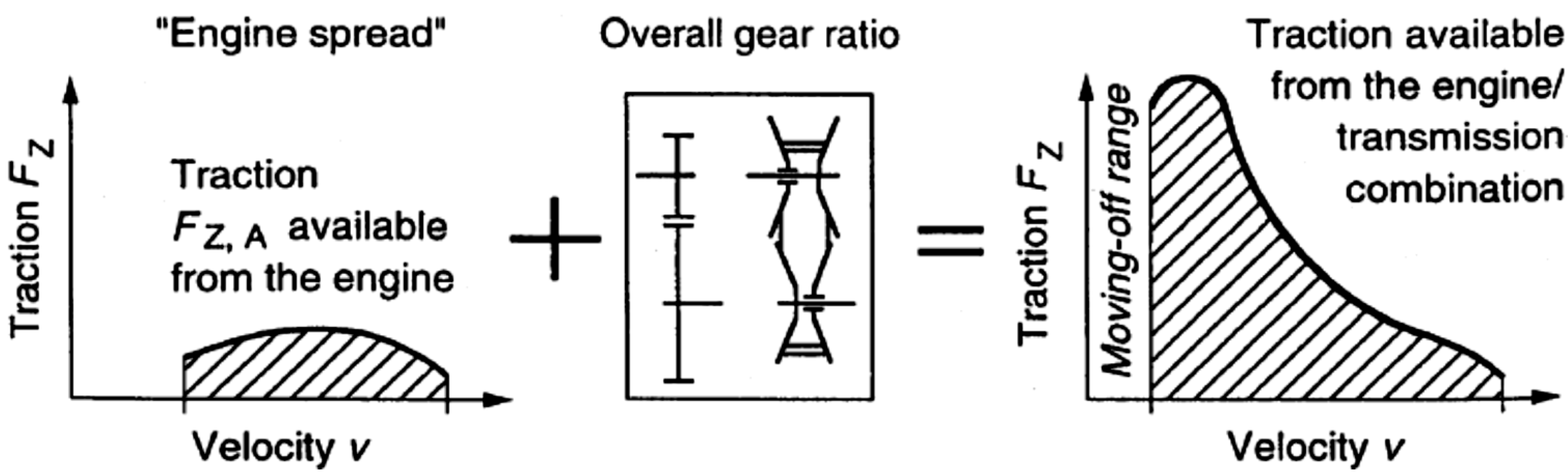
Effect of Transmission on Fuel Economy

- CVT gives better FE in 60-150 kmph than manual trans. but due to its lower mechanical efficiency (86-90%) the characteristics are observed same as manual trans.



❖ Requirements of Gearbox:

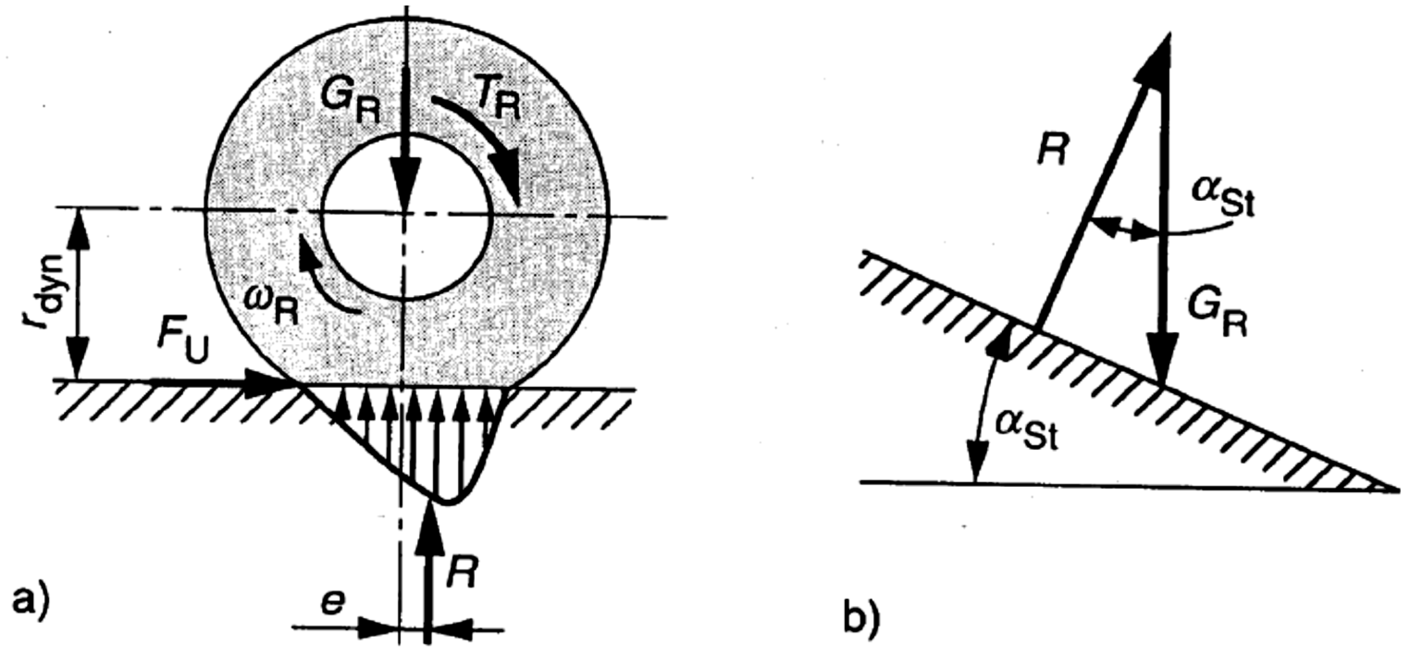
1. Overcome Resistances
2. Performance
3. Fuel Consumption
4. Emissions
5. Comfort
6. Weight
7. Cost
8. Simple Construction



❖ Resistance to motion of vehicle:-

- Power requirement at the drive wheels is determined by the driving resistance.
- Driving resistances offered to the vehicles :
  - **Rolling resistance (F_R)**
  - **Air resistance (F_L)**
  - **Gradient resistance (F_{St})**
  - **Miscellaneous resistance (F_A)**

Rolling Resistance (F_R)



$$F_R = f_R\, G_R$$

Where,

f_R = Proportionality factor or rolling resistance coefficient

G_R = Wheel load

$$f_R = \frac{e}{r_{dyn}}\,.$$

When travelling up gradients/ down slopes, then

$$F_R = f_R \cdot m_F \cdot g \cdot \cos \alpha_{St}$$

Table 3.1. Reference values for the rolling resistance coefficient f_R. For road speeds below 60 km/h, f_R can be assumed to be constant. (See also Table 5.1)

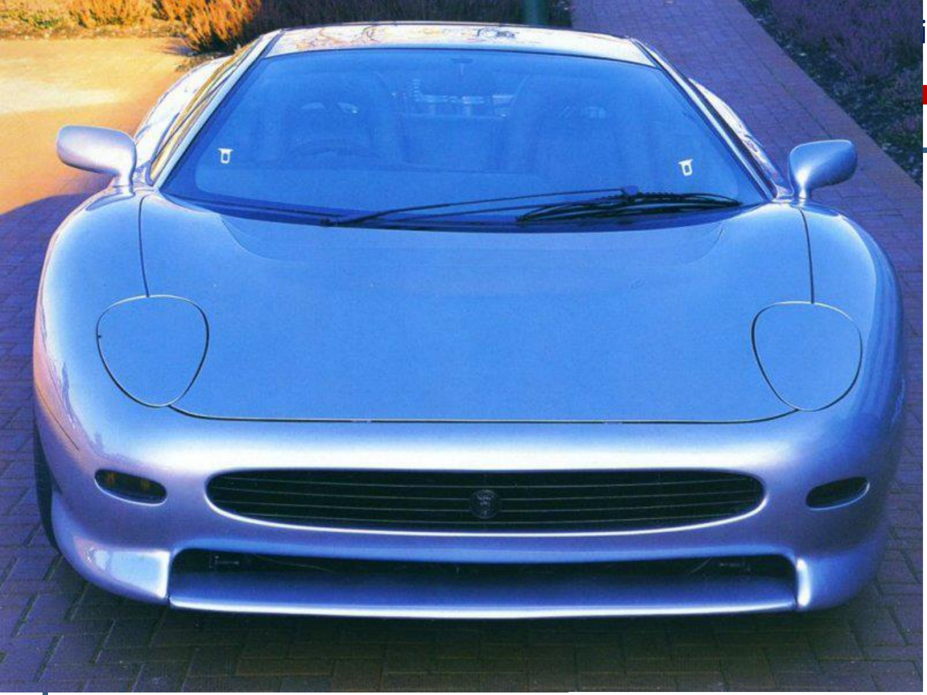
Road surface	Rolling resistance coefficient f_R
Firm road surface	
Smooth tarmac road	0.010
Smooth concrete road	0.011
Rough, good concrete surface	0.014
Good stone paving	0.020
Bad, worn road surface	0.035
Unmade road surface	
Very good earth tracks	0.045
Bad earth tracks	0.160
Tracked tractor on acre soil	0.070–0.120
Clamp wheels on acre soil	0.140–0.240
Loose sand	0.150–0.300

- **Composed primarily of**

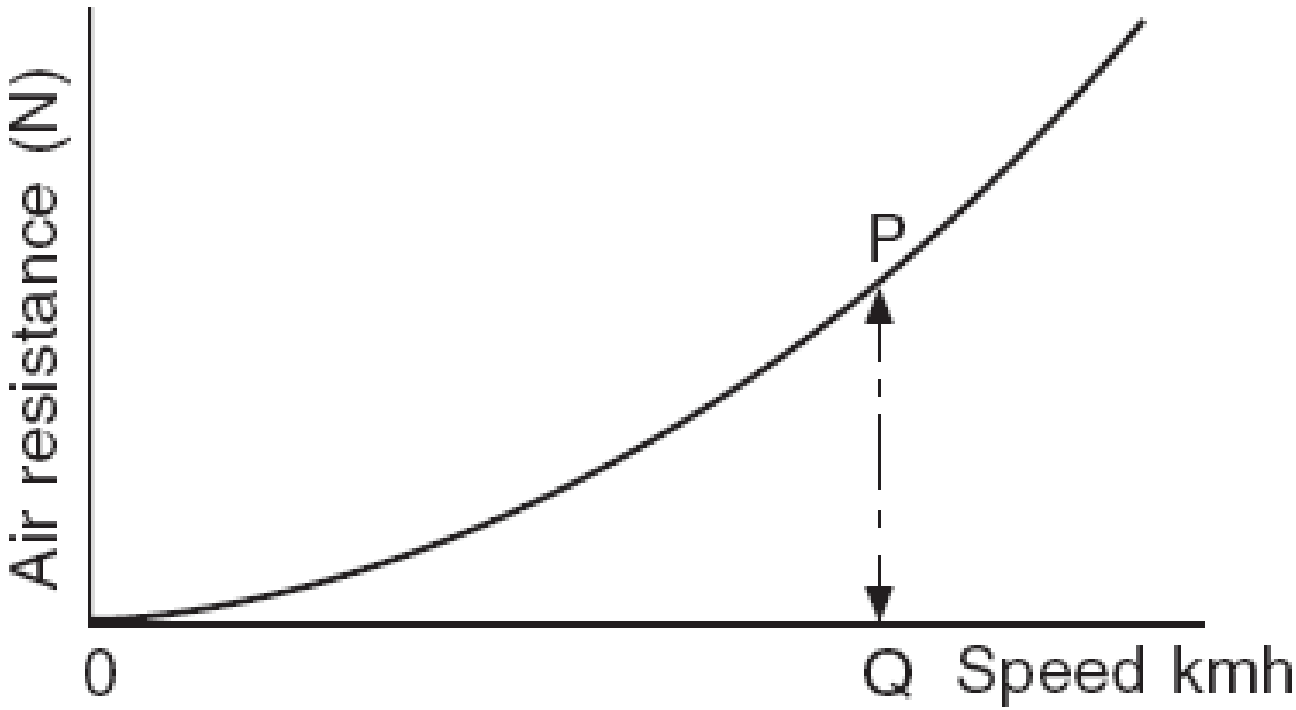
1. Resistance from tire deformation (~90%)
2. Tire penetration and surface compression (~4%)
3. Tire slippage and air circulation around wheel (~6%)

Wide range of factors affect total rolling resistance.

- **Influencing Factors**
  - Laden weight of vehicle
  - Type of road surface
  - The design, construction and materials used in manufacturing of tire.

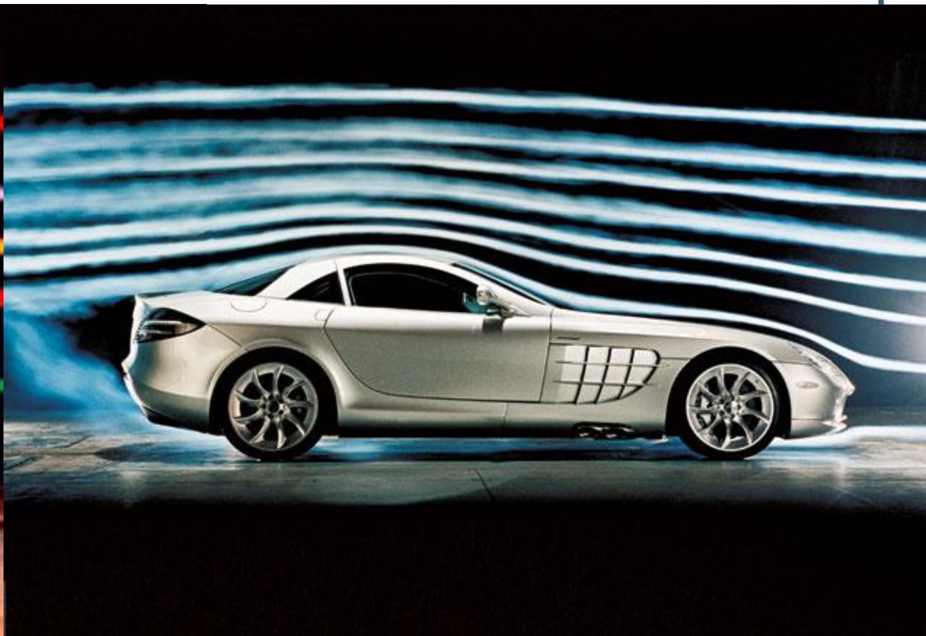


Air resistance (F_L)



Composed of:

1. Turbulent air flow around vehicle body (85%)
2. Friction of air over vehicle body (12%)
3. Vehicle component resistance, from radiators and air vents (3%)



- Power is required to counteract the tractive resistance created by the vehicle moving through air.
- This is caused by air being pushed aside and the formation of turbulence over the contour of the vehicle's body.

$$F_L = \frac{1}{2} \rho_L c_W A v^2 .$$

ρ_L is the mass density of the air,

C_W is the coefficient of aerodynamic resistance (Drag Resist.)

A is a characteristic area of the vehicle, usually taken as the frontal area and

V is the speed of the vehicle relative to the wind.

Table 3.4. Reference values for drag coefficient c_W. In the case of goods trucks, the c_W coefficient and the maximum vehicle cross-section are very much dependent on the particular design. *) Driver sitting and with fitting clothing

Vehicle	c_W	A (m^2)	$c_W A$ (m^2)
Motorcycle with rider)*	***0.5–0.7***	***0.7–0.9***	***0.4–0.6***
BMW K 1200 S*)	0.58	0.71	0.41
BMW R 1200 GS*)	0.62	0.85	0.52
Convertible	***0.29–0.53***	***1.58–2.90***	***0.58–1.54***
Opel Tigra TwinTop			
Roof open	0.40	1.94	0.78
Roof closed	0.35	1.94	0.67
Mercedes-Benz SLK 200 K			
Roof open	0.37	1.93	0.71
Roof closed	0.32	1.93	0.62
Mercedes-Benz SL 500			
Roof open	0.34	2.00	0.68
Roof closed	0.29	2.00	0.58
Audi A4 Cabrio			
Roof open	0.34	2.11	0.72
Roof closed	0.31	2.11	0.65

Limousine/SUV	***0.25–0.39***	***1.97–2.90***	***0.50–1.54***
Ford Fiesta 1.4l	0.34	2.06	0.70
VW Golf V 1.4l	0.32	2.22	0.72
Mercedes-Benz B 180 CDI	0.30	2.42	0.73
BMW 320i	0.28	2.11	0.59
Audi A6 Avant	0.31	2.26	0.70
Mercedes-Benz S 320 CDI	0.26	2.40	0.62
Mercedes-Benz ML 280 CDI	0.34	2.81	0.96
Porsche Cayenne Turbo	0.39	2.78	1.09
BMW 645i	0.29	2.15	0.62
Porsche 911 Carrera	0.28	2.00	0.56
Van	***0.35–0.40***	***3.1–4.2***	***1.1–1.7***
Opel Vivaro Life	0.37	3.38	1.24
Ford Transit MWB, MJ06	0.35	4.14	1.45
Bus	***0.4–0.8***	***6.0–10.0***	***2.4–8.0***
Setra 415 HD	0.44	8.26	3.63
Light trucks	***0.40–0.60***	***4.5–6.0***	***1.8–3.6***
Truck (Solo)	***0.45–0.80***	***6.0–10.0***	***2.7–8.0***
Truck with trailer	***0.55–0.85***	***7.0–10.0***	***3.9–8.5***
Articulated vehicle	***0.45–0.75***	***7.0–10.0***	***3.2–7.5***

❖ Gradient Resistance:

$$F_{St} = m_F\, g \sin \alpha_{St}$$

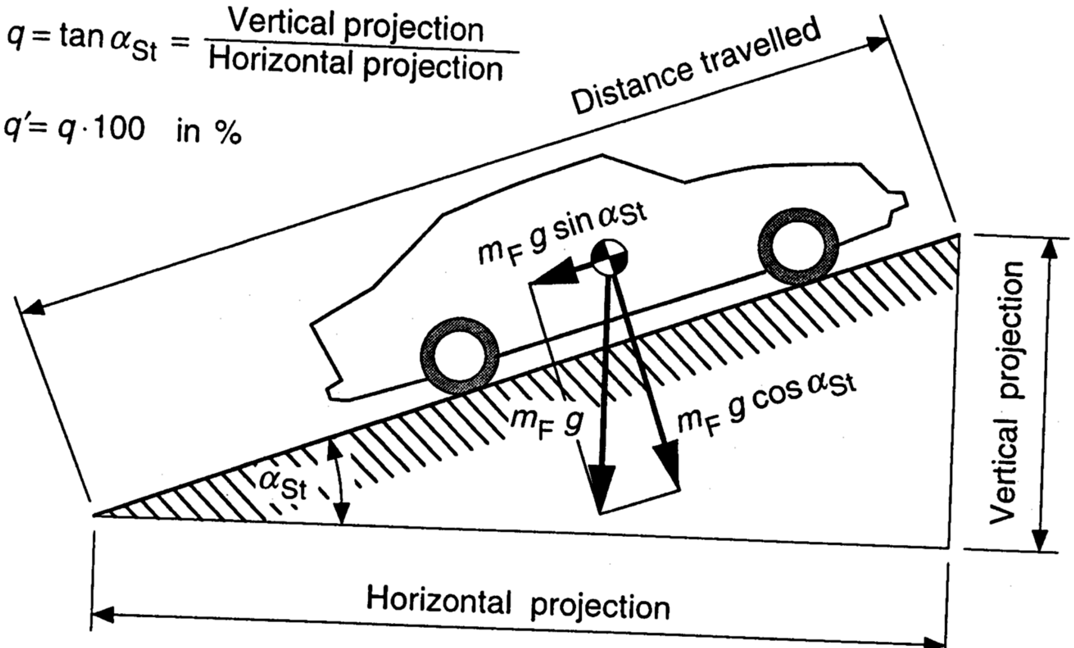
For a relatively small angle of α_{St}, $\sin \alpha_{St} = \tan \alpha_{St}$

$$\sin \alpha_{St} \approx \tan \alpha_{St} = \frac{q'}{100}$$

Therefore, the grade resistance may be approximated by W tan α_{St} , or W.q', where q' is the grade in percent.

$$q = \tan \alpha_{St} = \frac{\text{Vertical projection}}{\text{Horizontal projection}}$$

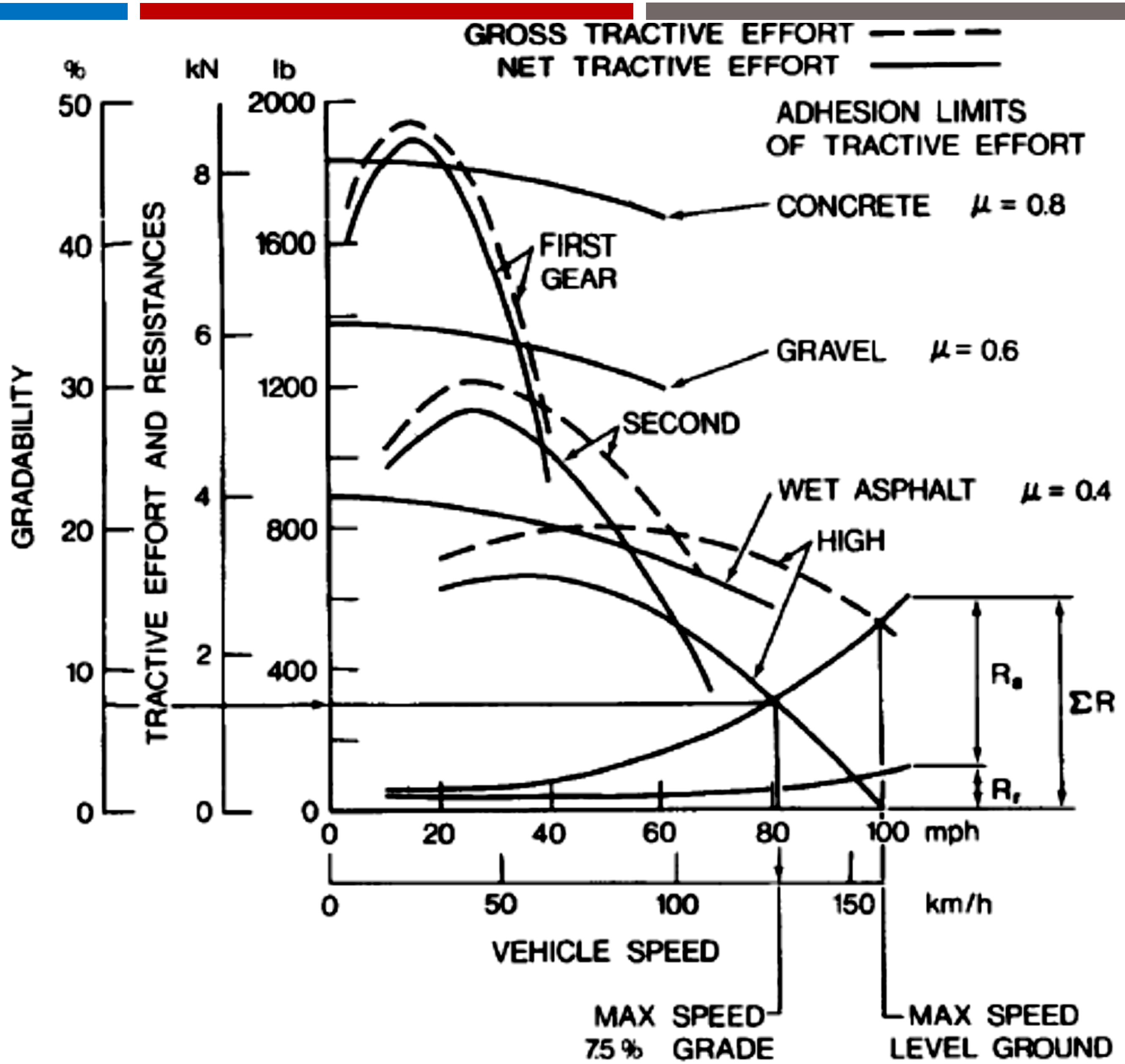
$q' = q \cdot 100$ in %



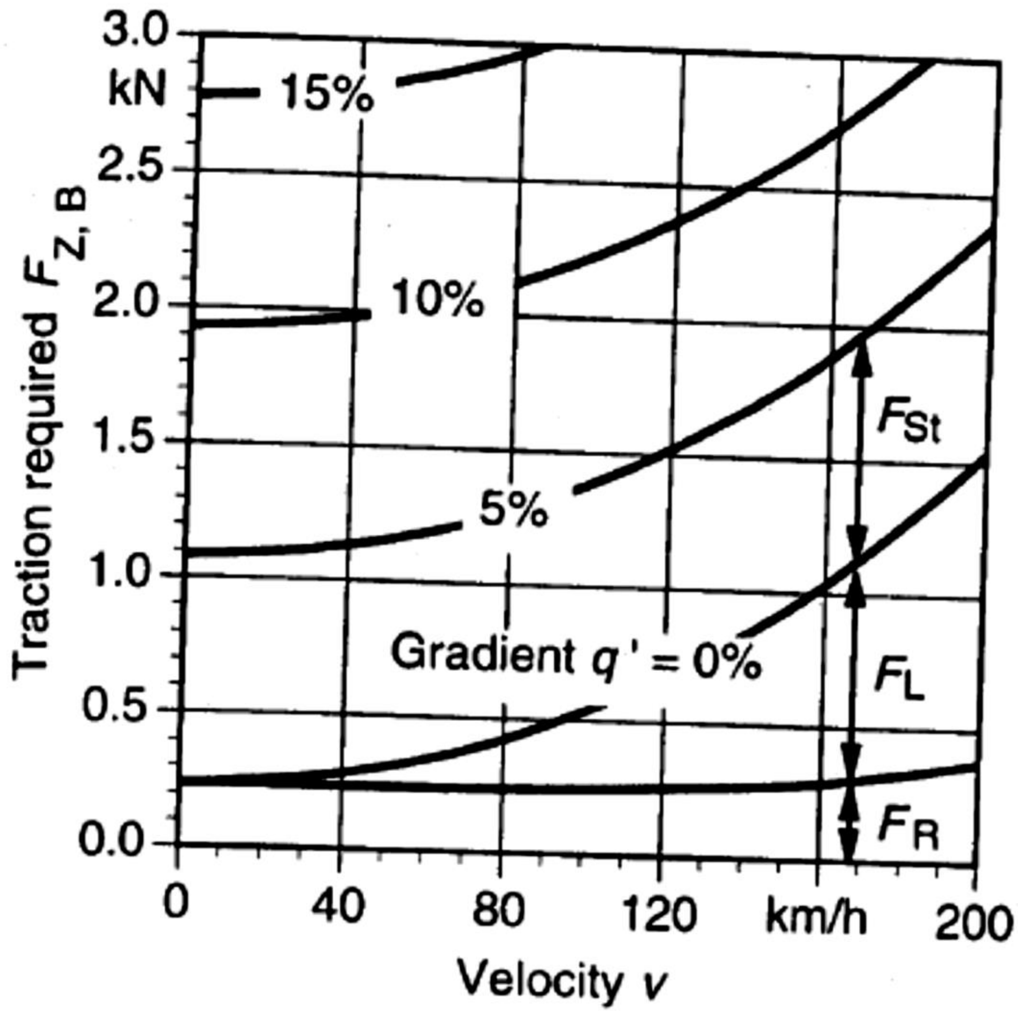
W= 17.79 kN

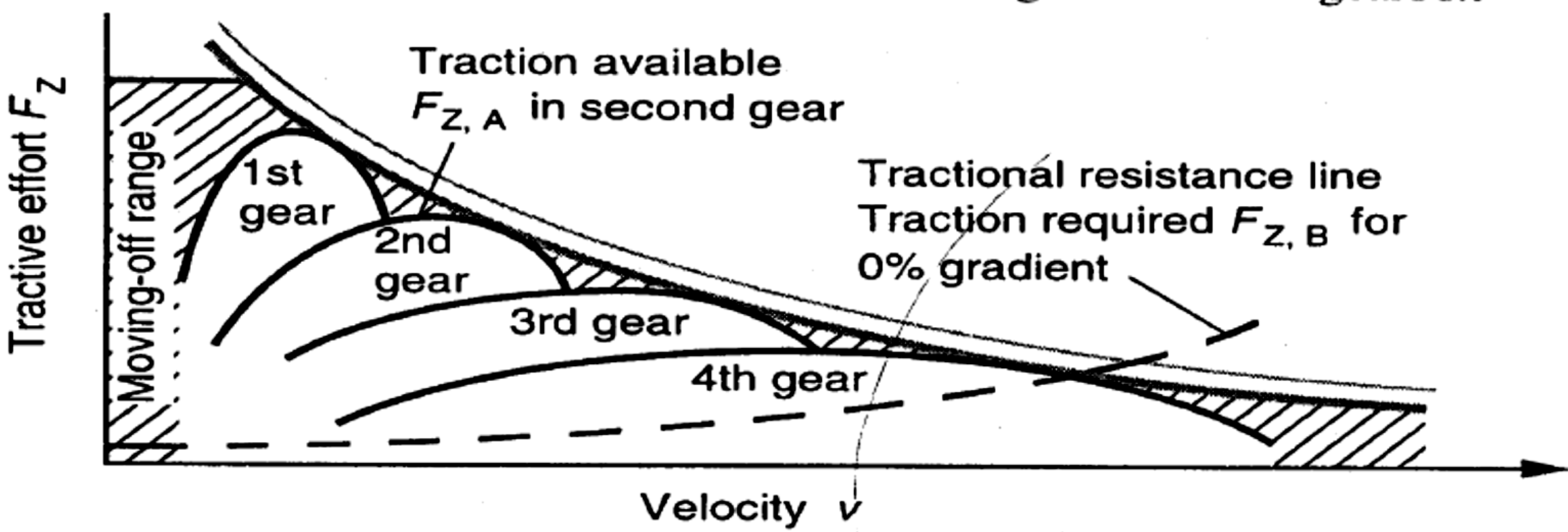
G = 7.5%

V= 133 km/h

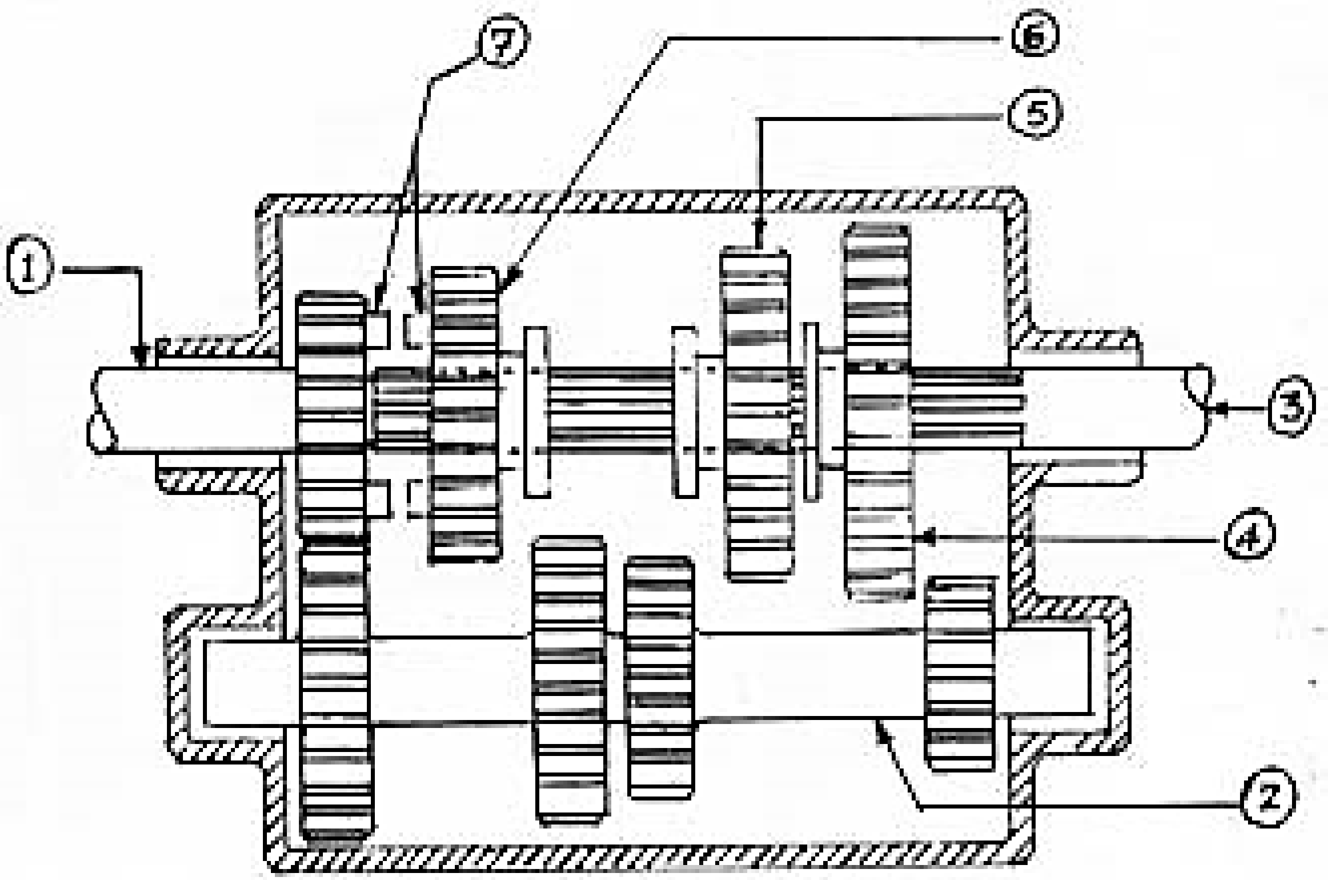


- When designing road (Over-bridges), gradients more than **7 %** are normally avoided.

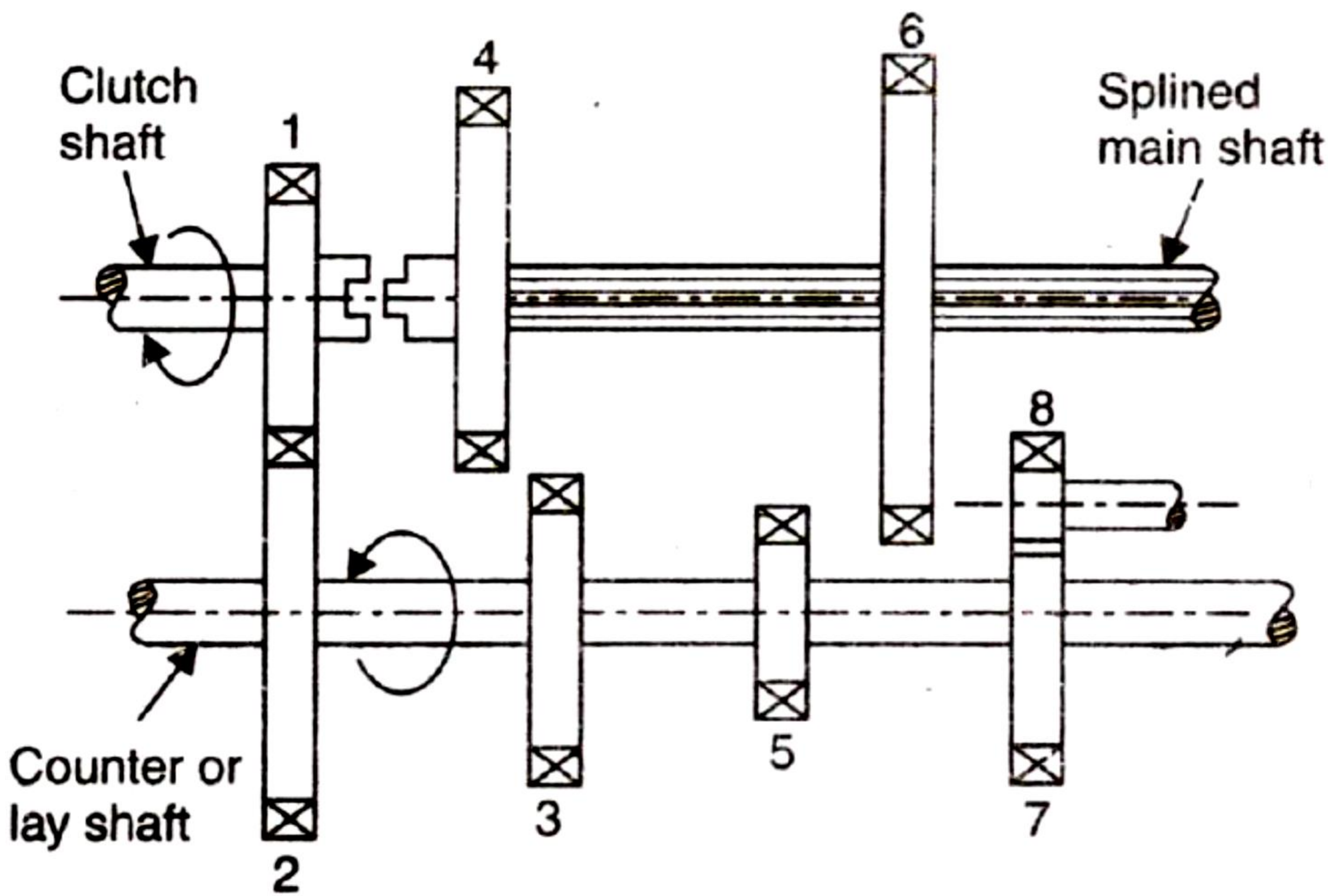



Tractive effort F_Z
Moving-off range
Traction available $F_{Z, A}$ in second gear
1st gear
2nd gear
3rd gear
4th gear
Tractional resistance line
Traction required $F_{Z, B}$ for 0% gradient
Velocity v

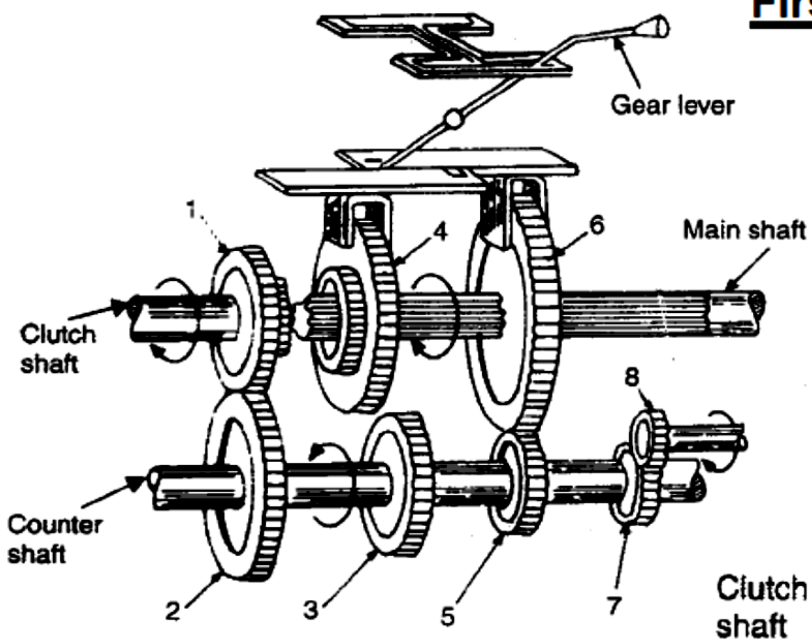
1. Sliding Mesh Gearbox:

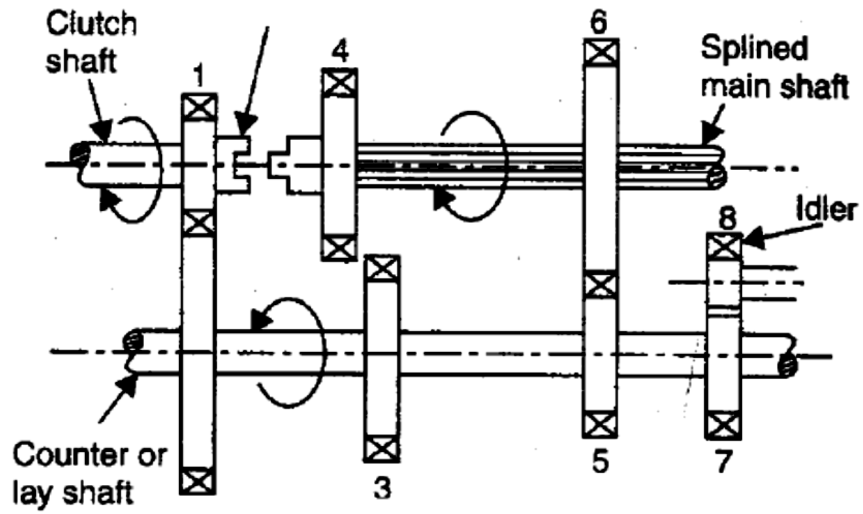


1.main drive gear
2.counter shaft
3.main shaft
4.I gear
5.II gear
6.III gear
7.top gear engaging dogs

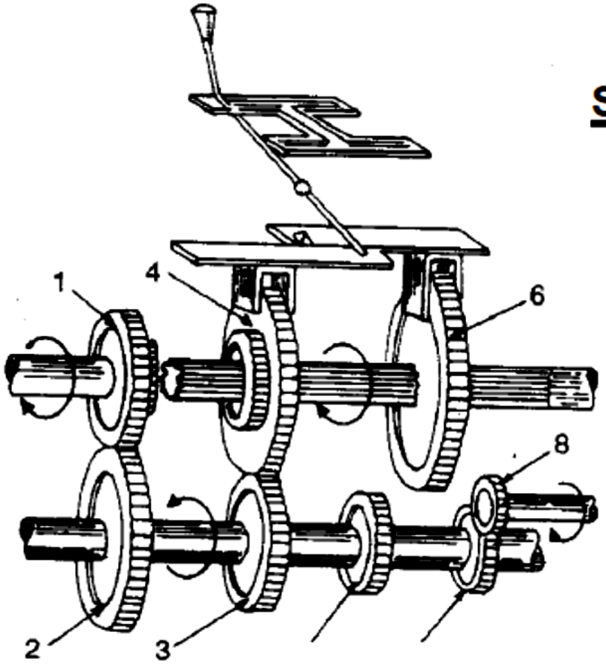

Clutch shaft
1
4
6
Splined main shaft
8
Counter or lay shaft
2
3
5
7

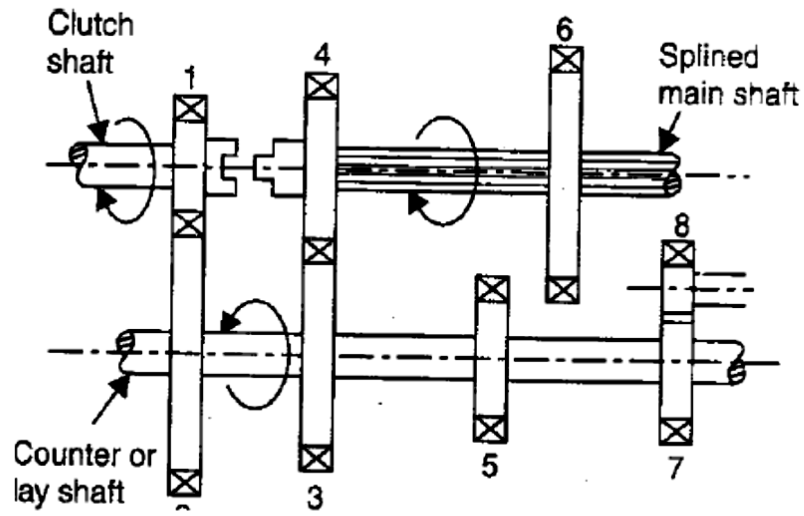
First gear position



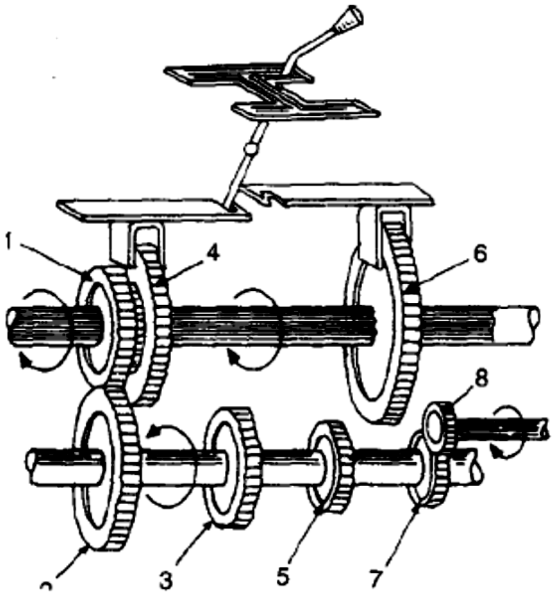


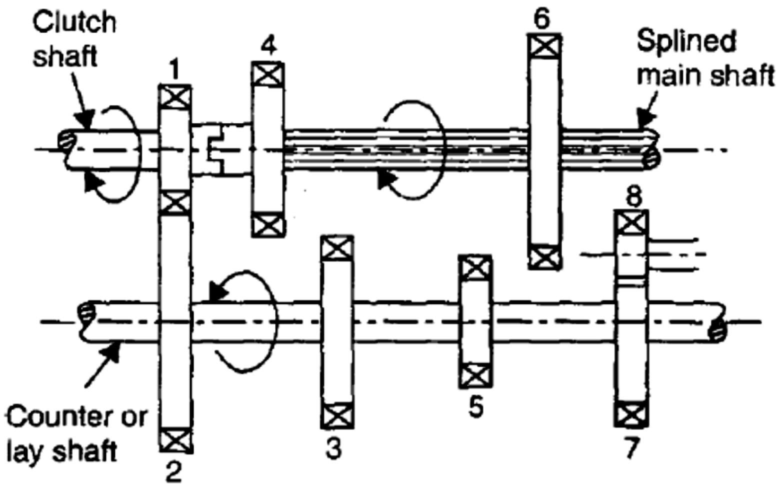
Second gear position

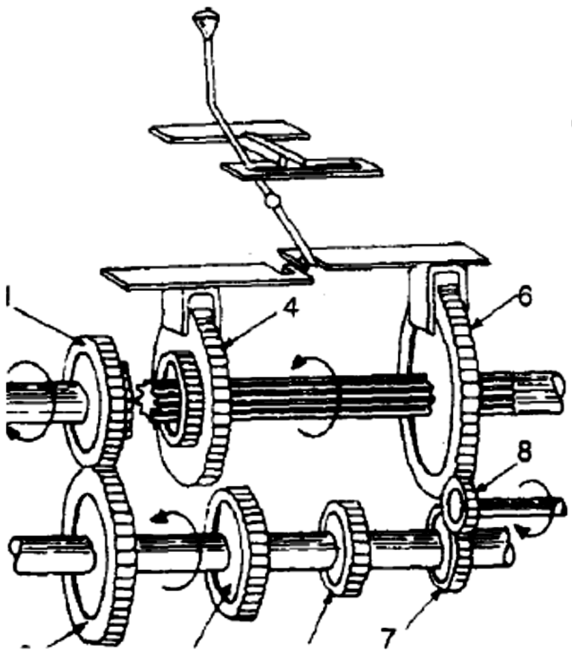




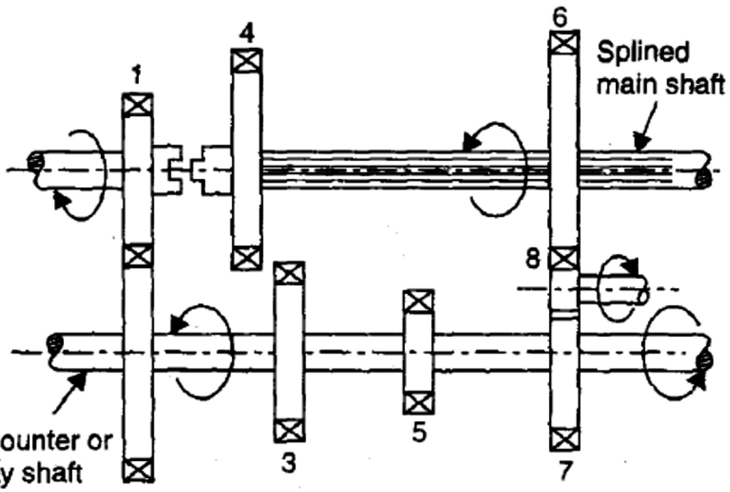
Third gear position







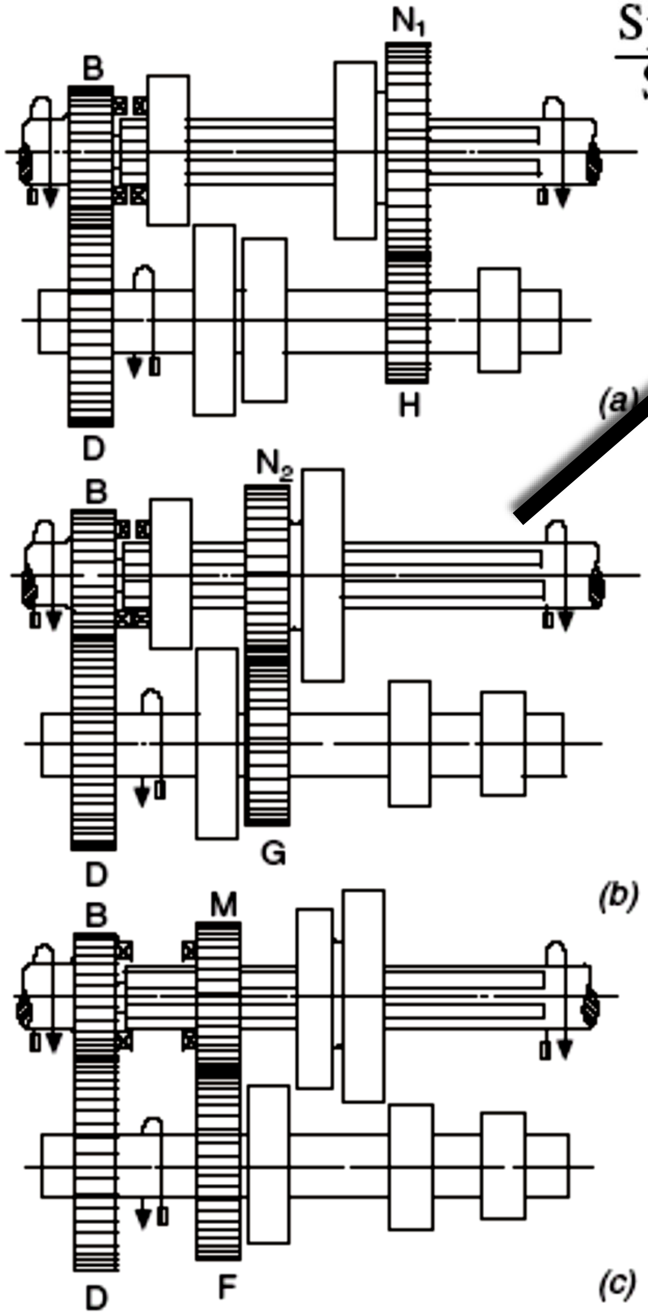
Reverse gear position

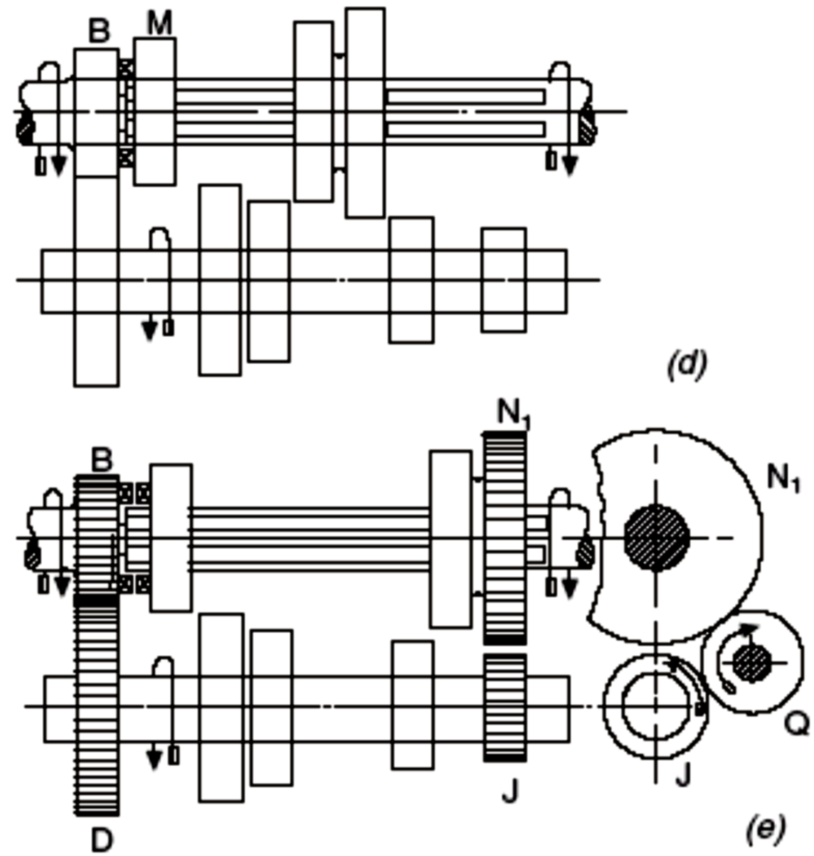


$$\frac{\text{Speed of engine shaft}}{\text{Speed of mainshaft}} = \frac{\text{No. teeth in D}}{\text{No. teeth in B}} \times \frac{\text{No. teeth in N}}{\text{No. teeth in H}}$$

$$\frac{\text{Speed of engine shaft}}{\text{Speed of mainshaft}} = \frac{\text{No. teeth in D}}{\text{No. teeth in B}} \times \frac{\text{No. teeth in } N_2}{\text{No. teeth in G}}$$

$$\frac{\text{Speed of engine shaft}}{\text{Speed of mainshaft}} = \frac{\text{No. teeth in D}}{\text{No. teeth in B}}$$





$$\frac{\text{Speed of engine shaft}}{\text{Speed of mainshaft}} = \frac{\text{No. teeth in D}}{\text{No. teeth in B}} \times \frac{\text{No. teeth in M}}{\text{No. teeth in F}}$$

$$\frac{\text{Speed of engine shaft}}{\text{Speed of mainshaft}} = \frac{\text{No. teeth in D}}{\text{No. teeth in B}} \times \frac{\text{No. teeth in } N_1}{\text{No. teeth in J}}$$

Advantages:

1. In SMG, less load on shafts since one gear is in mesh at all time resulting in less vibrations .
2. Due to all gears are in constant mesh in CMG less is the efficiency as compared to sliding mesh gearbox where only one gear is in mesh.
3. Easy manufacturing
4. Easy mechanism

Disadvantages

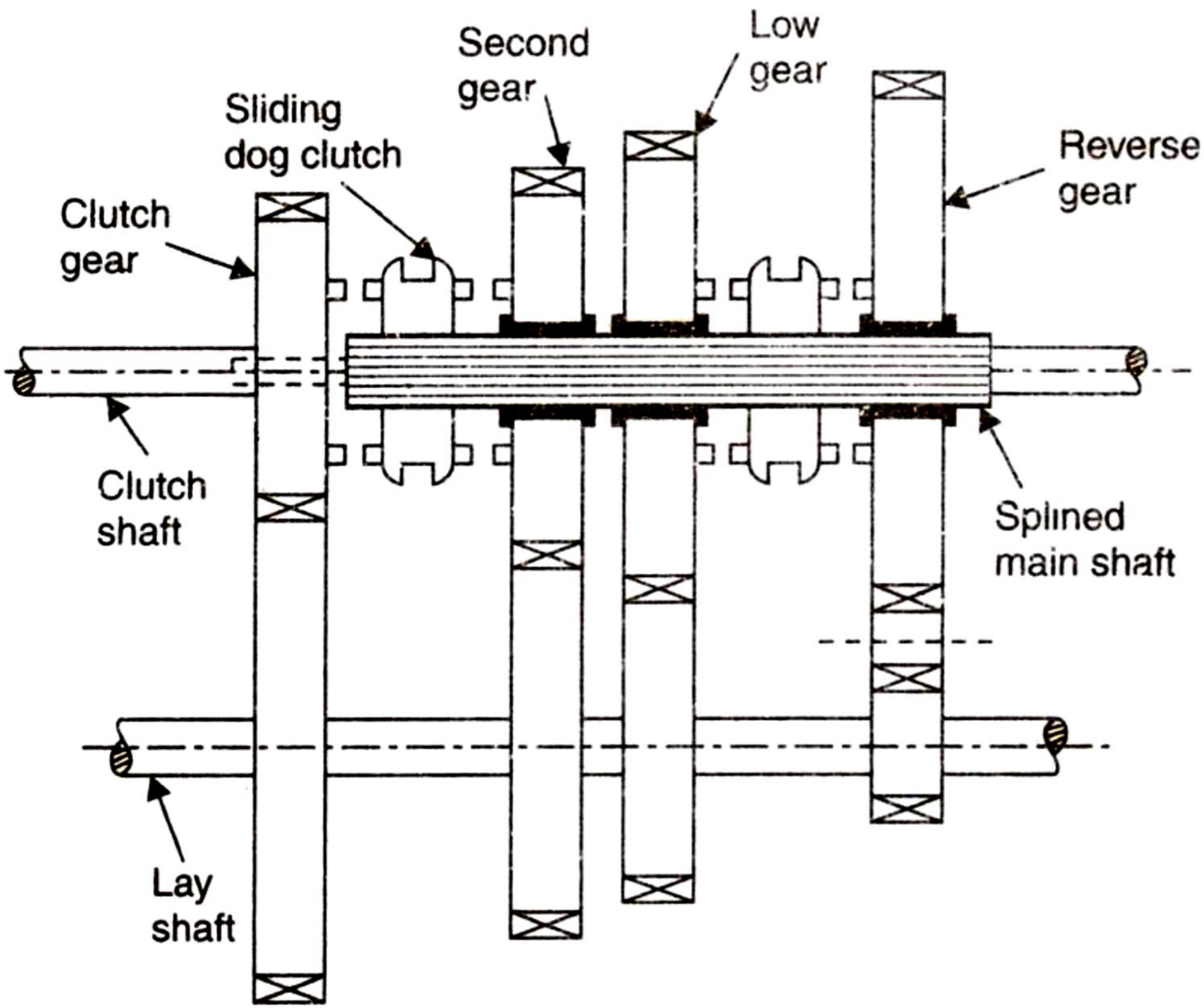
1. Since gears are in constant mesh in CMG, helical or herringbone gears can be used and in sliding mesh only straight spur gears can be used.
2. More effort is required in sliding mesh compared to CMG where only dog clutch has to slide so need for extra mechanism to reduce efforts required.
3. More chances of failure since gear tooth while sliding has to bear more impact loading and for frequent changing of gears more chances of gear failure but in CMG only chance of failure is of dog clutch.
4. Less lifespan compared to CMG due more wearing of gears in sliding mesh.
5. Increased cost since tooth designed must be of high stability under fluctuating loads.
6. CMG dog clutch can be easily replaced but in case of SMG, failure is of gears, so if it fails than it requires time and money to manufacture new gear to perform the same task.

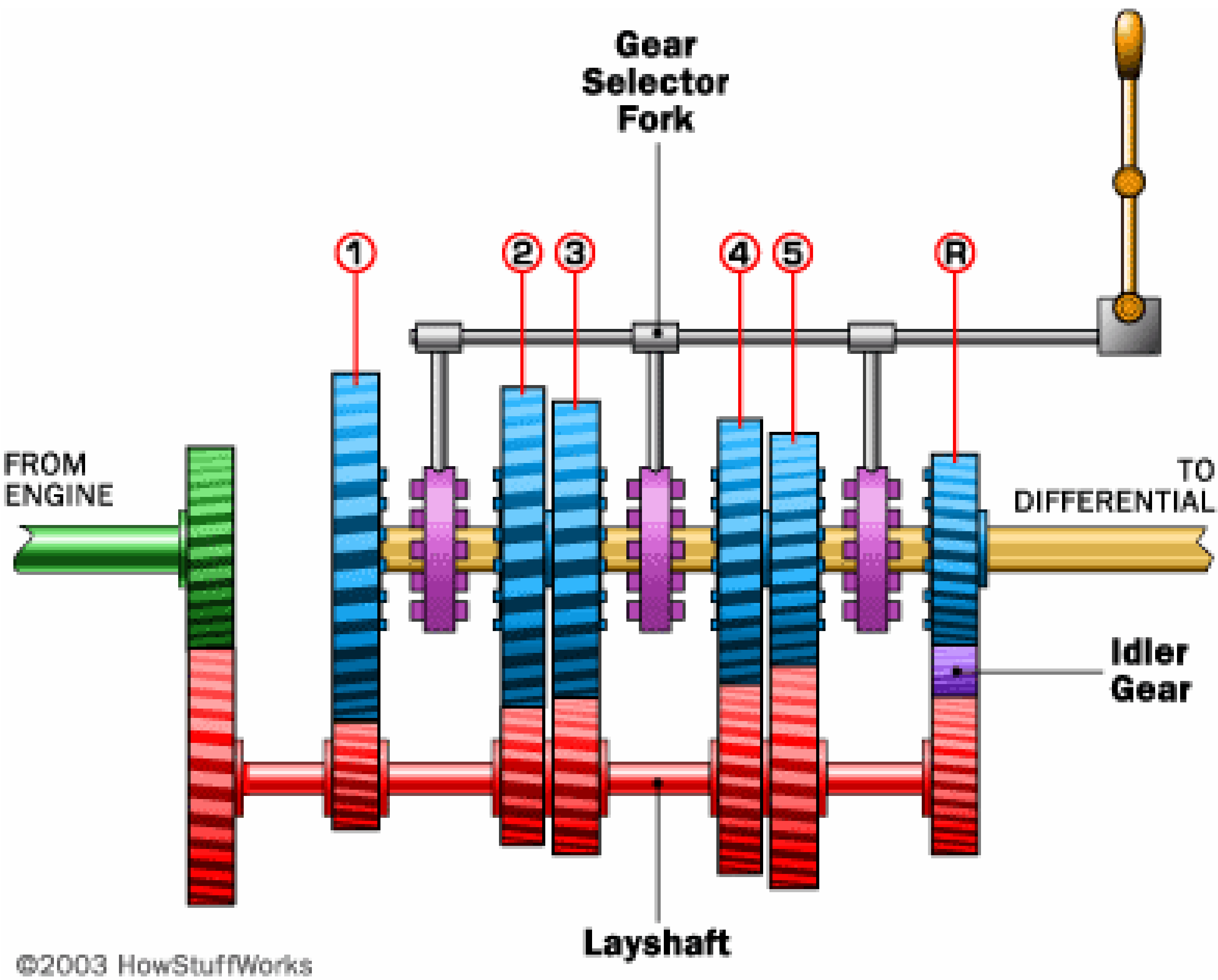
❖ Constant Mesh Gearbox:

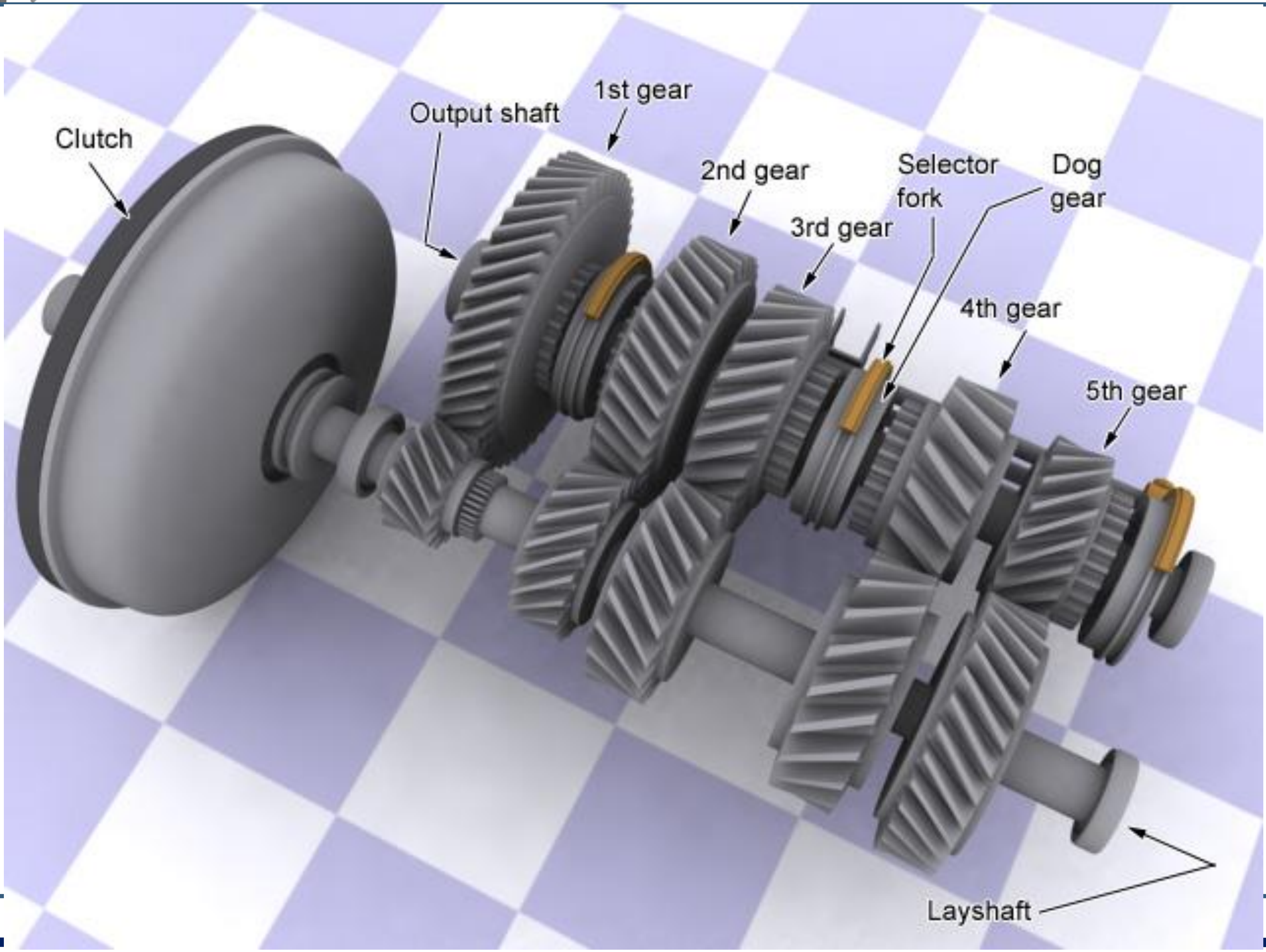
- All the gears are always in mesh
- Gears on counter shaft are fixed to it
- Gears on main shaft are also fixed but free to rotate
- Dog clutches can slide on the main shaft and rotate with it
- Dog clutches engage with gears on the main shaft to obtain desired speed

Advantages over Sliding mesh Gearbox:

- Helical and herringbone gear can be used in these gearboxes and therefore, constant mesh gearboxes are quieter.
- Since the gears are engaged by dog clutches, if any damage occurs while engaging the gears, the dog unit members get damaged and not the gear wheels.


Second gear
Low gear
Sliding dog clutch
Reverse gear
Clutch gear
Clutch shaft
Splined main shaft
Lay shaft


Gear
Selector
Fork
1
2
3
4
5
R
FROM
ENGINE
TO
DIFFERENTIAL
Idler
Gear
Layshaft
©2003 HowStuffWorks

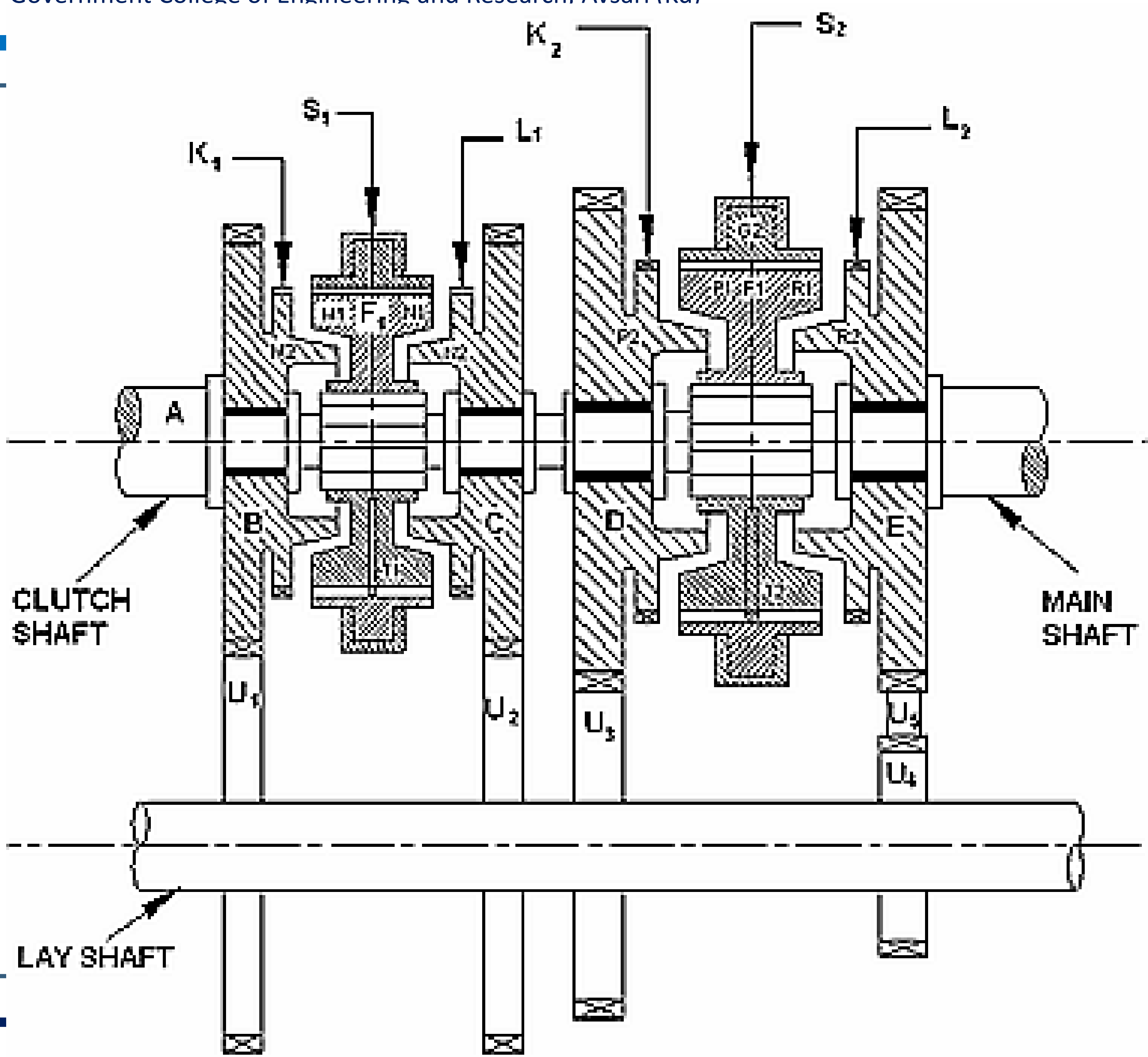

Clutch
Output shaft
1st gear
2nd gear
3rd gear
Selector fork
Dog gear
4th gear
5th gear
Layshaft

❖ Double Declutching

The double declutching technique involves the following steps:

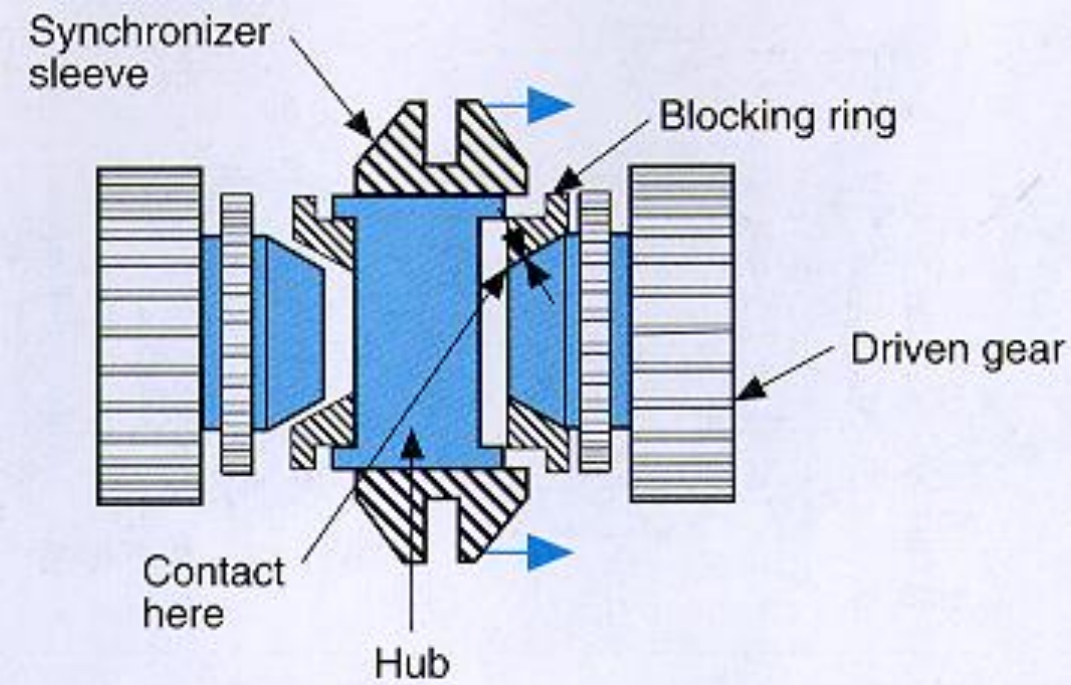
- The accelerator (throttle) is released, the clutch pedal is pressed, and the gearbox is shifted into neutral.
- The clutch pedal is then released, the driver matches the engine speed to the gear speed either using the throttle (accelerator) (when changing to a lower gear) or waiting for engine speed to decrease (when changing to a higher gear) until they are at a level suitable for shifting into the next gear (although double clutching as almost always used for downshifting only).
- At the moment when the revs between input shaft (i.e. engine revs) and gear are closely matched, the driver then instantly presses the clutch again to shift into the next gear. The result should be a very smooth gear change.

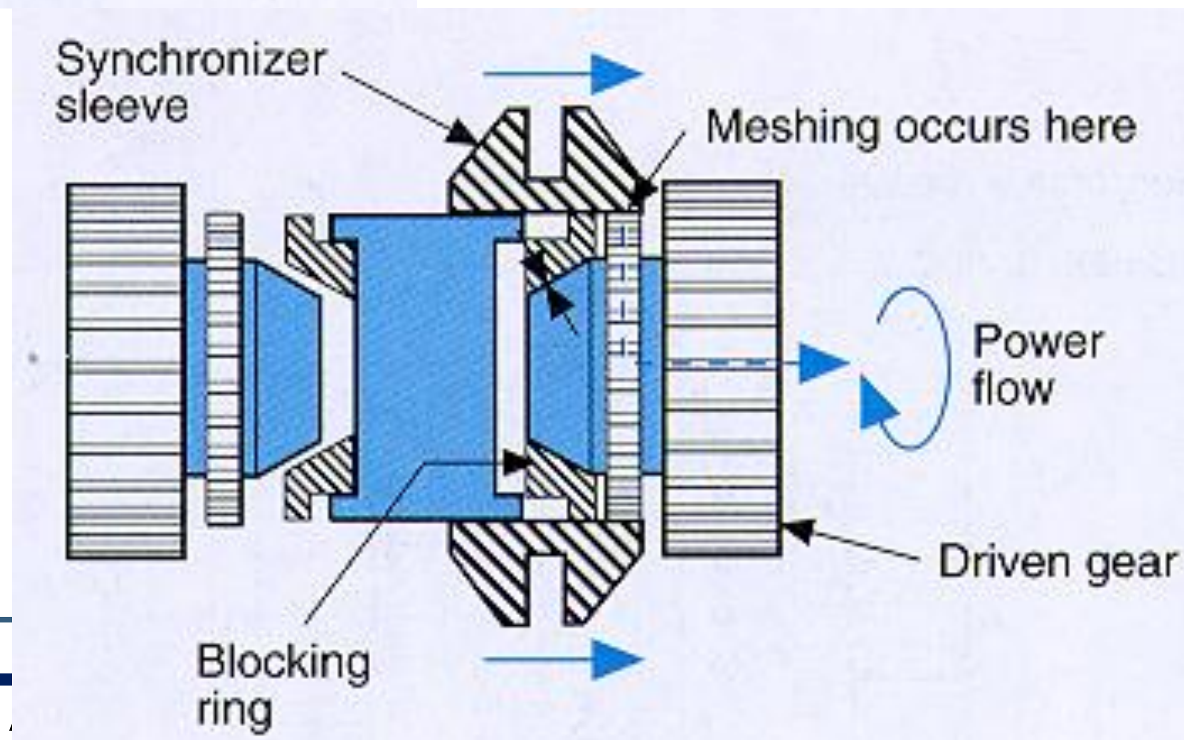
Synchromesh Gearbox:

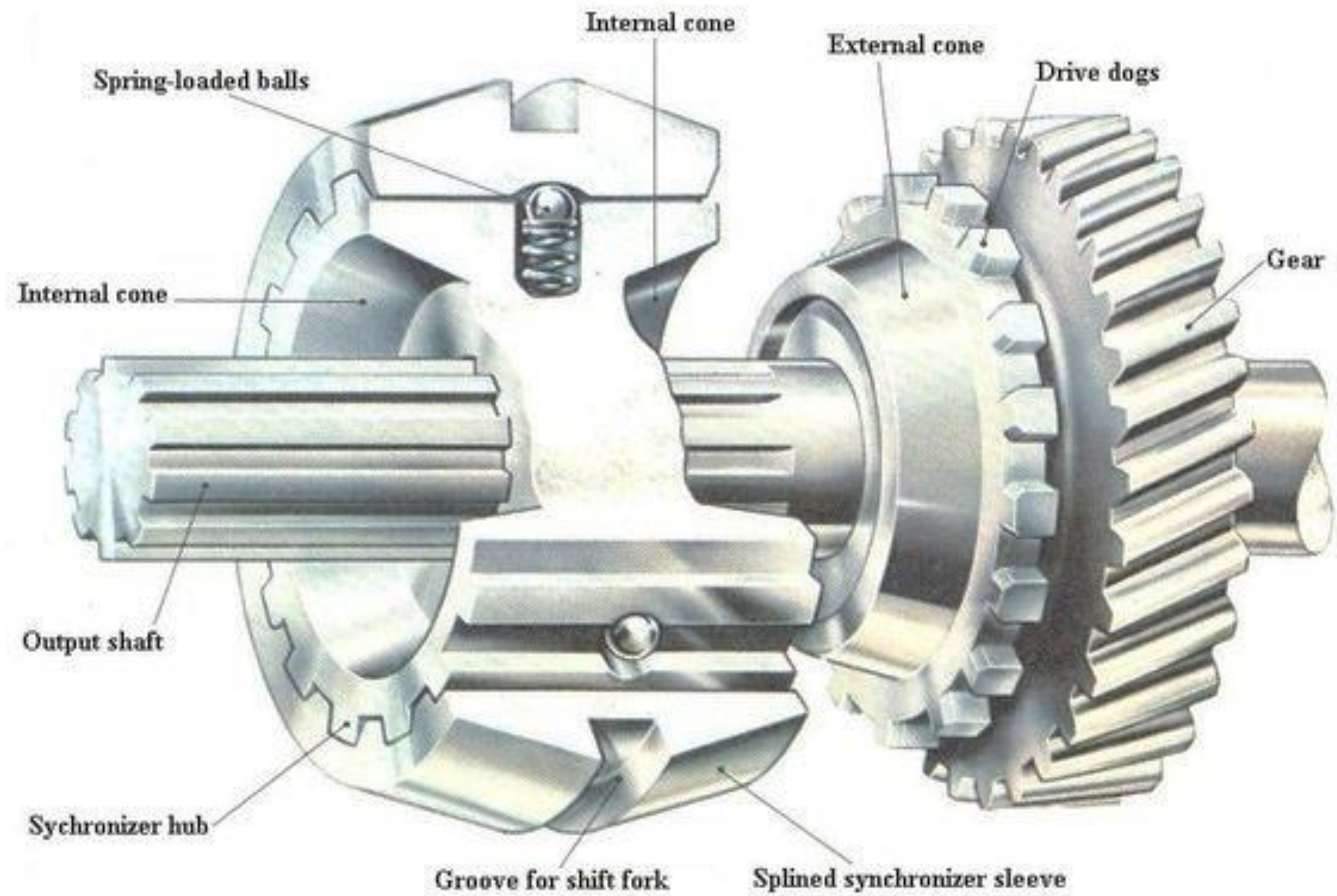


Synchromesh Gearbox:

- A synchromesh transmission is a constant mesh, collar shift transmission equipped with synchronizers, which equalize the speed of the shafts and gears before they are engaged.
- Purpose to equalize shaft and gear speeds.
- Four Main Components
  - Hub
  - Sleeve
  - Blocking (Synchronizing) Rings
  - Inserts or spring & ball devices


Synchronizer
sleeve
Blocking ring
Driven gear
Contact
here
Hub


Synchronizer
sleeve
Meshing occurs here
Power
flow
Driven gear
Blocking
ring


Internal cone
External cone
Spring-loaded balls
Drive dogs
Gear
Internal cone
Output shaft
Sychronizer hub
Groove for shift fork
Splined synchronizer sleeve

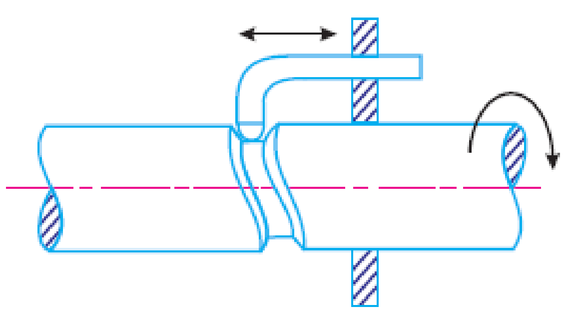
- Sliding synchronizing units are provided to equalize the speeds of gear and dog before meshing
- The device works like a friction clutch
- Equal speeds ensure smooth meshing
- Normally not used in 1st and reverse gear

Working

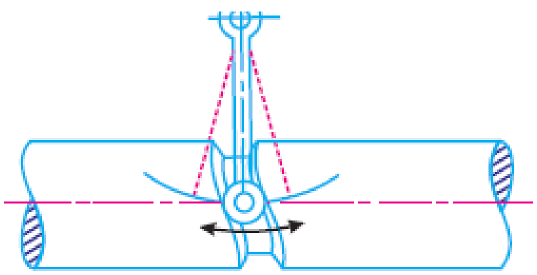
- Output shaft is always rotating (because it is positively connected to the wheels)
- Layshaft is connected to the engine, but it rotates freely when the clutch is disengaged
- Because the gears are meshed all the time, the synchro brings the layshaft to the right speed for the dog gear to mesh.
- The layshaft is now rotating at a different speed to the engine. Now, the clutch gradually equalizes the speed of the engine and layshaft, either bringing the engine to the same speed as the layshaft or vice versa depending on engine torque and vehicle speed.

❖ Motorcycle Gearbox:

- Manual transmissions use the standard "H" pattern in the shifter. The manual transmission in a motorcycle is nothing like this.
- On a motorcycle, you shift gears by clicking a lever up or down with your toe. It is a much faster way to shift. This type of transmission is called a **sequential gearbox** or a **sequential manual transmission**.
- It turns out that most race cars use sequential gearboxes as well

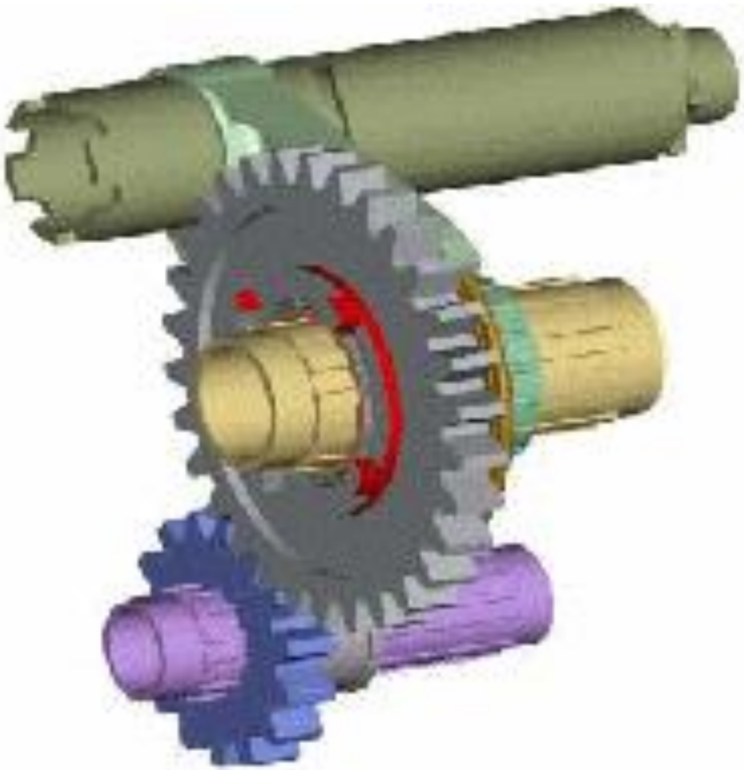


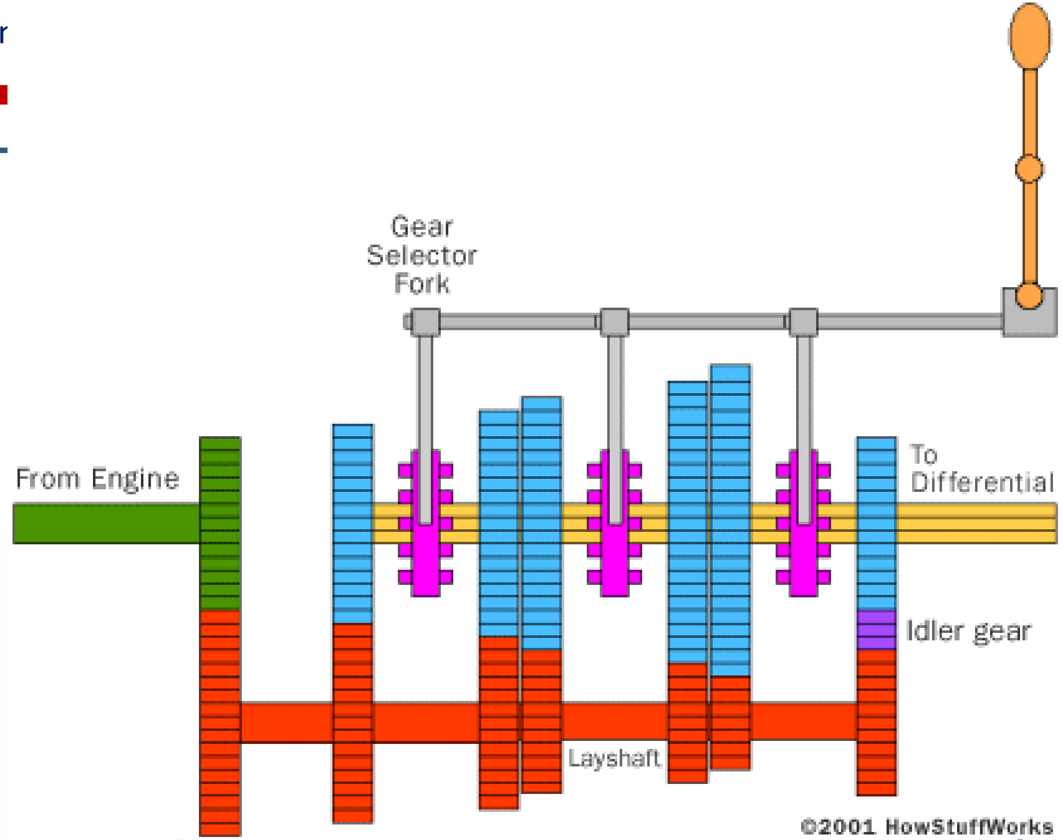
(*a*) Cylindrical cam with reciprocating follower.

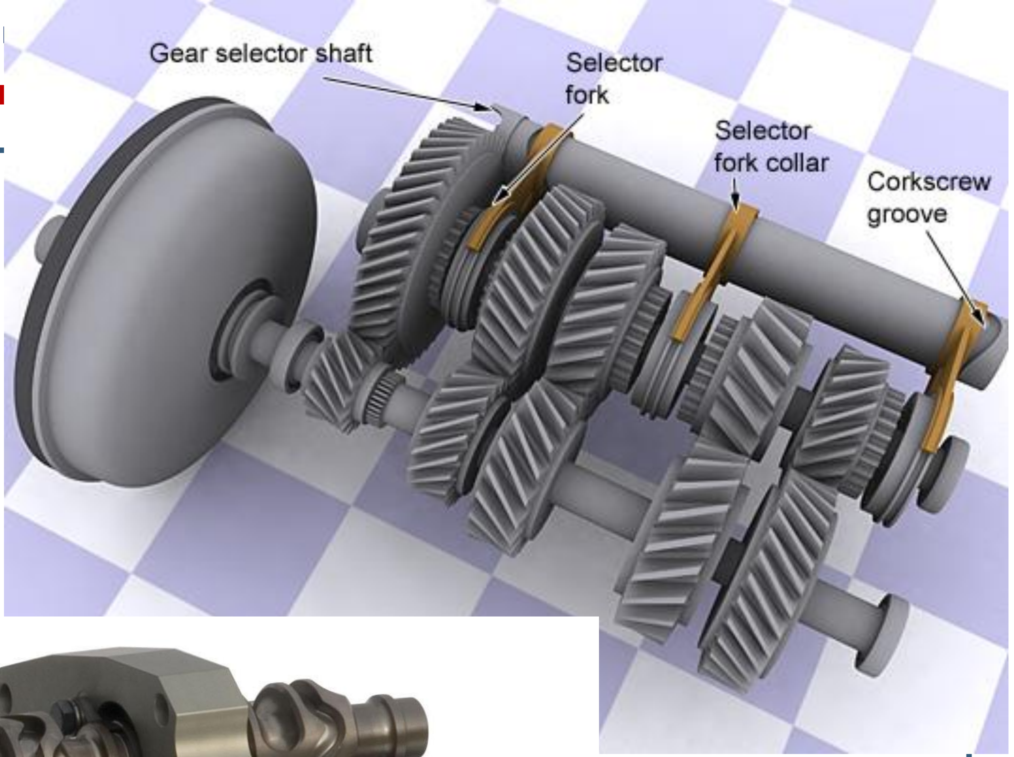


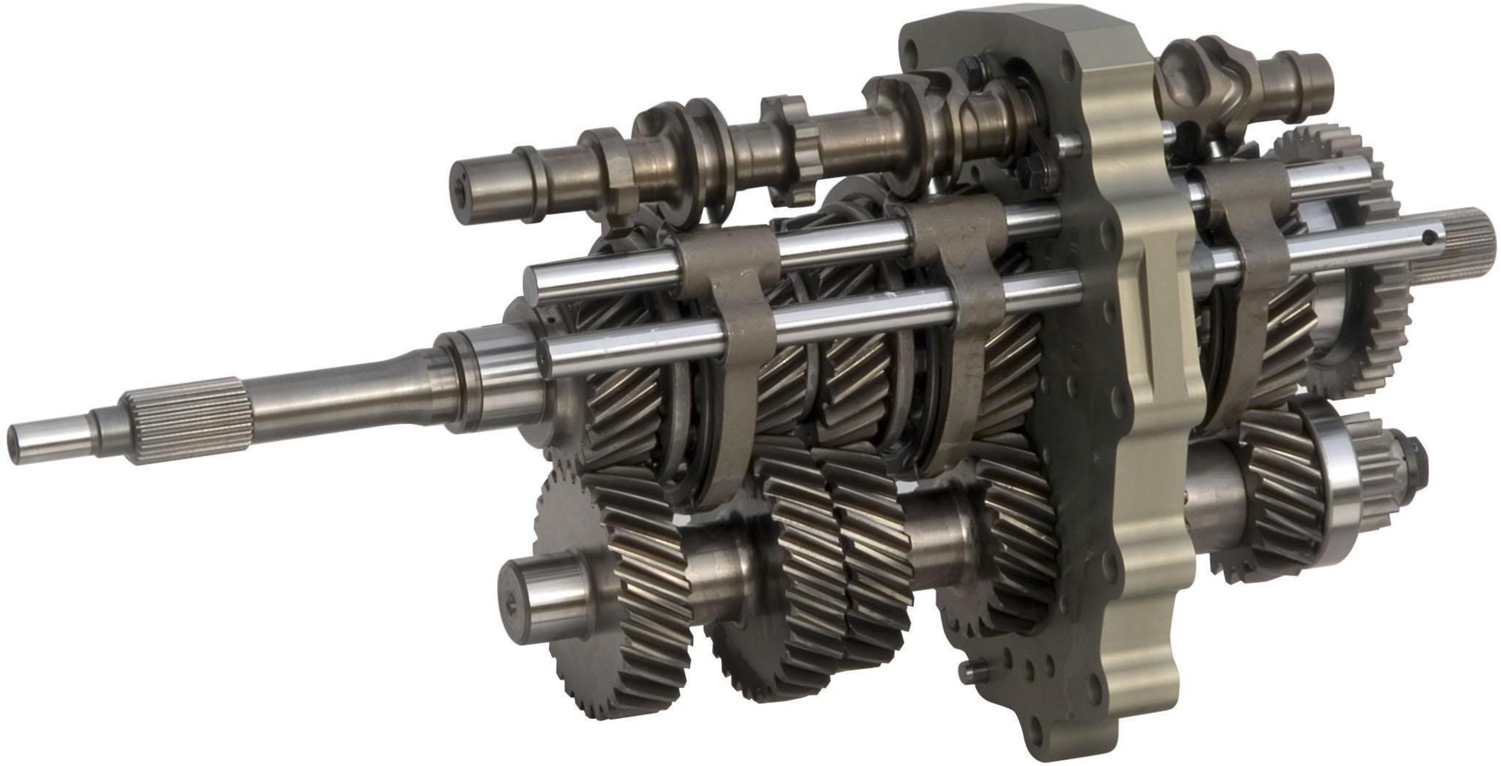
(*b*) Cylindrical cam with oscillating follower.

❖ Sequential Gearbox:






Gear selector shaft
Selector fork
Selector fork collar
Corkscrew groove



- In a sequential box, those selector forks are connected to a single shaft that has corkscrew-type grooves in it.
- The collar that fits around this selection shaft has a ball bearing in it which sits in a recess in the collar as well as in one of the corkscrew grooves.
- When the gear stick is moved forwards or backwards, the selector shaft is mechanically turned by some number of degrees.
- That twisting motion rotates the corkscrew groove which in turn interacts with the ball bearings and the selector fork collars, forcing them to slide back and forth.
- Each click of the gear stick rotates the shaft another number of degrees and all the selector forks change position in one go.

Gearbox Configurations:

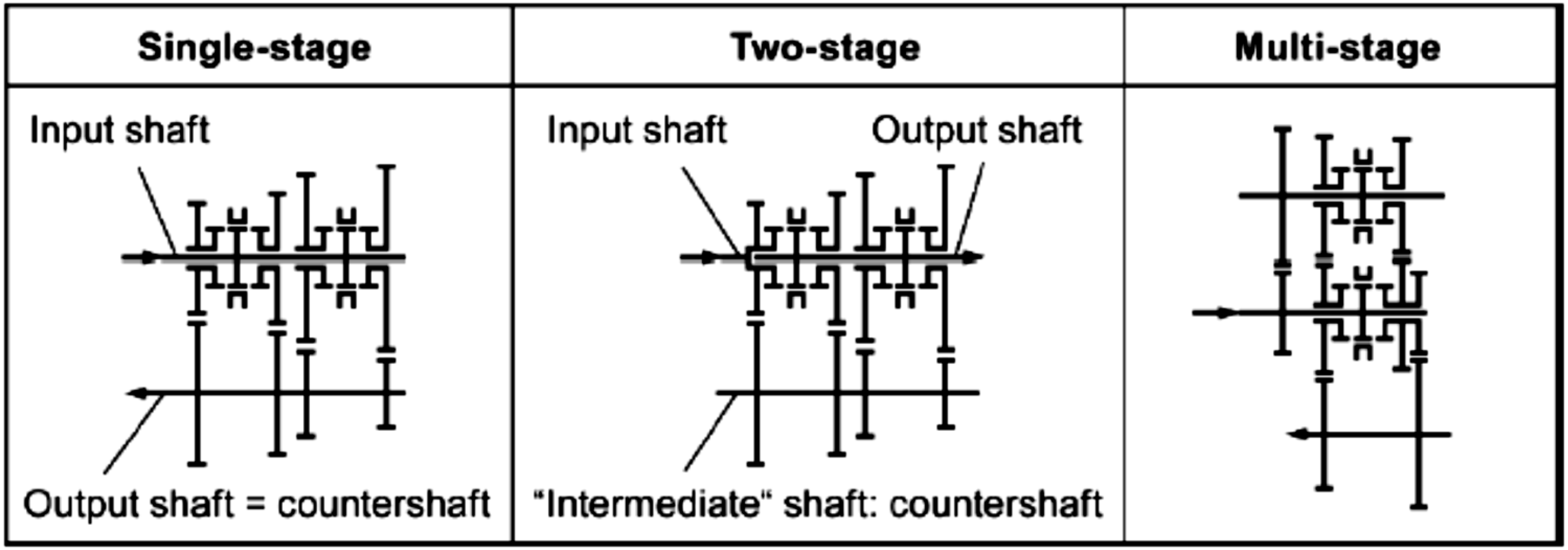
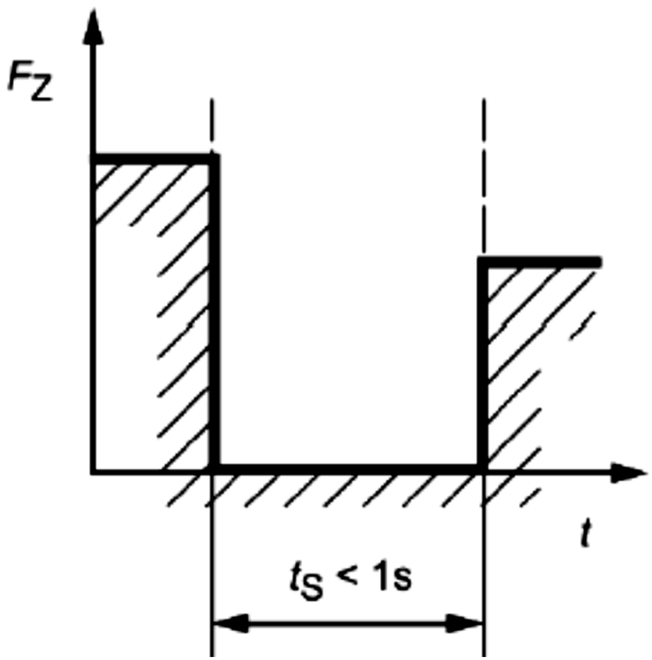
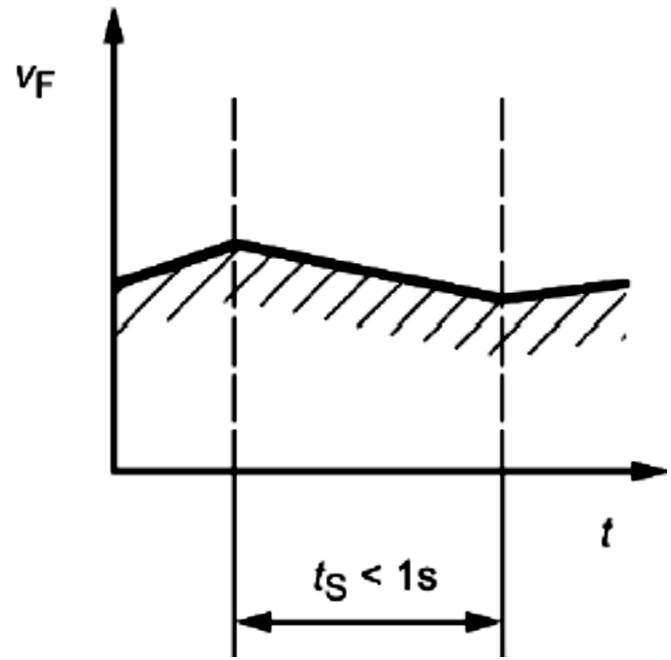


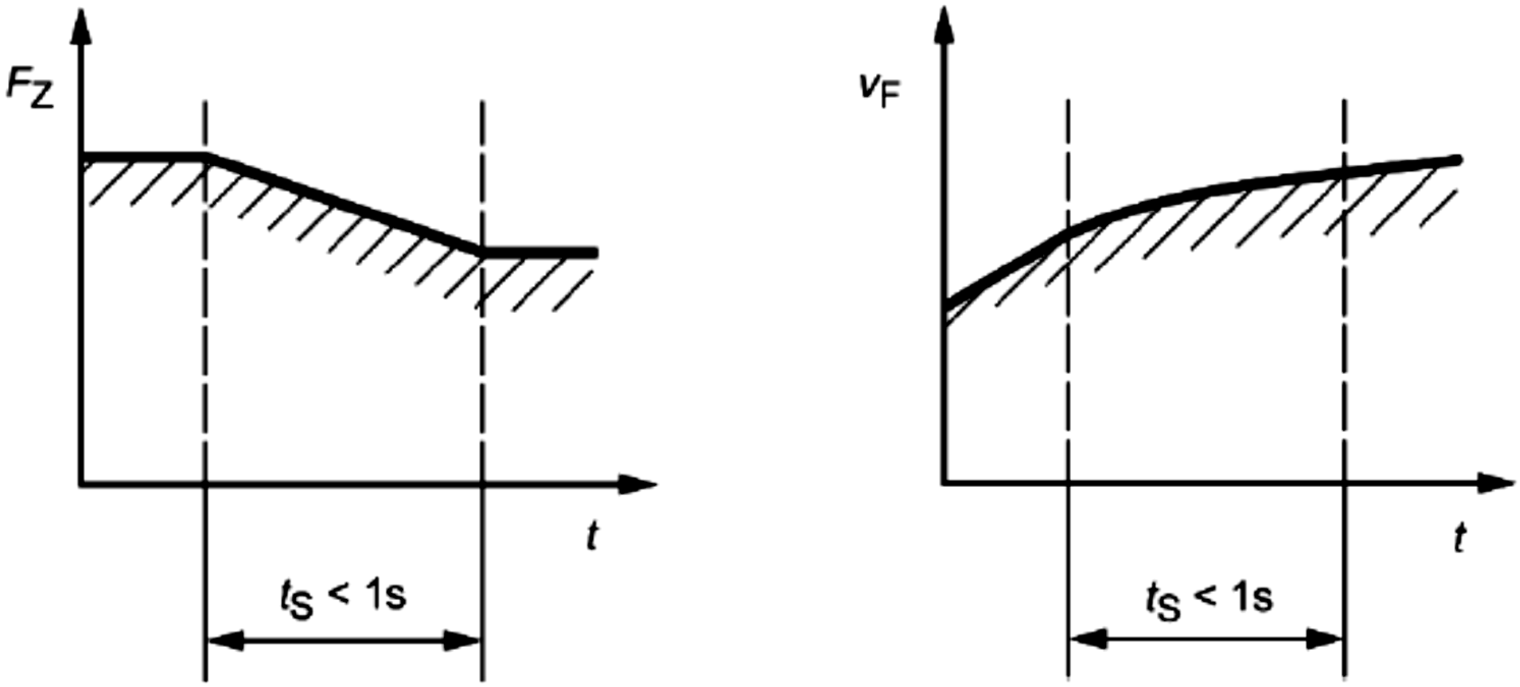
Fig. 6.11. Configuration of the ratio stages using 4-speed gearboxes as examples

Shifting with Power interruption:





Shifting without Power interruption:



- **Also known as Powershift transmission.**

❖ Continuously Variable Transmissions without Power Interruption

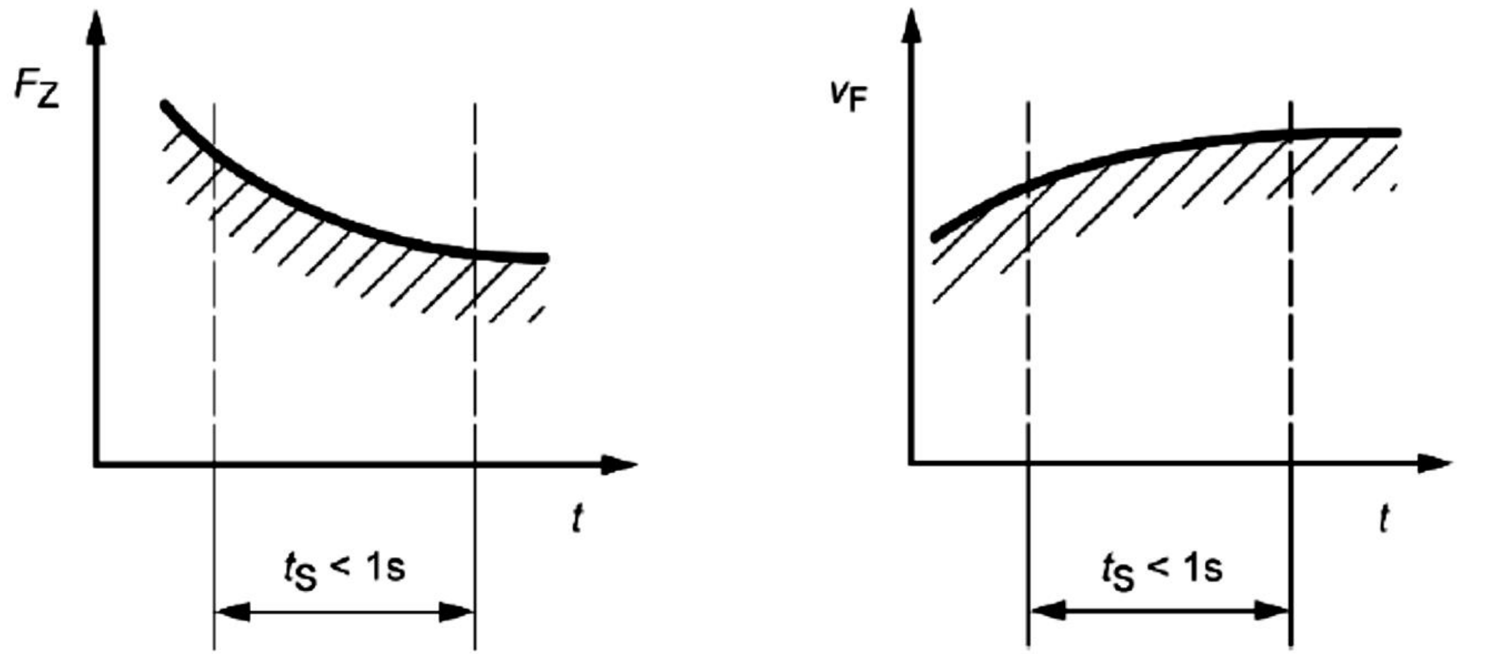
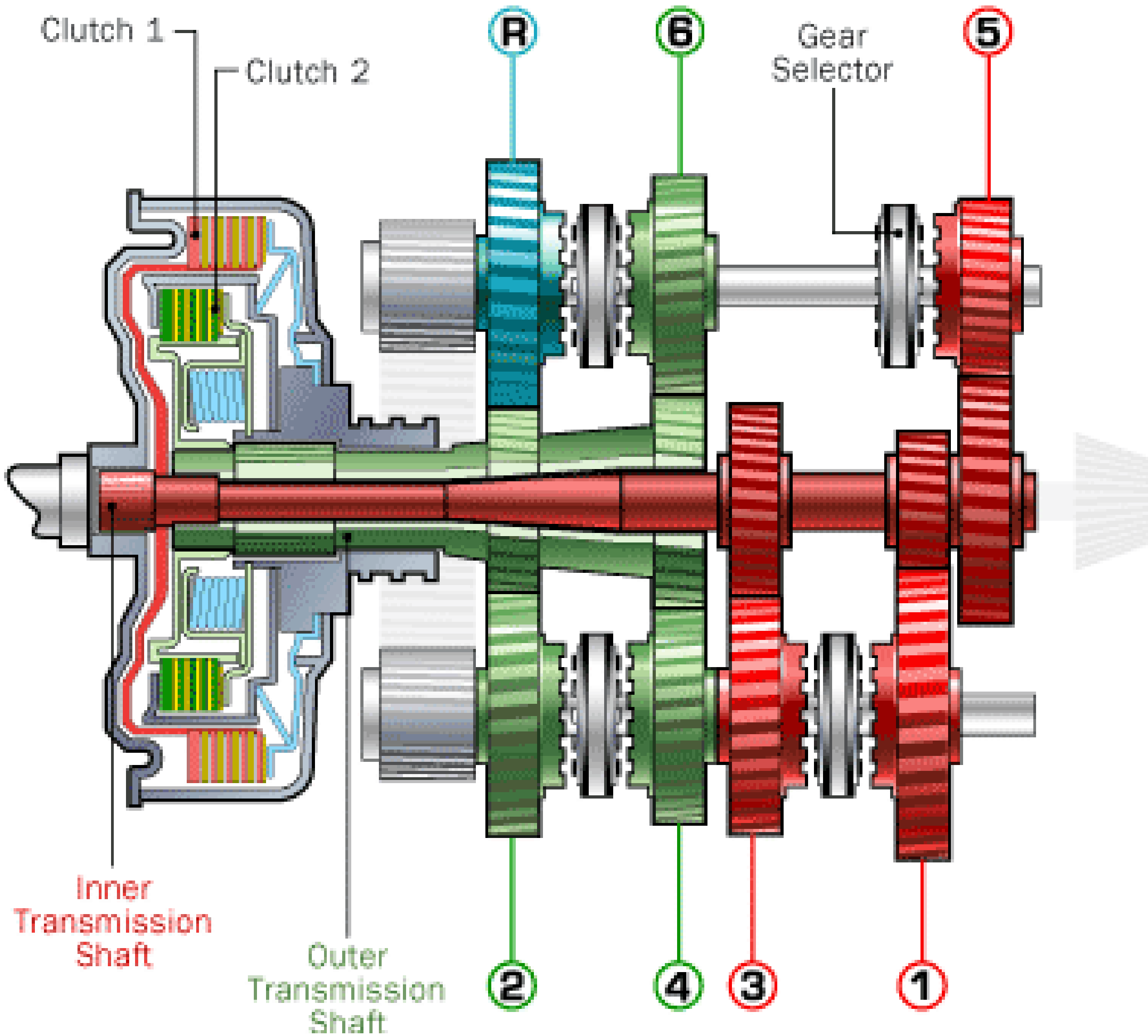


Fig. 6.14. Qualitative traction and velocity profile for continuously upward powershift with CVT

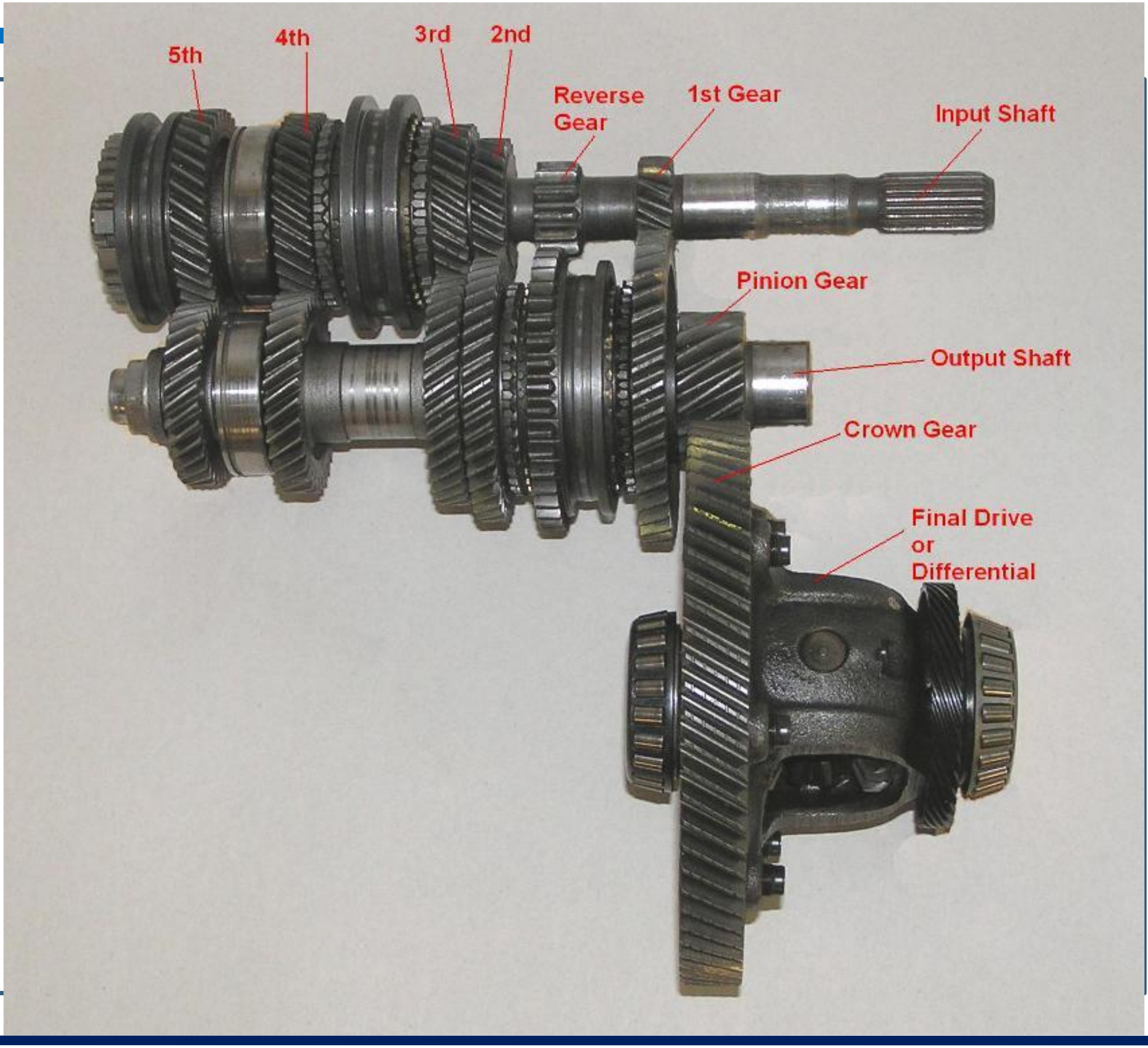
❖ Dual Clutch Transmission:

- A dual clutch transmission [DCT] invented by Frenchman **Adolphe Kégresse** is also known as twin-clutch gearbox, double clutch transmission. It is a differing type of semi-automatic or automated manual automotive transmission.
- It utilizes two separate clutches for **odd + reverse** and **even** gear sets. It can fundamentally be described as two separate manual transmissions (with their respective clutches) contained within one housing, and working as one unit.
- They are usually operated in a fully automatic mode, and many also have the ability to allow the driver to manually shift gears, albeit still carried out by the transmissions electro-hydraulics.
-

- A dual clutch transmission **eliminates the torque converter** as used in conventional epicyclic geared automatic transmissions.
- Instead, they primarily use two oil-bathed **wet multi-plate clutches**, similar to the clutches used in most motorcycles, though dry clutch versions are also available.


Clutch 1
Clutch 2
R
6
Gear Selector
5
Inner Transmission Shaft
Outer Transmission Shaft
2
4
3
1

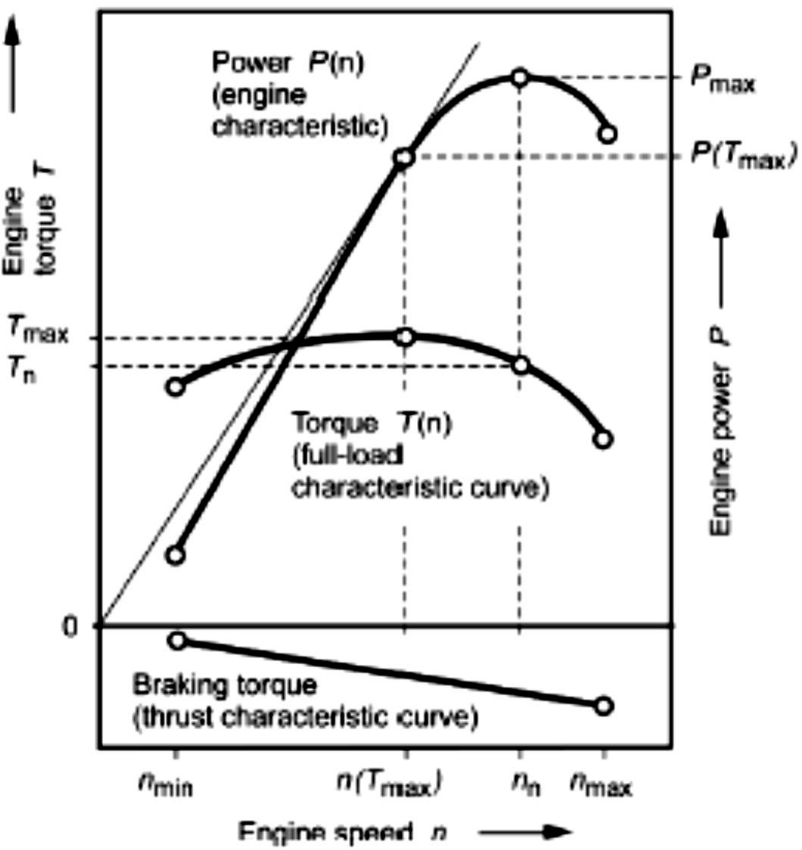
Transaxle:



5th
4th
3rd
2nd
Reverse Gear
1st Gear
Input Shaft
Pinion Gear
Output Shaft
Crown Gear
Final Drive or Differential

Overdrive Gears:-

- **Overdrive** is a term used to describe the operation of an automobile cruising at sustained speed with reduced engine RPM, leading to better fuel consumption, lower noise and lower wear



Characteristic points

$P_{max} = P_n$
Maximum engine Pow
= Nominal power

$P(T_{max})$
Engine power at maximum torque

T_{max}
Maximum engine torq

$T(P_{max}) = T_n$
Engine torque at maximum power
= Nominal torque

$n(P_{max}) = n_n$
Engine speed at maximum power
= Nominal speed

$n(T_{max})$
Engine speed at maximum torque

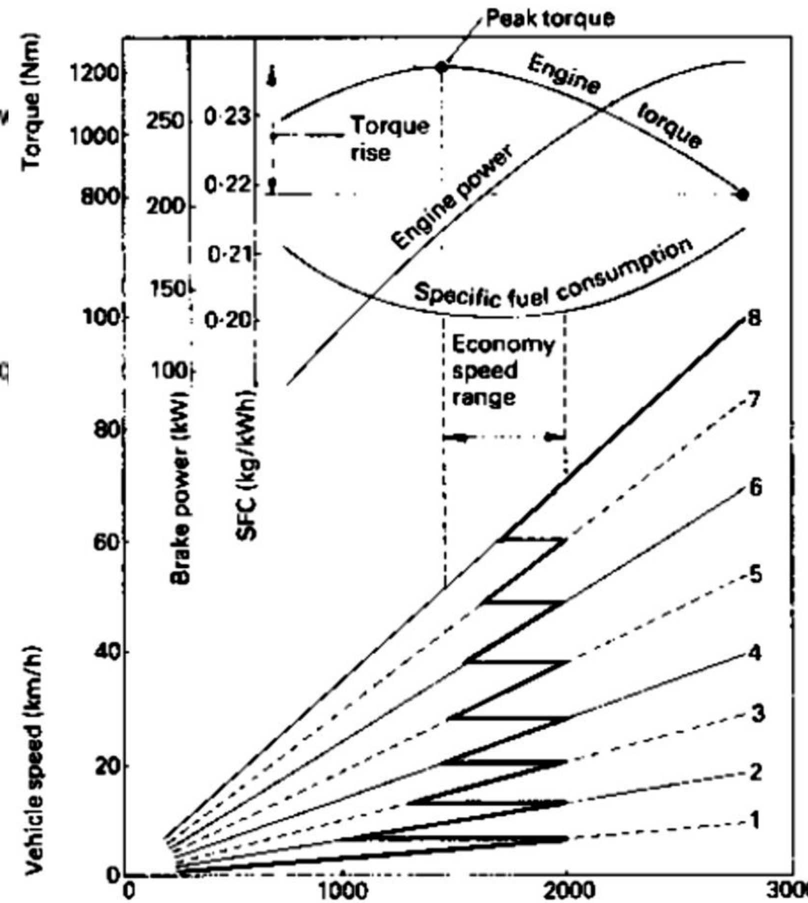
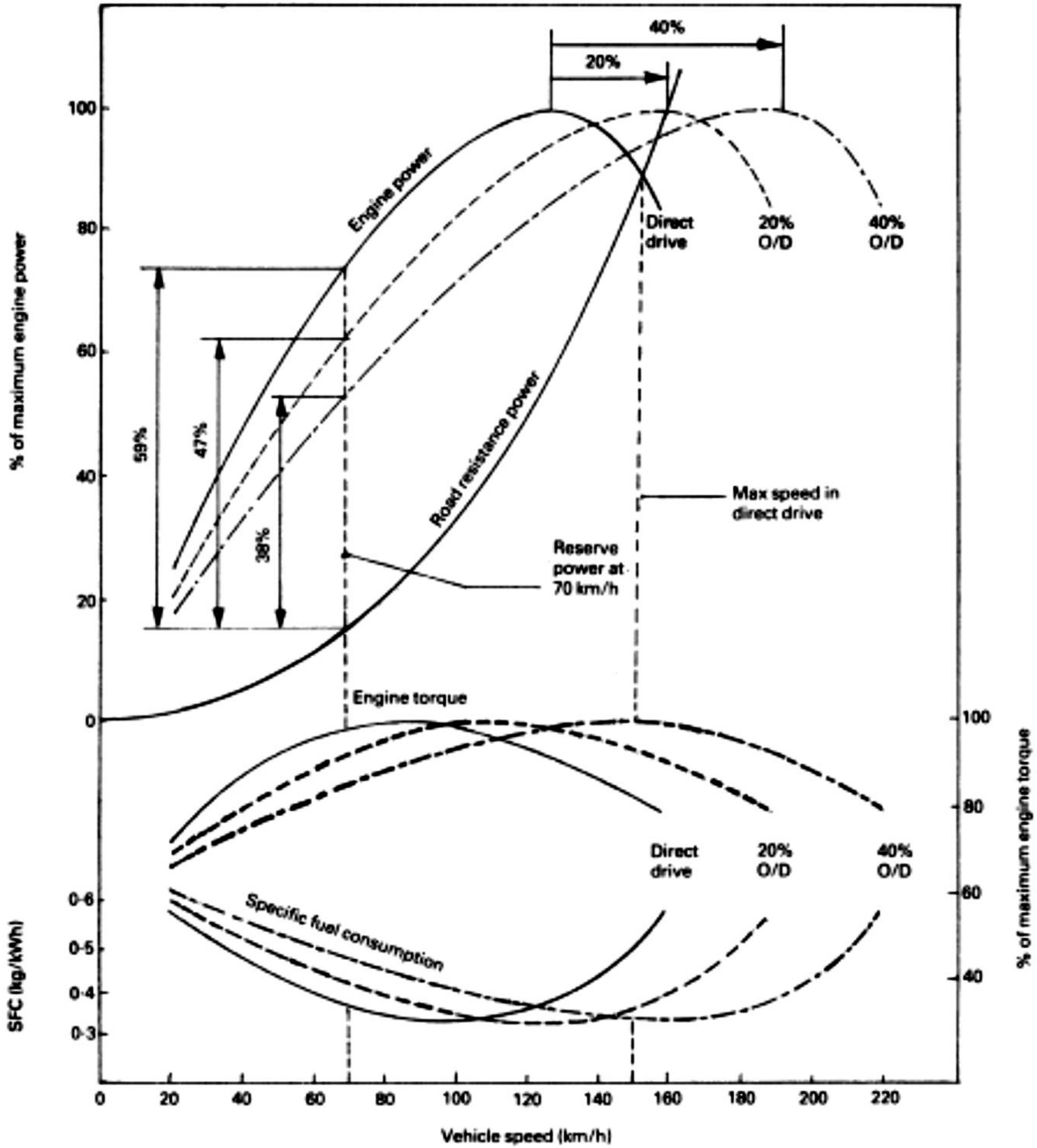


Fig. 3.14. Characteristic curves of an internal combustion engine

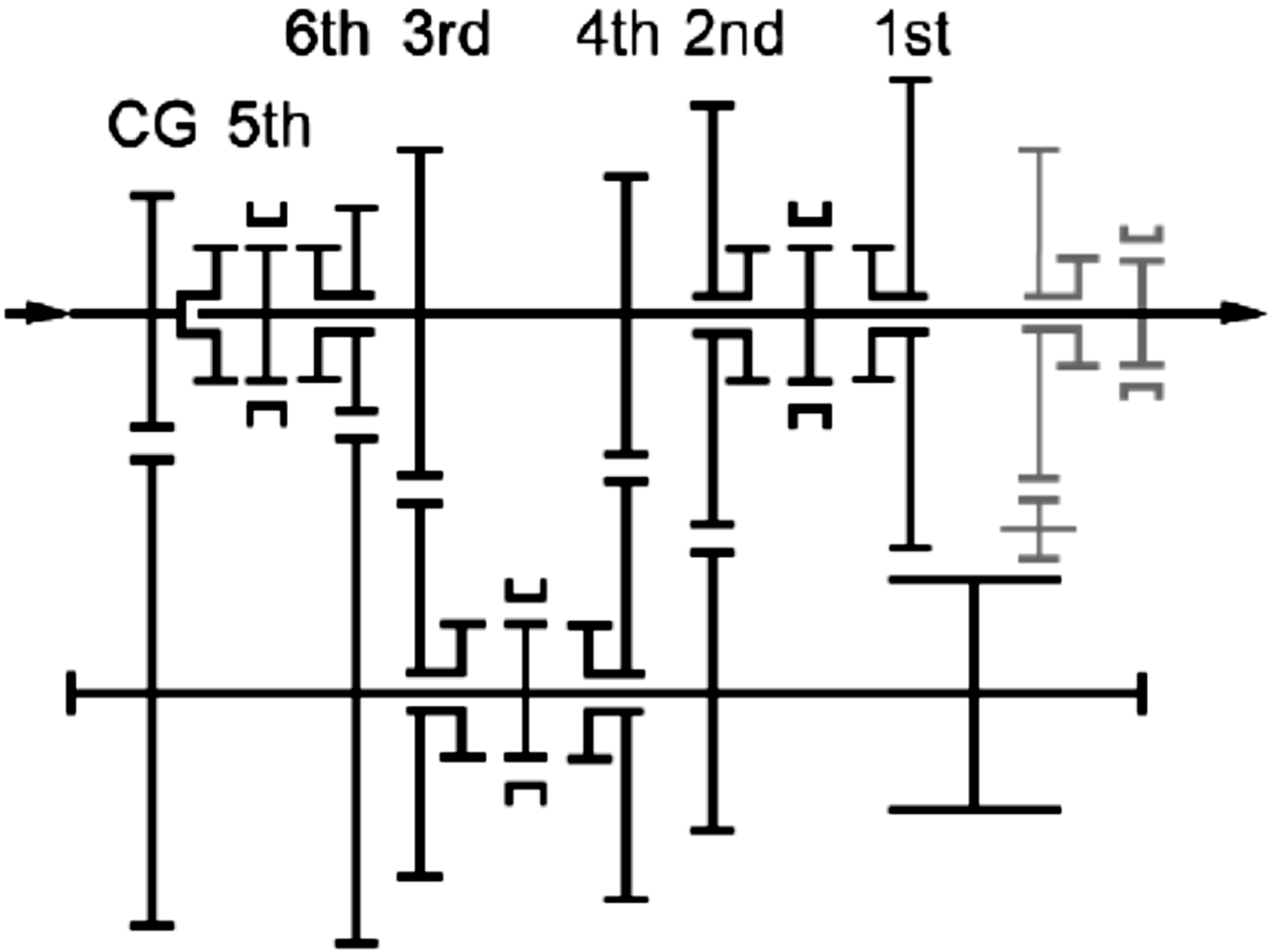


40%
20%
100
80
60
40
20
0
Engine power
Direct drive
20% O/D
40% O/D
% of maximum engine power
59%
47%
38%
Road resistance power
Max speed in direct drive
Reserve power at 70 km/h
Engine torque
100
80
60
40
Direct drive
20% O/D
40% O/D
% of maximum engine torque
Specific fuel consumption
SFC (kg/kWh)
0·6
0·5
0·4
0·3
0
20
40
60
80
100
120
140
160
180
200
220
Vehicle speed (km/h)

- The power produced by an engine increases with the engine's RPM to a maximum (Peak power), then falls away.
- Petrol engine is usually geared so that in its normal direct top gear on a level road the engine speed exceeds the peak power by about 10 to 20% of this speed.
- By selecting a 20% overdrive top gear, say, the transmission gear ratio can be so chosen that the engine power and road resistance power curve meet at the peak engine power.

- The amount of overdrive (undergearing) used for cars, vans, coaches and commercial vehicles varies from as little as 15% to as much as 45%
- This corresponds to undergearing ratios of between 0.87: to 1 and 0.69:1 respectively.
- Typical overdrive gear ratios which have been frequently used are 0.82:1(22%), 0.78:1 (28%), and 0.75:1(37%).

Overdrive Gears:-



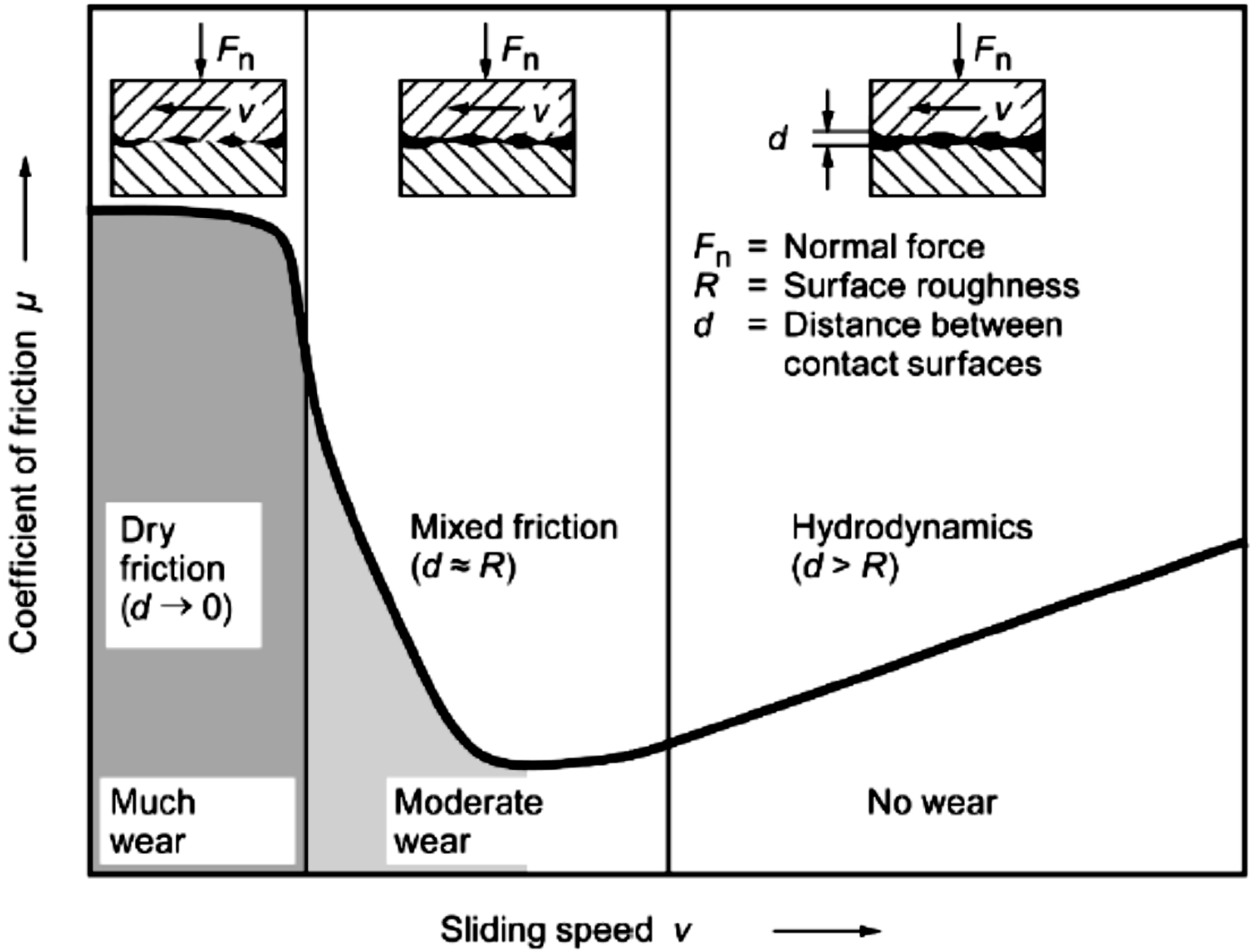
Gearbox Lubrication:

Lubricants

- **Solid Lubricants** — e.g. Graphite and Molybdenum di-sulphide etc.
- **Semi-Solid Lubricants** — e.g. Greases
- **Liquid Lubricants** — e.g. Petroleum Oils, Vegetable Oils, Mineral Oils, etc.

Types of Lubrication:

- Types of Lubrication based on film strength and μ
  - Thin Film or Boundary Lubrication
  - Partial or Mixed Lubrication
  - Thick Film Lubrication



Stribeck Curve

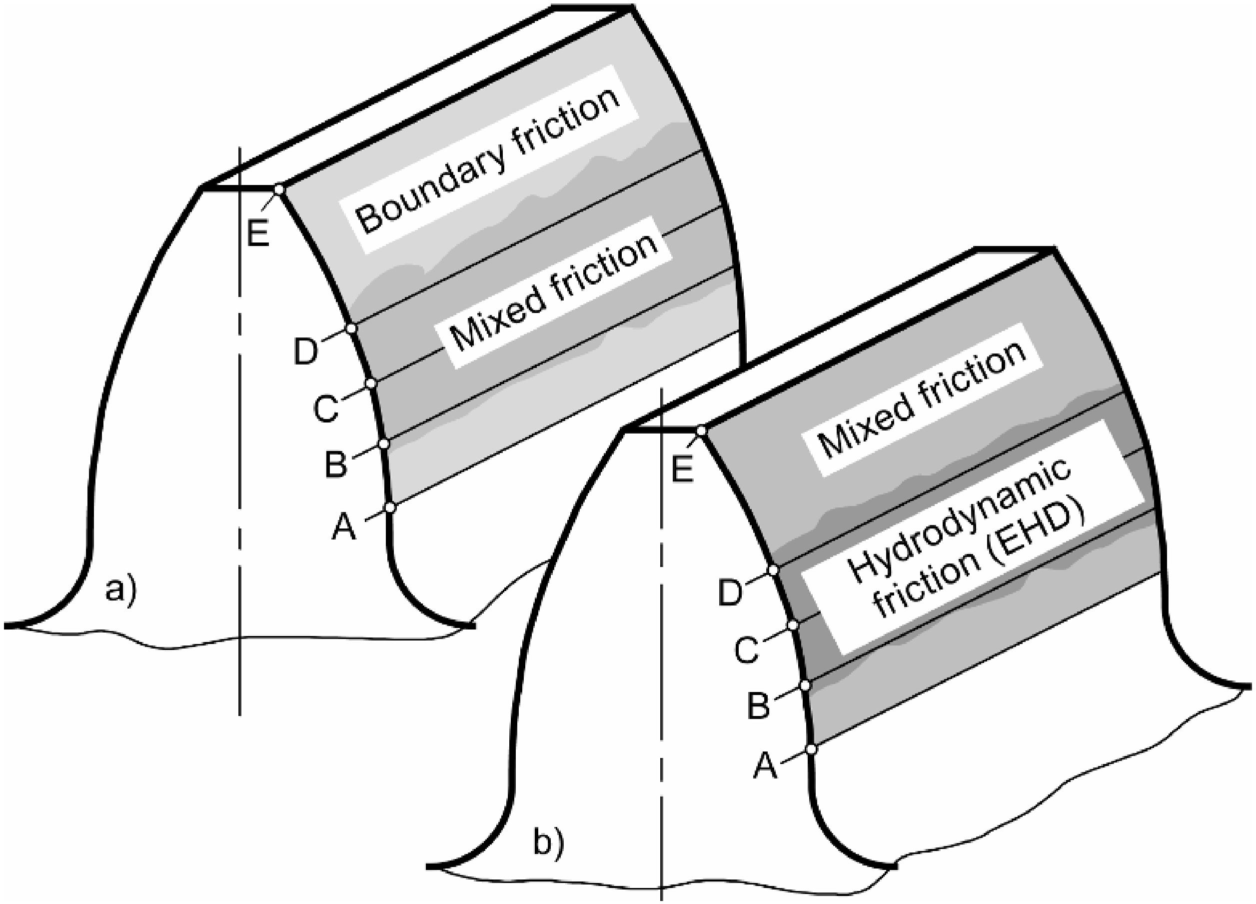
Types of Lubrication:

- Types of Lubrication based on fluid action
  - Hydrostatic Lubrication (External Pump)
    - Marine Engine Shafts, High Power Generation Turbine Shafts
  - Hydrodynamic Lubrication (Speed)
    - Journal Bearings, Crankshaft Bearings of IC Engines, Bearings of Centrifugal Pumps
  - Elasto-hydrodynamic Lubrication (Hertz's Contact Stress Condition)
    - Rolling Contact Bearings, Gear Teeth Lubrication, Cams & Followers
  - Extreme Pressure Lubrication (EP Additives)
    - Bearings used in High Pressure Regions of IC Engines, Turbines

The lubricant must fulfil the following functions:

- reduce friction and wear (saving energy),
- prevent possible damage, or prevent or delay further damage where mechanisms are already damaged,
- dissipate heat,
- create hydrodynamic lubricating wedges,
- form barrier layers in the mixed friction zone,
- protect materials used in the gearbox against corrosion,
- non-aggressive to seals and paintwork,
- good dirt removal/cleaning,
- good dirt absorption capability,
- water separation,
- stability at high and low temperatures,
- resistant to ageing and
- low cost.

❖ Principles of Lubricating Gearwheel Mechanisms:



Typical friction zones on tooth flanks at high contact pressures

- The sliding speed is at its maximum at the beginning *A* or the end *E* of tooth contact, i.e. at the root or the tip of the tooth.
- The sliding speed at pitch point C is zero.
- The wear increases as the proportion of sliding increases.
- At the tooth flanks, the **most favorable lubrication conditions** arise around the **pitch point**, whilst conditions are **less favorable** at the **tooth tips**, because of the meshing impact and high temperatures resulting from higher sliding speed.

Elasto-hydrodynamic Lubrication (EHD):

- Hydrodynamic lubrication theory of plain bearings is not applicable because of the high contact pressures for the toothing.
- Elasto-hydrodynamic lubrication theory has to be applied. This theory takes into account the pressure viscosity of the oil and the elasticity of the tooth flanks.
- Elasto-hydrodynamic lubrication is characterised by two fundamental features:
  - The viscosity of the oil film increases erratically because of the high surface stress.
  - Because of the high surface stress, there is elastic deformation at the tooth flank contact points. The crowned engaged tooth flanks flatten under load.

❖ Selecting the Lubricant:

- In normal operation, the oil temperature in the sump is approximately 60–90°C for passenger cars and CV gearboxes.
- Under extreme conditions, for example on mountain roads with a trailer, the oil sump temperature can reach approximately 110°C.
- The most common additives for gearbox lubricants in accordance with,
  - EP (Extreme Pressure) additives for improving high-pressure characteristics,
  - Corrosion inhibitors for preventing rust, verdigris and similar harmful products of oxidation
  - D/D (Detergent/Dispergent) additives for removing dirt,
  - Friction modifiers for reducing friction and wear,
  - VI improver to improve high and low temperature performance

GEAR BOX DESIGN

- Gear Ratio Selection
- Gear Teeth Selection
- Gear parameters (module, pr.angle etc)

Gear ratio selection

Transmission gear ratio design involves :

- Move off under difficult condition (maximum gradient).
- Reach the required maximum speed.
- Operate in the fuel efficient range of the engine performance map.

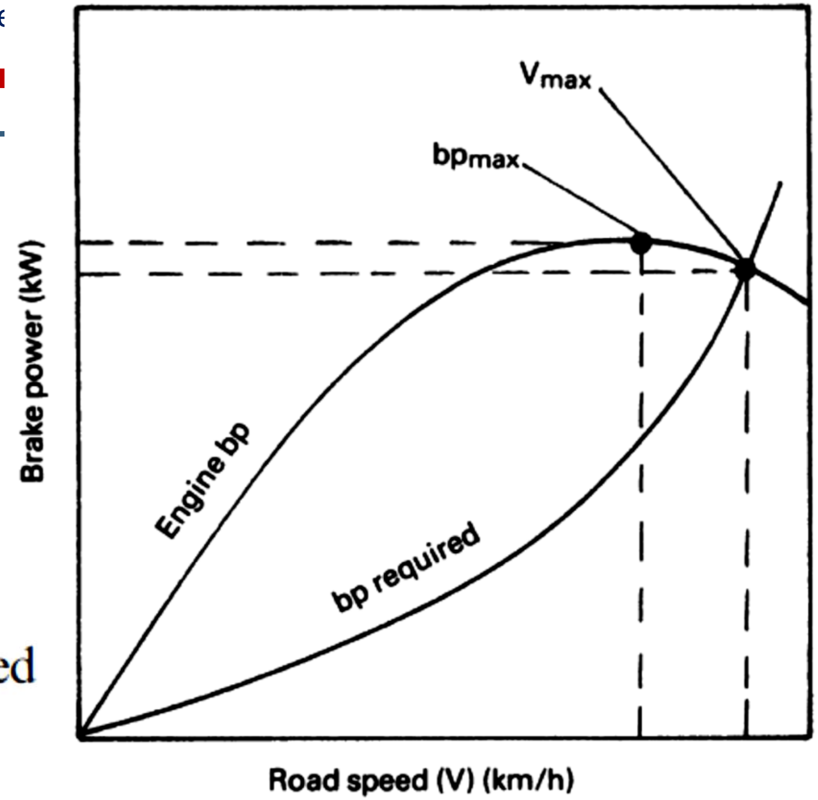
Basic design of the transmission involves first determining the maximum & minimum ratios and then selecting the intermediate ratios.

- ✓ Maximum ratio is fixed by the first condition.
- ✓ Minimum ratio is fixed by the maximum road speed.
- ✓ Intermediate ratio is based on the last condition

Factors affecting the gear ratio selection :

- Type of vehicle
- Type of engine
- Other factors

Setting up Top Gear Ratio (Overall):-



Thus Linear wheel speed = Linear road speed

$$\frac{\pi d N}{G_F} = \frac{1000}{60} V \text{ (m/min)}$$

$$\therefore \text{ Final drive gear ratio } \quad G_F = \frac{60\ \pi d N}{100\ V}$$

$$= 0.06\ \frac{\pi d N}{V}$$

where G_F = final drive gear ratio

N = engine speed (rev/min)

d = effective wheel diameter (m)

V = road speed at which peak power is developed (km/h)

Example A vehicle is to have a maximum road speed of 150 km/h. If the engine develops its peak power at 6000 rev/min and the effective road wheel diameter is 0.54 m, determine the final drive gear ratio.

$$G_F = \frac{0.06\ \pi d N}{V}$$

$$= \frac{0.06 \times 3.142 \times 0.54 \times 6000}{150}$$

$$= 4.07 : 1$$

Setting up Bottom Gear Ratio (Overall):-

The rolling resistance opposing motion may be determined by the formula:

$$R_r = 10 C_r W$$

where R_r = rolling resistance (N)
C_r = coefficient of rolling resistance
W = gross vehicle weight (kg)

Likewise, the gradient resistance (Fig. 3.33) opposing motion may be determined by the formula:

$$R_g = \frac{10W}{G} \quad \text{or} \quad 10W \sin\theta$$

where R_g = gradient resistance (N)

W = gross vehicle weight ($10W$ kg = W N)

G = gradient (1 in x) = $\sin\theta$

Tractive effort = Resisting forces opposing motion

$$E = R$$

$$= R_r + R_g \text{ (N)}$$

where E = tractive effort (N)

R = resisting forces (N)

Once the minimum tractive effort has been calculated, the bottom gear ratio can be derived in the following way:

$$\text{Driving torque} = \text{Available torque}$$

$$ER = T\ G_B G_F \eta_M$$

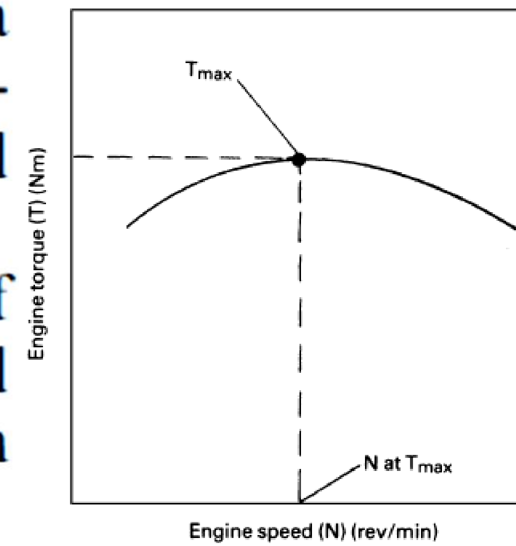
$$\therefore\ \text{Bottom gear ratio } G_B = \frac{ER}{T G_F \eta_M}$$

where
G_F = final drive gear ratio
G_B = bottom gear ratio
η_M = mechanical efficiency
E = tractive effort (N)
T = maximum engine torque (Nm)
R = effective road wheel radius (m)

Example A vehicle weighing 1500 kg has a coefficient of rolling resistance of 0.015. The transmission has a final drive ratio 4.07:1 and an overall mechanical efficiency of 85%.

If the engine develops a maximum torque of 100 Nm (Fig. 3.34) and the effective road wheel radius is 0.27 m, determine the gearbox bottom gear ratio.

Assume the steepest gradient to be encountered is a one in four.



$$R_r = 10 C_r W$$

$$= 10 \times 0.015 \times 150 = 225\text{N}$$

$$R_g = \frac{10W}{G}$$

$$= \frac{10 \times 1500}{4} = 3750\text{N}$$

$$E = R_r + R_g$$

$$= 3750 + 225 = 3975\text{N}$$

$$G_B = \frac{eR}{T G_F \eta_M}$$

$$= \frac{3975 \times 0.27}{100 \times 4.07 \times 0.85} = 3.1{:}1$$

❖ Overall Gear Ratios

- Final gear ratio x 1st gear ratio = total gear ratio

4.1 x 3.1 = 12.7:1

–This tells us that the engine turns 12.7 revolutions for every 1 revolution of the tires (speed reduction)

- Torque multiplication can also be calculated

–The 305 engine produces 230 N-m of torque at 3200 RPM

–@ 3200 RPM in 1stgear the torque acting on the rear tires

= 230 N-m x 12.7 = **2921** N-m torque !!!

- When choosing the lowest and highest gear ratio, the factor to be considered is not just the available engine power, but it also depends on the weight of vehicle and load expected to propel, so the power to weight ratio is important.
- **Power to weight ratio= Brake power developed/ laden weight of vehicle.**

a) A car fully laden with passengers and luggage weighs 1.2 tonne and the maximum power produced by the engine amounts to 120 kW.
b) A fully laden articulated truck weighs 38 tonne and a 290 kW engine is used to propel this load.

a) Power to weight ratio $= \frac{120}{1.2} = 100\,\text{kW/tonne}$

b) Power to weight ratio $= \frac{290}{38} = 7.6\,\text{kW/tonne.}$

Car and light van gearboxes have ratio spans of about 3.5:1 if top gear is direct, but with overdrive this may be increased to about 4.5:1. Large commercial vehicles which have a low power to weight ratio, and therefore have very little surplus power when fully laden, require ratio spans of between 7.5 and 10:1, or even larger for special applications.

For a vehicle such as a saloon car or light van which only weighs about one tonne and has a large power to weight ratio, a four or five speed gearbox is adequate to maintain tractive effect without too much loss in engine speed and vehicle performance between gear changes.

Unfortunately, this is not the situation for heavy goods vehicles where large loads are being hauled so that the power to weight ratio is usually very low. Under such operating conditions if the gear ratio steps are too large the engine speed will drop to such an extent during gear changes that the engine torque recovery will be very sluggish (Fig. 3.17). Therefore, to minimize engine speed fall-off whilst changing gears, smaller gear ratio steps are required, that is, more gear ratios are necessary to respond to the slightest change in vehicle load, road conditions and the driver's requirements. Figs 3.2 and 3.18 show that by dou-

i.e. $$\text{Ratio span} = \frac{\text{Road speed in highest gear}}{\text{Road speed in lowest gear}}$$

(both road speeds being achieved at similar engine speed).

Type of vehicle	Gear	Ratio	km/h/1000 rev/min
Car	Top	0.7	39
	First	2.9	9.75
Commercial vehicle (CV)	Top	1.0	48
	First	6.35	6

$$\text{Car ratio span} = \frac{39}{9.75} = 4.0{:}1$$

$$\text{Commercial vehicle ratio span} = \frac{48}{6} = 8.0{:}1$$

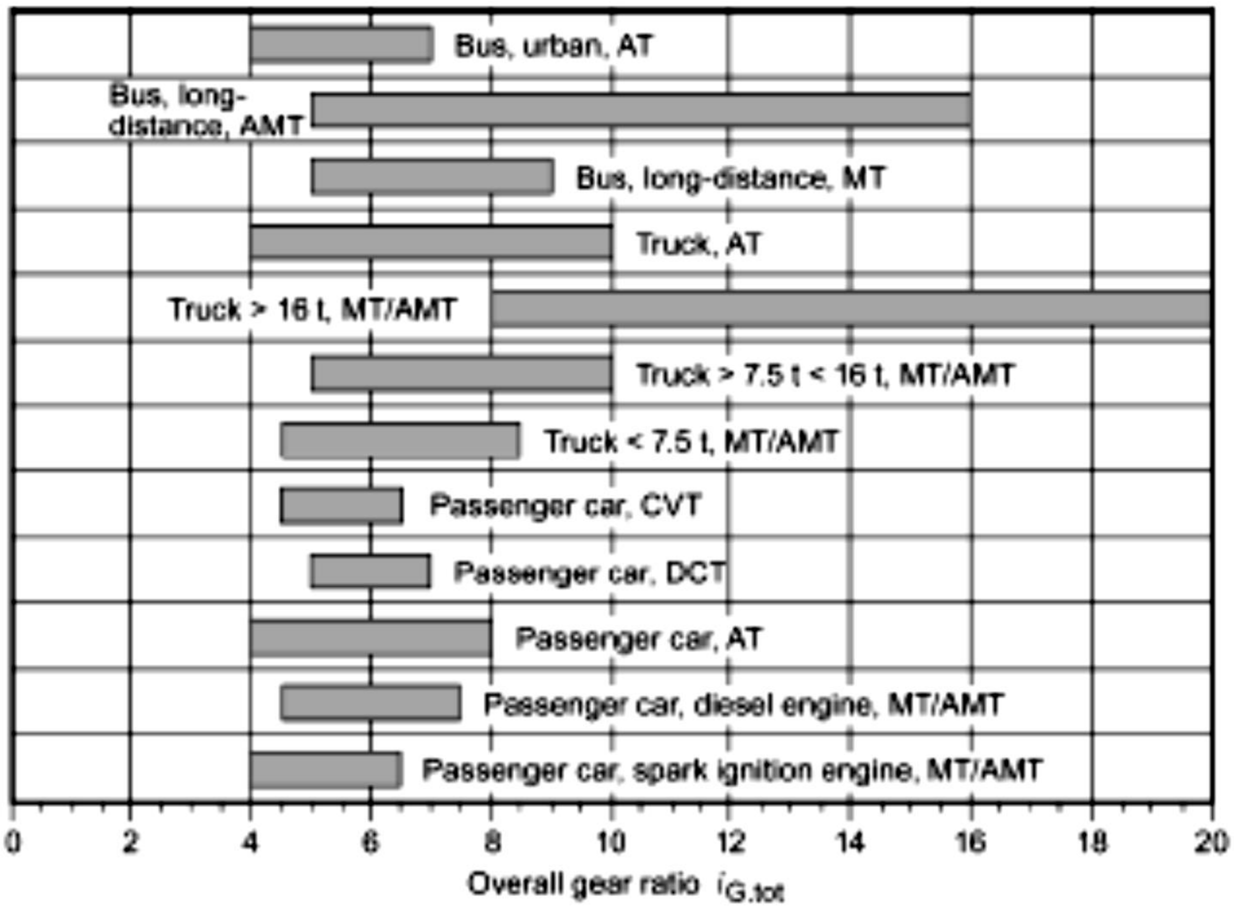


Fig. 4.4. Reference values for overall gear ratios for various types of vehicle. In the case of automatic transmissions, the conversion of the torque converter ($\mu_{max} \approx 2...3$) has to be added

❖ Intermediate Gear Ratio:

3.8.3 Setting intermediate gear ratios

Ratios between top and bottom gears should be spaced in such a way that they will provide the tractive effort–speed characteristics as close to the ideal as possible. Intermediate ratios can be best selected as a first approximation by using a geometric progression. This method of obtaining the gear ratios requires the engine to operate within the same speed range in each gear, which is normally selected to provide the best fuel economy.

Consider the engine to vehicle speed characteristics for each gear ratio as shown (Fig. 3.35). When changing gear the engine speed will drop from the highest N_H to the lowest N_L without any change in road speed, i.e. V_1, V_2, V_3 etc.

Let G_1 = 1st overall gear ratio
G_2 = 2nd overall gear ratio
G_3 = 3rd overall gear ratio
G_4 = 4th overall gear ratio
G_5 = 5th overall gear ratio

where $\text{Overall gear ratio} = \dfrac{\text{Engine speed (rev/min)}}{\text{Road wheel speed (rev/min)}}$

Wheel speed when engine is on the high limit N_H in first gear $G_1 = \dfrac{N_H}{G_1}$ (rev/min)

Wheel speed when engine is on the low limit N_L in second gear $G_2 = \dfrac{N_L}{G_2}$ (rev/min)

These wheel speeds must be equal for true rolling

Hence $\dfrac{N_H}{G_1} = \dfrac{N_L}{G_2}$

$$\therefore\ G_2 = G_1 \frac{N_L}{N_H}$$

Also $\dfrac{N_H}{G_2} = \dfrac{N_L}{G_3}$

$$\therefore\ G_3 = G_2 \frac{N_L}{N_H}$$

and $\dfrac{N_H}{G_3} = \dfrac{N_L}{G_4}$

$$\therefore\ G_4 = G_3 \frac{N_L}{N_H}$$

$$\frac{N_H}{G_4} = \frac{N_L}{G_5}$$

$$\therefore\ G_5 = G_4 \frac{N_L}{N_H}$$

The ratio $\dfrac{N_L}{N_H}$ is known as the minimum to maximum speed range ratio K for a given engine.

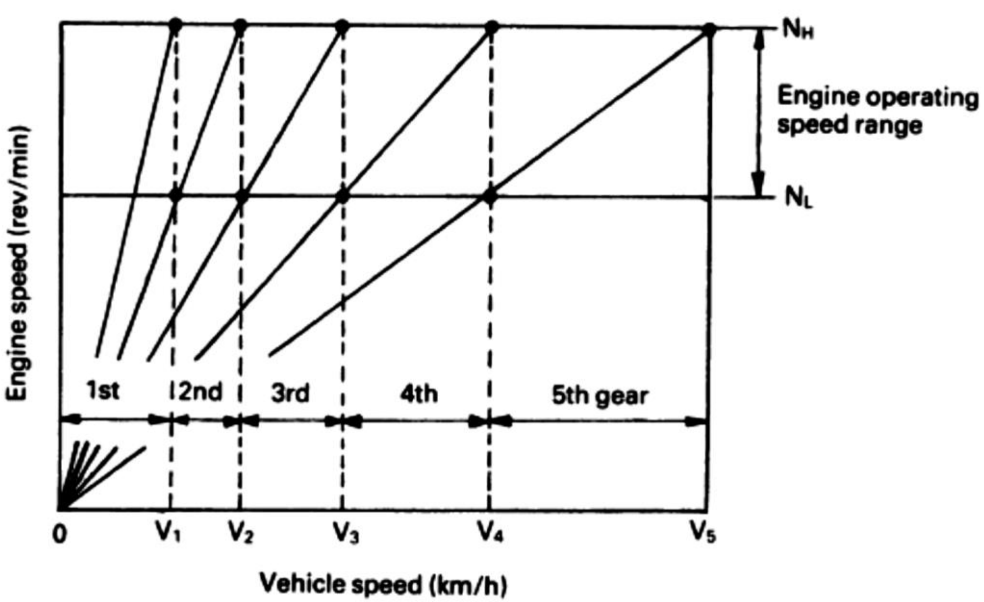
$$\text{Now, gear } G_2 = G_1 \frac{N_L}{N_H} = G_1 K,$$

$$\text{since } \frac{N_L}{N_H} = k \text{ (a constant)}$$

$$\text{gear } G_3 = G_2 \frac{N_L}{N_H} = G_2 K = (G_1 K)K$$
$$= G_1 K^2$$

$$\text{gear } G_4 = G_3 \frac{N_L}{N_H} = G_3 K = (G_1 K^2)K$$
$$= G_1 K^3$$

$$\text{gear } G_5 = G_4 \frac{N_L}{N_H} = G_4 K = (G_1 K^3)K$$
$$= G_1 K^4.$$



Hence the ratios form a geometric progression

The following relationship will also apply for five speed gearbox:

$$\frac{G_2}{G_1}=\frac{G_3}{G_2}=\frac{G_4}{G_3}=\frac{G_5}{G_4}=\frac{N_L}{N_H}=K$$

and $G_5 = G_1K^4$ or $K^4=\frac{G_5}{G_1}$

Hence $K=\left[\frac{G_5}{G_1}\right]^{\frac{1}{4}}$ or $\sqrt[4]{\frac{G_5}{G_1}}$

In general, if the ratio of the highest gear (G and that of the lowest gear (G_B) have been dete mined, and the number of speeds (gear ratios) the gearbox n_G is known, the constant K can l determined by:

$$K=\left[\frac{G_T}{G_B}\right]^{\frac{1}{n_{G^{-1}}}}$$

So $\frac{G_T}{G_B}=K^{n_{G^{+1}}}$

$\therefore$ $G_T = G_BK^{n_{G^{-1}}}$

For commercial vehicles, the gear ratios in the gearbox are often arranged in geometric progression. For passenger cars, to suit the changing traffic conditions, the step between the ratios of the upper two gears is often closer than that based on geometric progression. As a result, this will affect the selection of the lower gears to some extent.

Example A transmission system for a vehicle is to have an overall bottom and top gear ratio of 20:1 and 4.8 respectively. If the minimum to maximum speeds at each gear changes are 2100 and 3000 rev/min respectively, determine the following:

a) the intermediate overall gear ratios
b) the intermediate gearbox and top gear ratios.

$$K = \frac{N_L}{N_H} = \frac{2100}{3000} = 0.7$$

a) 1st gear ratio $G_1 = 20.0{:}1$
2nd gear ratio $G_2 = G_1 K = 20 \times 0.7 = 14.0{:}1$
3rd gear ratio $G_3 = G_1 K^2 = 20 \times 0.7^2 = 9.8{:}1$
4th gear ratio $G_4 = G_1 K^3 = 20 \times 0.7^3 = 6.86{:}1$
5th gear ratio $G_5 = G_1 K^4 = 20 \times 0.7^4 = 4.8{:}1$

b) $G_1 = \frac{20.0}{4.8} = 4.166{:}1$

$$G_2 = \frac{14.0}{4.8} = 2.916{:}1$$

$$G_3 = \frac{9.8}{4.8} = 2.042{:}1$$

$$G_4 = \frac{6.86}{4.8} = 1.429{:}1$$

$$\text{Top gear } G_5 = \frac{4.8}{4.8} = 1.0{:}1$$