MECA0063 : Driveline systems

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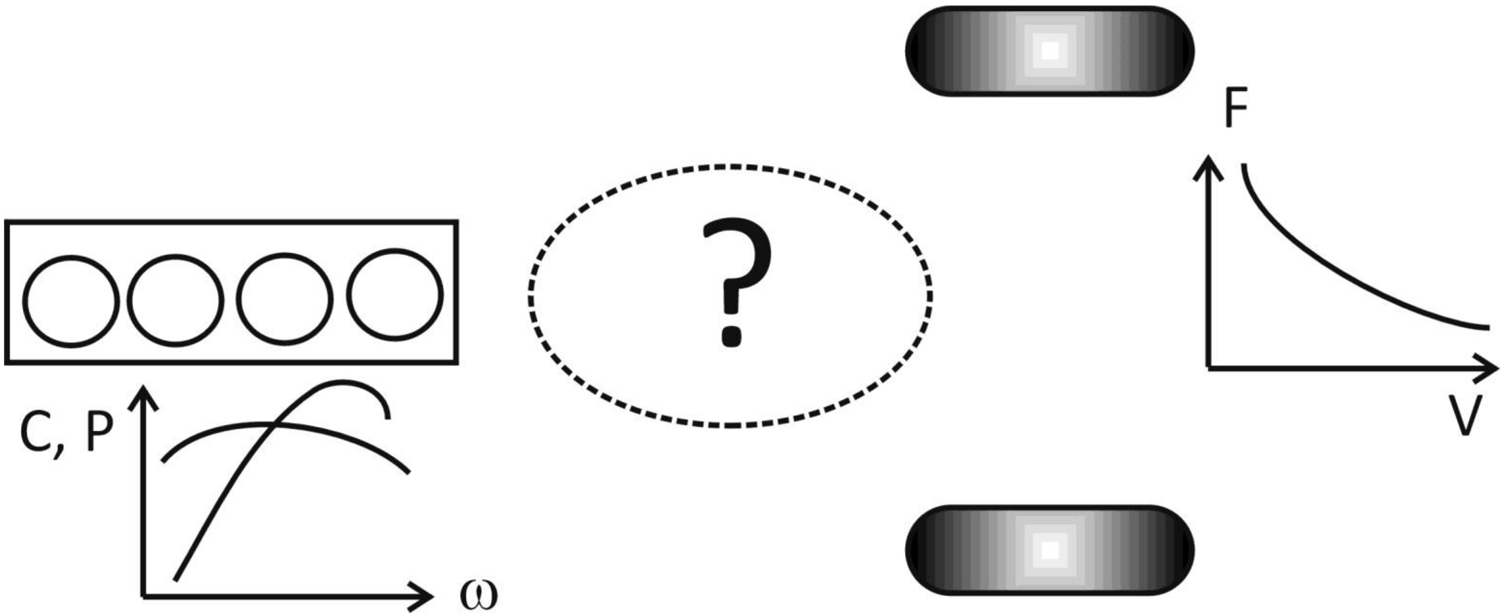
WHY A DRIVELINE?

- For ground vehicles using a powertrain, a driveline system is necessary to fit the powertrain characteristics to the vehicle driving conditions



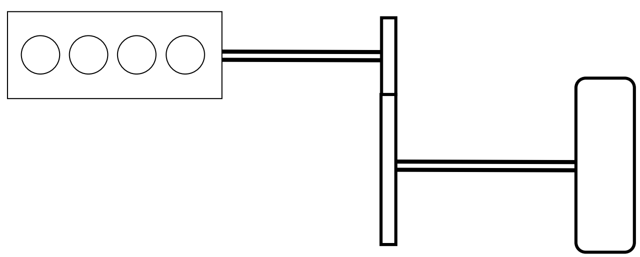
WHY A DRIVELINE?

- For ground vehicles using a powertrain, a driveline system is necessary to:
  - Transfer the power from the engine /e-motor to the wheel (localization problem)
  - Adapt the characteristic (rotation speed, torque) of the engine to the vehicle motion requirement while minimizing the energy consumption and taking advantage of the optimal performance of the power plant
  - Functional adaptation as a sliding power: Interrupt and disconnect the power from engine to wheels, start from rest and progressively accelerate
  - Functional adaptation by enabling an optimal distribution of the power between front / rear axles and right / left wheels
  - Enabling to reverse the rotation speed while this is impossible for internal combustion engines

WHY A DRIVELINE?

- Adaptation of the characteristic of the powertrain to the load
  - Idle regime and maximal regime of the engine
  - Modify the reduction ratio between the engine and the wheels to adapt the tractive force/speed at the wheels with the engine rotation speed and torque
  - Adapt the propulsive force to road driving conditions

$$P_1 = \omega_1 . C_1$$

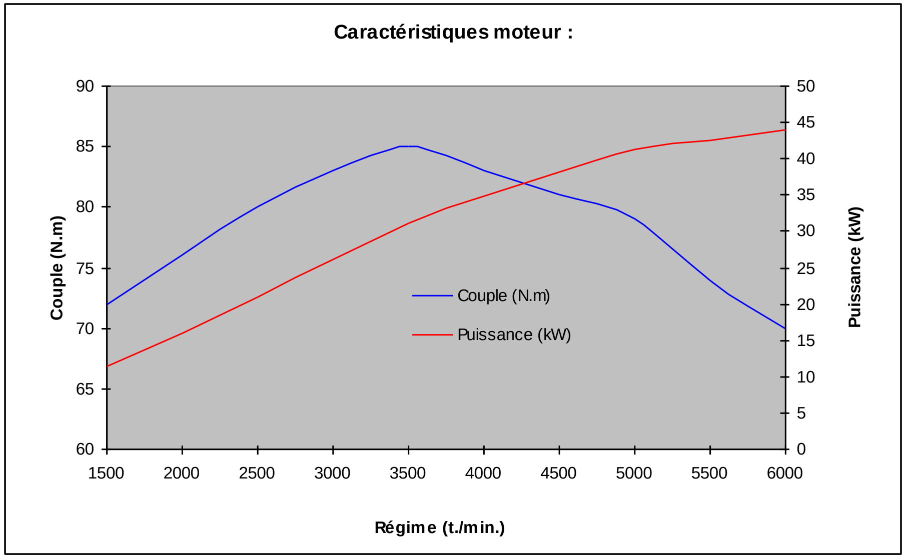


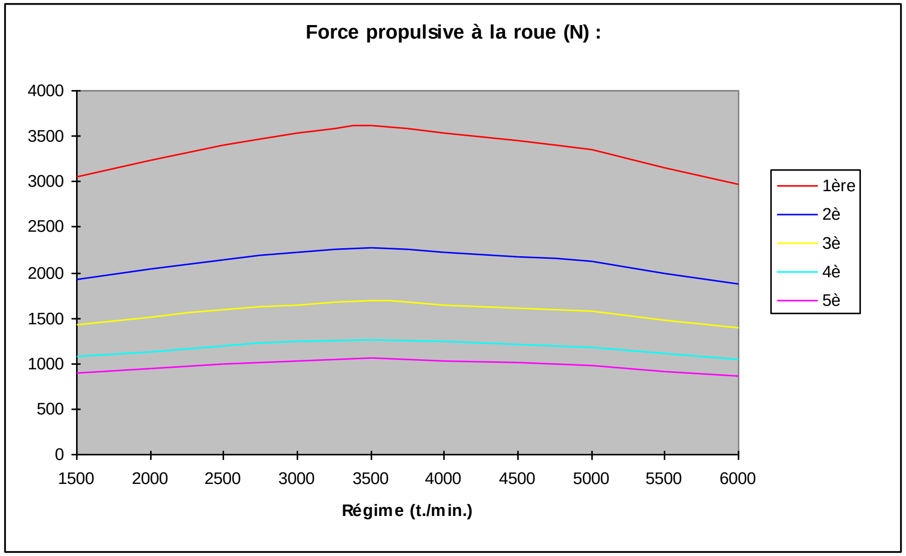
$$P_2 = \omega_2 . C_2$$

$$\boxed{\omega_2 < \omega_1 \quad \Rightarrow \quad C_2 > C_1}$$

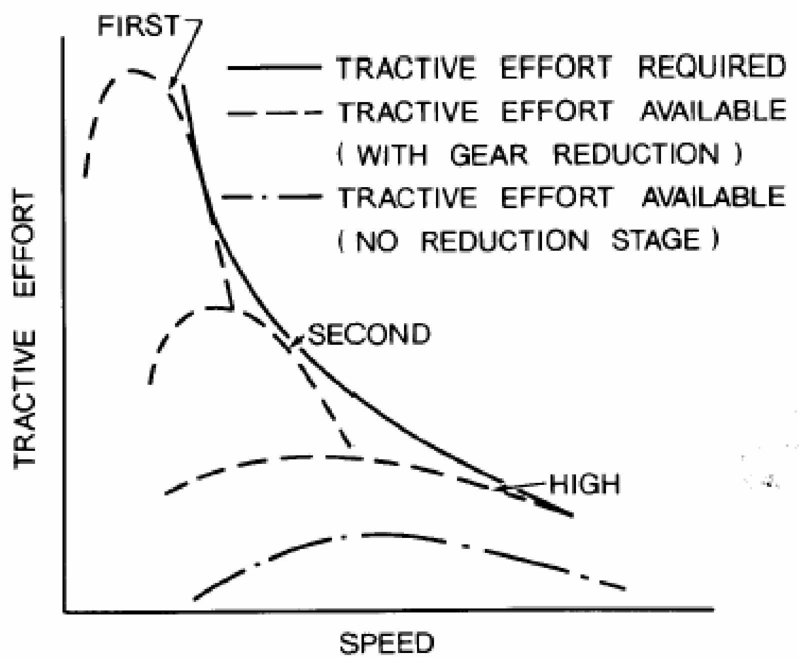
WHY A DRIVELINE?

- Adapt the propulsive force at wheels to driving conditions and adherence capabilities





WHY A DRIVELINE?



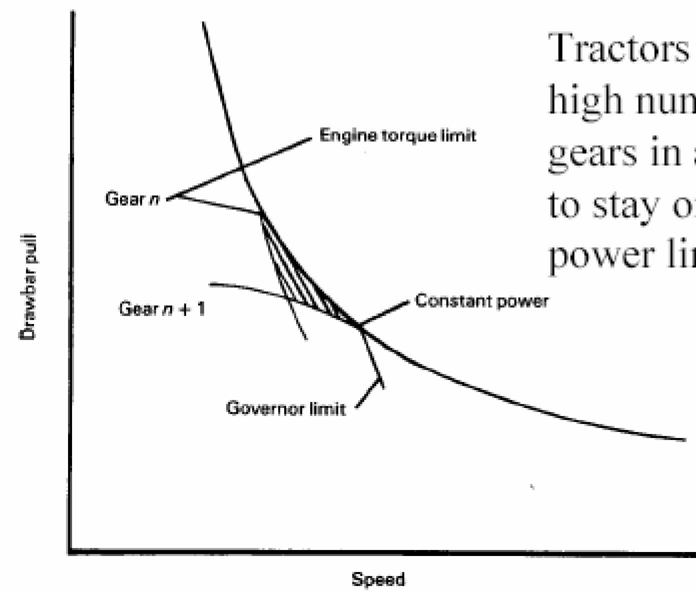


FIGURE 13-2 Tractor performance envelope.

Tractors have a high number of gears in an effort to stay on constant power line.

- Modifying the gear ratio is necessary to deliver the maximum power within a large range of driving speeds.
- Passenger cars: generally 4 to 6 gear speeds. For light duty vehicles, 5 to 15 gear ratios. For off road vehicles: more than 15 gear ratios

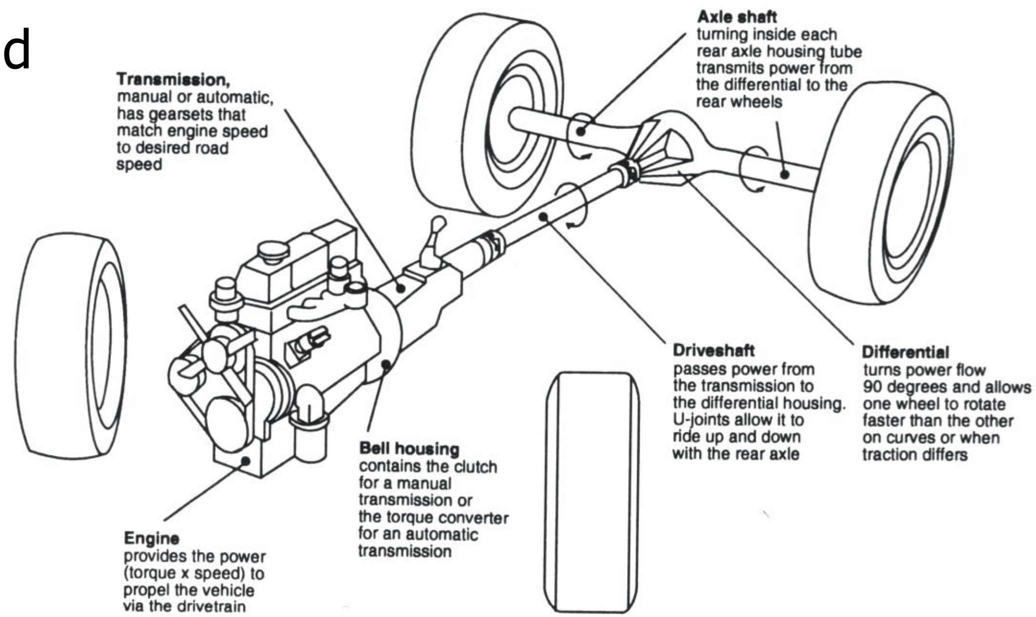
WHY A DRIVELINE?

- Functional adaptation as a sliding power
  - Enabling the interruption of the power flow to the wheels,
  - Enabling the coupling and uncoupling of the engine and of the wheels with a progressive maneuver

- Functional adaptation of the power by managing the repartition of the power split between the tires :
  - Optimal distribution between the front and left/right wheels
  - Distribution in cornering
  - Distribution of power in low grip conditions: anti-skip and limited slip operation
  - Stability control

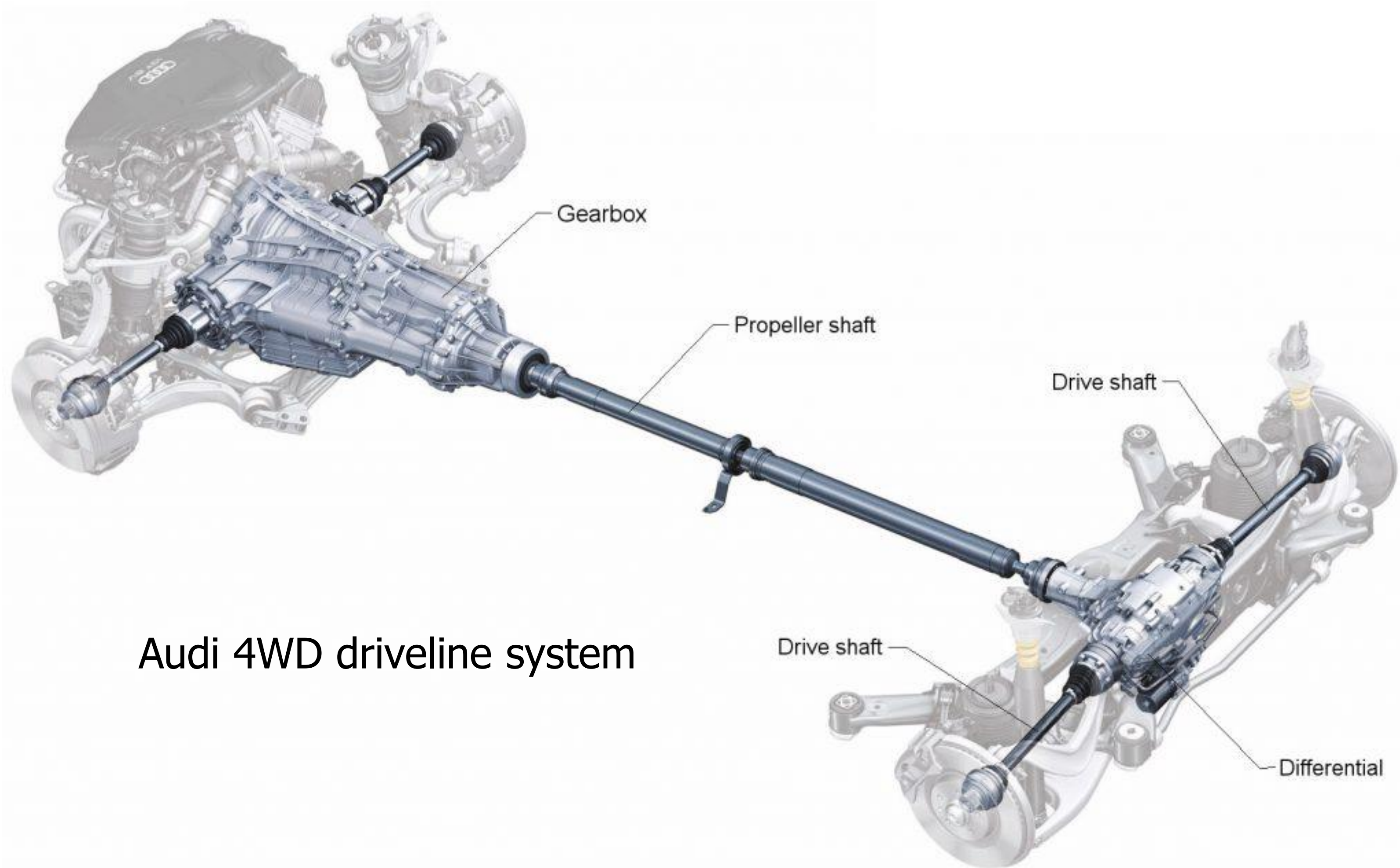
DRIVELINE SYSTEM

- The driveline systems generally includes several components and subsystems:
  - A flywheel
  - A clutch device
  - A gear box
  - A set of transmission shafts
  - Differential devices
  - Axles
- There are different kinds of components to match these functions, each of them having different levels of complexity and satisfaction of the requirements



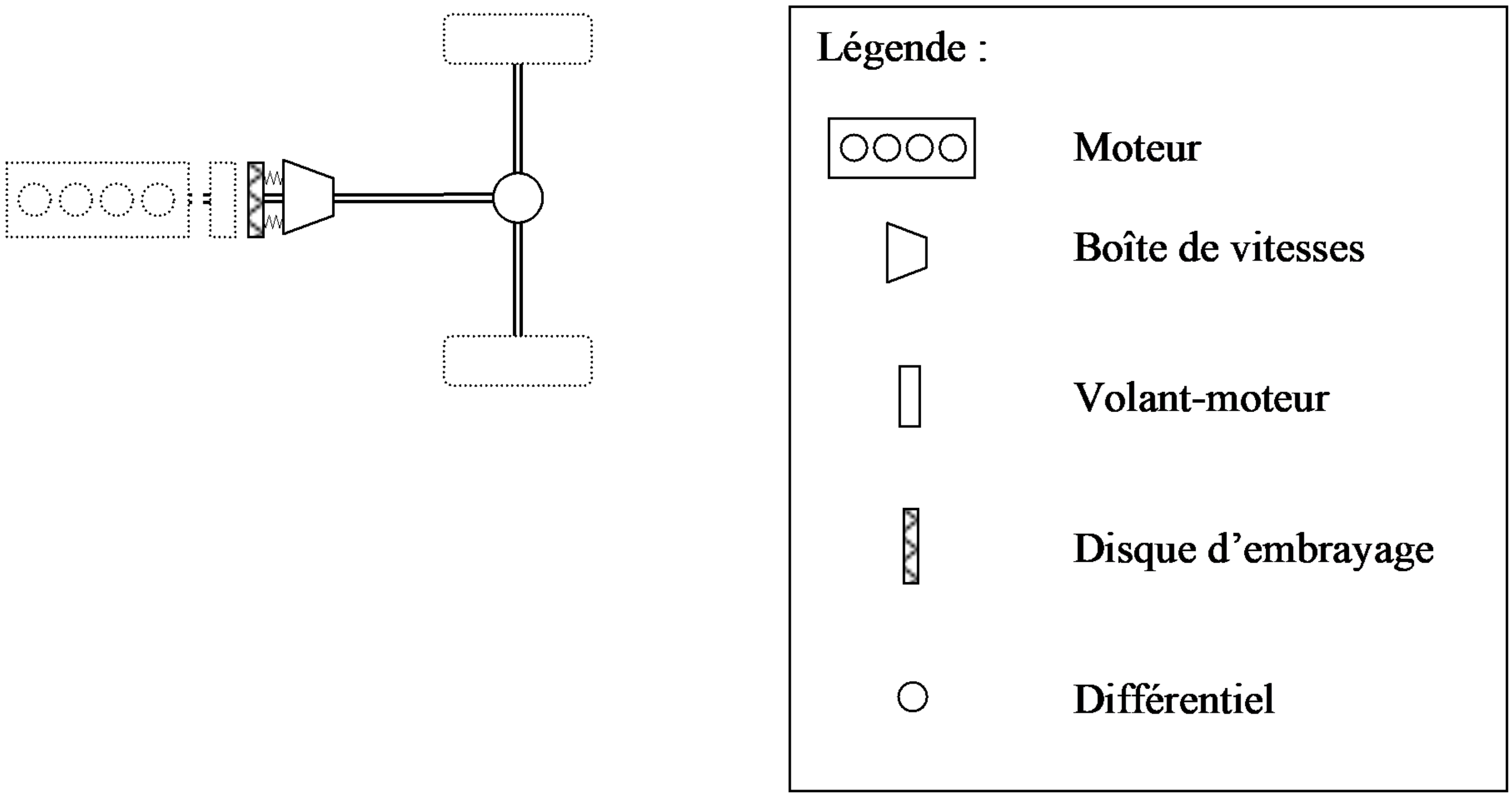
Gillespie: Fig 2.4

DRIVELINE SYSTEM



Audi 4WD driveline system

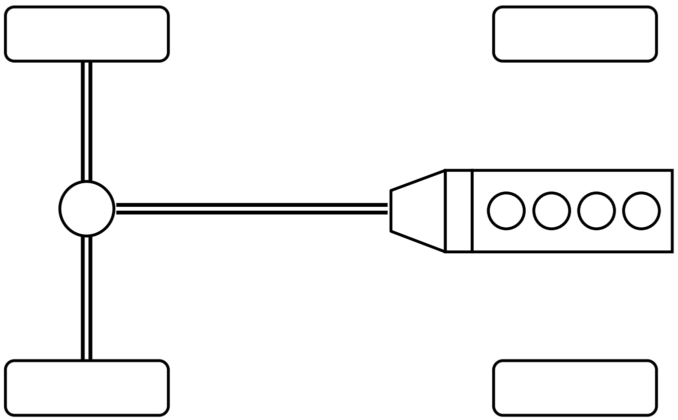
DRIVELINE SYSTEM

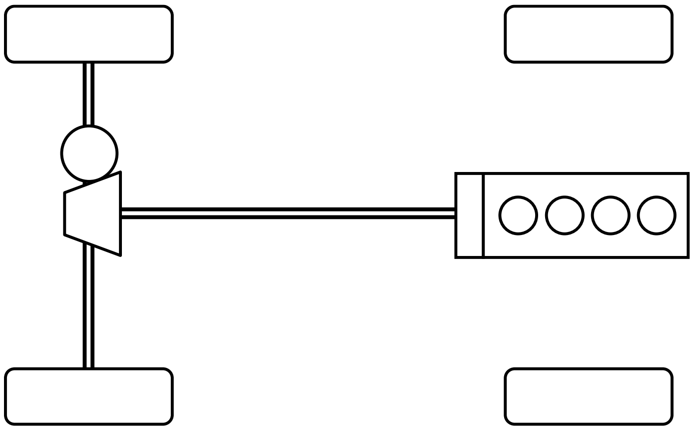


DRIVELINE SYSTEM

- There are different configurations of the driveline and powertrain:
  - Engine :
    - At the front / at the rear / central position
    - Transversal or longitudinal mounting
    - Central (unique) position vs distributed (local) layout (in-wheel motors)
  - Tractive wheels
    - Front wheel drive / rear wheel drive / all wheel drive
  - Differential and transfer boxes :
    - At the front / at the rear
    - Close to the engine or not
    - With parallel rotation axes or skew rotation directions

Layout of driveline systems

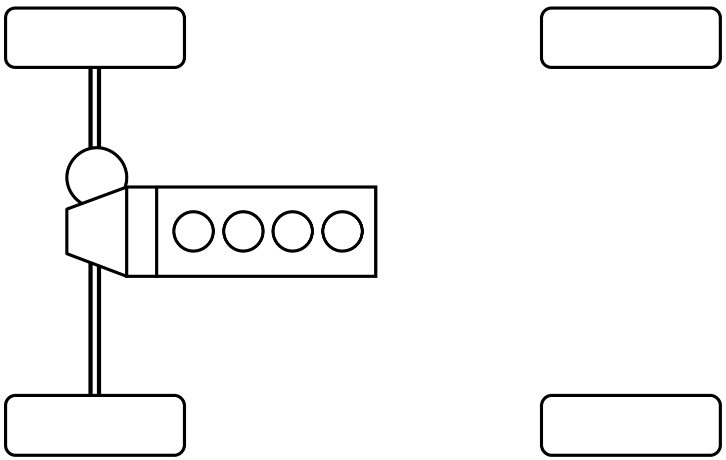


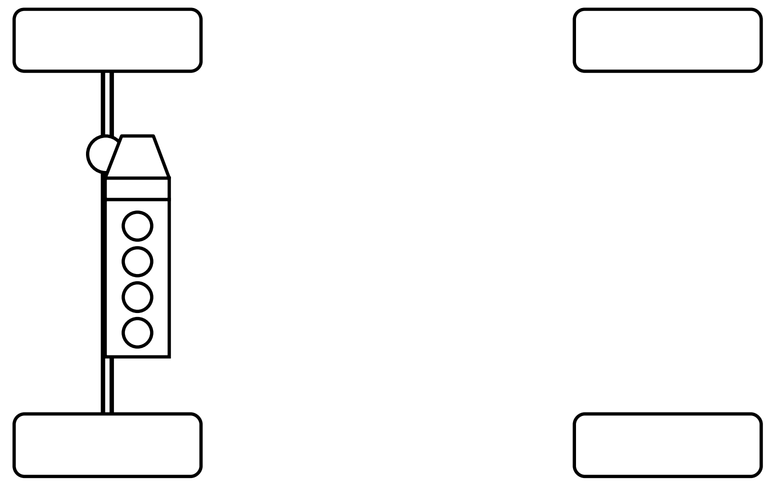


BMW Series 3

Alfa Romeo 75

Layout of driveline systems





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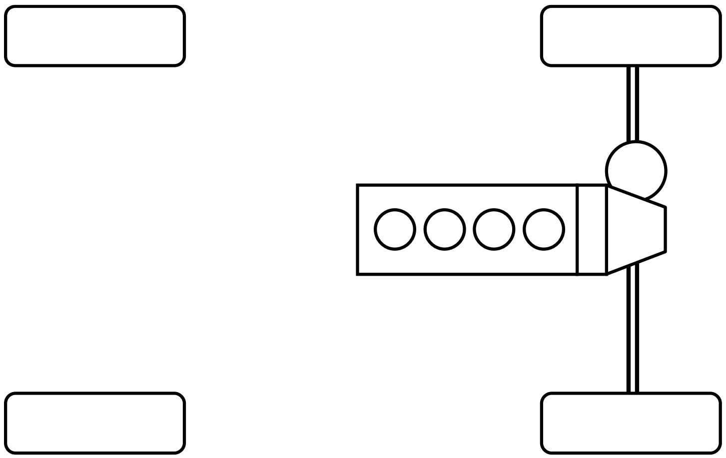
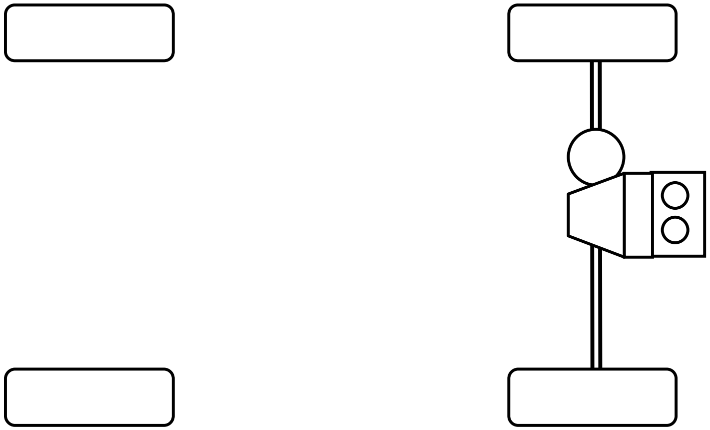
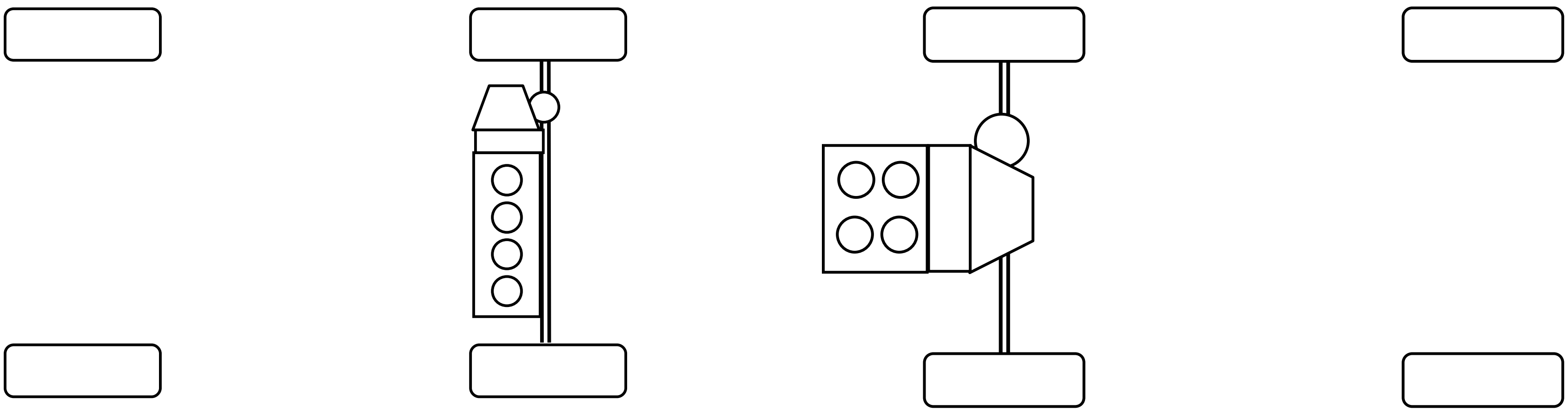




Citroën DS

Citroën 2CV

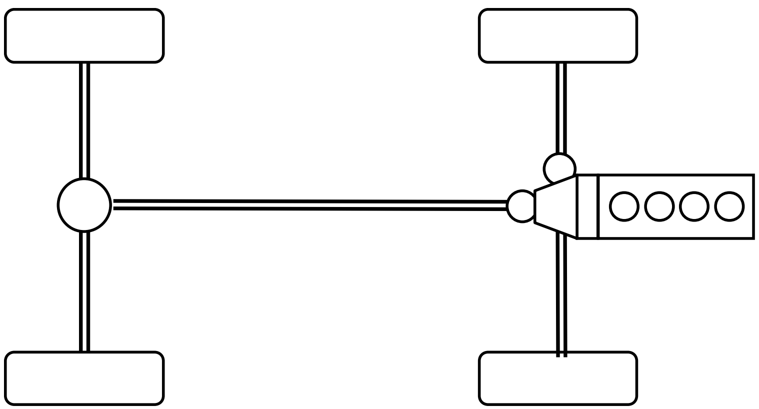
Configurations du système de transmission

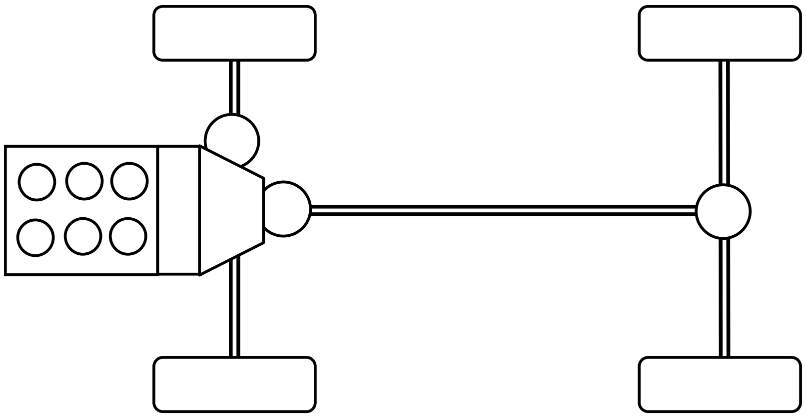


Renault Scenic

VW Beetle

Layout of driveline systems

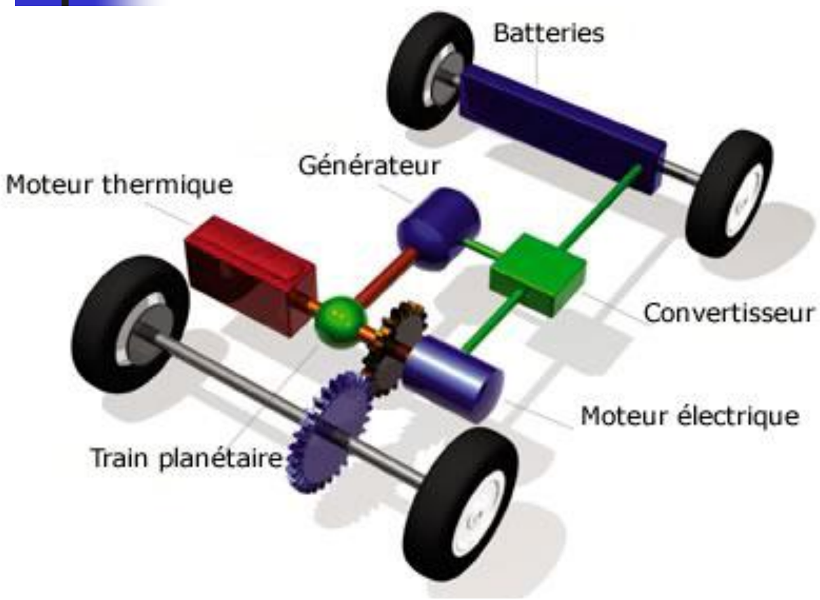


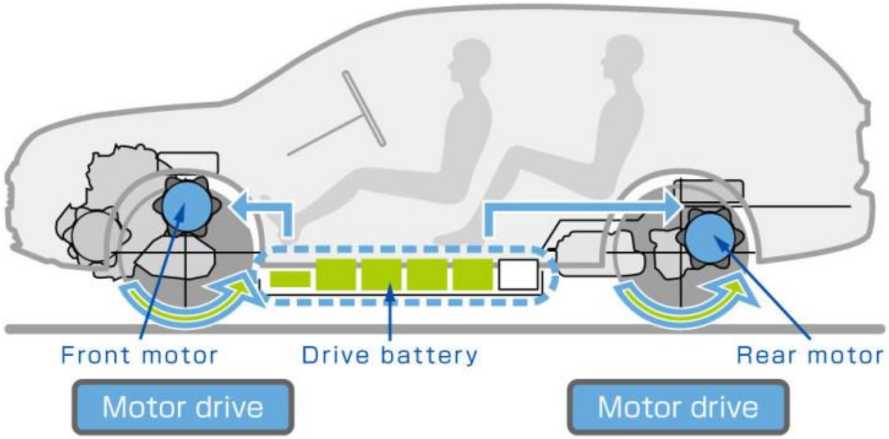


Audi Quattro

Porsche Carrera 4

Layout of e-driveline systems





Toyota Prius

Mitsubishi Outlander PHEV

Usual reduction ratio systems

- Gear boxes
  - Spur gears / helical gears
  - Synchromesh
  - Automatic gear boxes using planetary gears
  - Continuous variables transmissions
  - Infinitely variables transmissions
- Power split systems
  - Differentials
  - Transfer boxes
- Other systems
  - Hydrostatic reduction
  - Hydro mechanical systems
  - Electrical systems

PERFORMANCE SPECIFICATIONS

Newton's law of motion

- Newton's law for longitudinal motion:

$$\boxed{F_T = F_{AERO} + F_{RR} + mg\sin\theta + m_e\frac{dV}{dt}}$$

- The traction force F_T is used to face the resistance forces and to accelerate the vehicle

- Driving resistance forces:
  - Aerodynamics forces
  - Rolling resistance forces
  - Slope forces

Driving resistance forces

- Aerodynamic drag

$$\boxed{F_{AERO} = \frac{1}{2}\rho S C_x\, V^2}$$

- Rolling resistance forces

$$\boxed{F_{RR} = mg\cos\theta\; f_{RR}}$$

- Slope resistance

$$\boxed{F_{SLOPE} = mg\sin\theta}$$

Aerodynamic drag coefficient of automobiles

TABLE 3.3 Values of Aerodynamic Resistance Coefficient for Various Types of Vehicle

Vehicle Type	Aerodynamic Resistance Coefficient C_D
Passenger cars	0.3–0.52
Vans	0.4–0.58
Buses	0.5–0.8
Tractor–semitrailers	0.64–1.1
Truck–trailers	0.74–1.0

Source: Reference 3.12,

(Wong Table 3.1)

Coefficients et puissances de pénétration dans l'air de véhicules de différentes formes

		Coefficient de pénétration dans l'air c_x	Puissance de pénétration dans l'air en kW, valeurs moyennes pour $A = 2$ m² et différentes vitesses[1])			
			40 km/h	80 km/h	120 km/h	160 m/h
	Cabriolet décapoté	0,5 ... 0,7	1	7,9	27	63
	Limousine	0,5 ... 0,6	0,91	7,2	24	58
	Berline	0,4 ... 0,55	0,78	6,3	21	50
	Coupé; phares et pare-chocs intégrés dans la coque, roues recouvertes, plancher caréné, circulation optimisée de l'air de refroidissement.	0,3 ... 0,4	0,58	4,6	16	37
	Phares et toutes les roues intégrés dans la coque; plancher recouvert	0,2 ... 0,25	0,37	3,0	10	24
	Forme K (faible maître-couple)	0,23	0,38	3,0	10	24
	Forme profilée	0,15 ... 0,20	0,29	2,3	7,8	18
Camions, trains routiers		0,8 ... 1,5	–	–	–	–
Motocycles		0,6 ... 0,7	–	–	–	–
Autobus		0,6 ... 0,7	–	–	–	–
Autobus de forme aérodynamique		0,3 ... 0,4	–	–	–	–

[1]) sans vent contraire ($v_0 = 0$)

Estimation of rolling resistance coefficient

- A typical formula given by Wong

  Radial tires for passenger cars with a nominal inflation pressure p and smooth road profile:

$$f_{RR} = 0,0136 \; + \; 0,4\,10^{-7}\,V^2 \quad \text{V in km/h}$$

- Approximation provided by tables (ex Automotive handbook, Bosch)

Road surface	Coefficient of rolling resistance *f*
Pneumatic car tires on	
Large sett pavement	0.015
Small sett pavement	0.015
Concrete, asphalt	0.013
Rolled gravel	0.02
Tarmacadam	0.025
Unpaved road	0.05
Field	0.1...0.35
Pneumatic truck tires on concrete, asphalt	0.006...0.01
Strake wheels in field	0.14...0.24
Track-type tractor in field	0.07...0.12
Wheel on rail	0.001...0.002

$$f_{RR} = f_0 \; + \; f_2\,V^2$$

General expression of the driving resistance forces

- It comes

$$F_{RES} = F_{AERO} + F_{RR} + F_{SLOPE}$$

- Generic expression

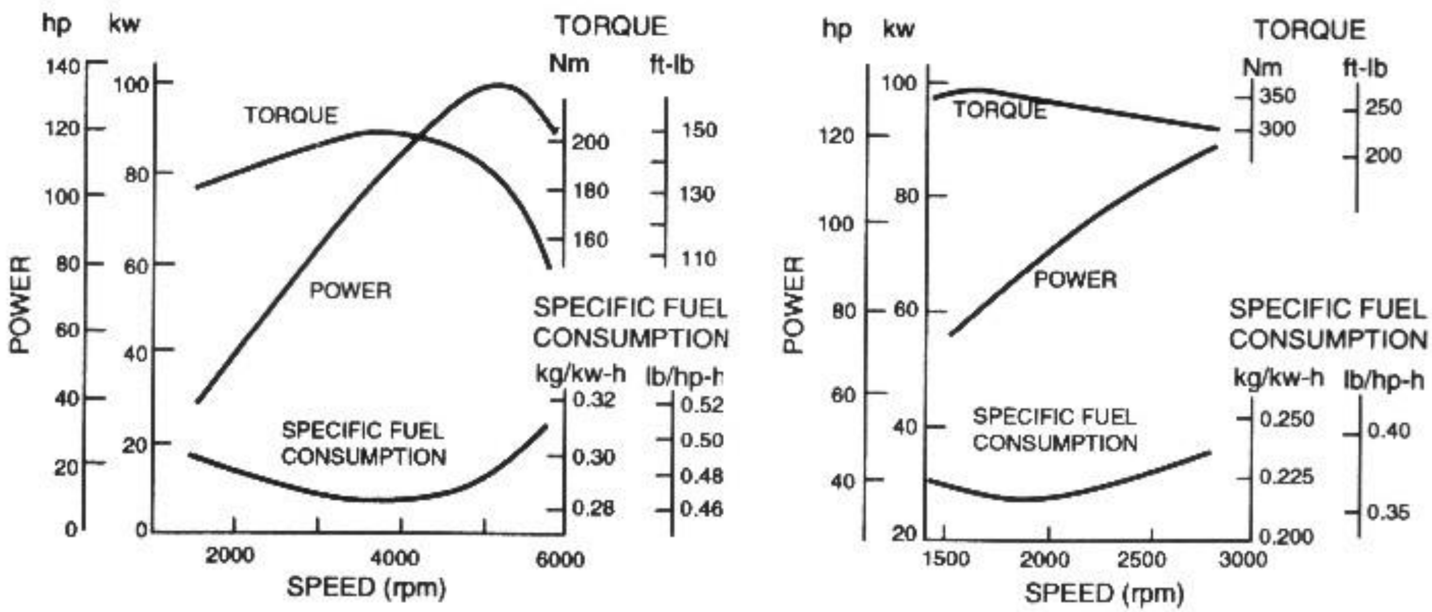
$$F_{RES} = A + B\,V^2$$

  - with A, B > 0

$$A = mg\cos\theta f_0 + mg\sin\theta$$
$$B = 1/2\rho S C_x + mg\cos\theta\, f_2$$

IC engines (gasoline and Diesel)

- ICE are the most usual power plants for road vehicles
- The torque and power curves with respect to engine rotation speed are typically given by



Gasoline Gillespie, Fig. 2.1 Diesel

Tractive power and forces

POWER AT WHEELS

- The power that comes to the wheels is the engine power multiplied by the efficiency of the transmission efficiency η

$$\mathcal{P}_w = \eta \, \mathcal{P}_p$$

- The driveline efficiency η :

$$\eta = \eta_{clutch} \, \eta_{box} \, \eta_{dif} \, \eta_{joints}$$

- Order of magnitude:
  - Manual gear box with direct connection: 100%
  - Manual gear box with two pairs of gears reduction: 97,5%
  - Differential and transfert boxes with 90° angle change: 97,5%

Power and tractive effort at wheels

Global efficiency in various situations

	Gear ratio	Longitudinal layout	Transversal layout
Friction clutch	Normal	0,95	0,96
	Direct	0,975	x
Hydraulic coupling	Normal	0,86	0,865
	Direct	0,88	x

Tractive power and effort at wheels

TRACTIVE FORCE AT WHEELS

- Traction power at engine and at wheels

$$\mathcal{P}_w = F_w \, v \qquad\qquad \mathcal{P}_p = C_p \, \omega_p$$

- Reduction ratio i>1

$$\omega_p = i \, \omega_w \qquad\qquad i = i_{box} \, i_{dif}$$

- Vehicle velocity and engine rotation speed

$$v = \omega_w \, R_e$$

Traction power and forces at wheels

TRACTIVE FORCE AT WHEELS

- It comes

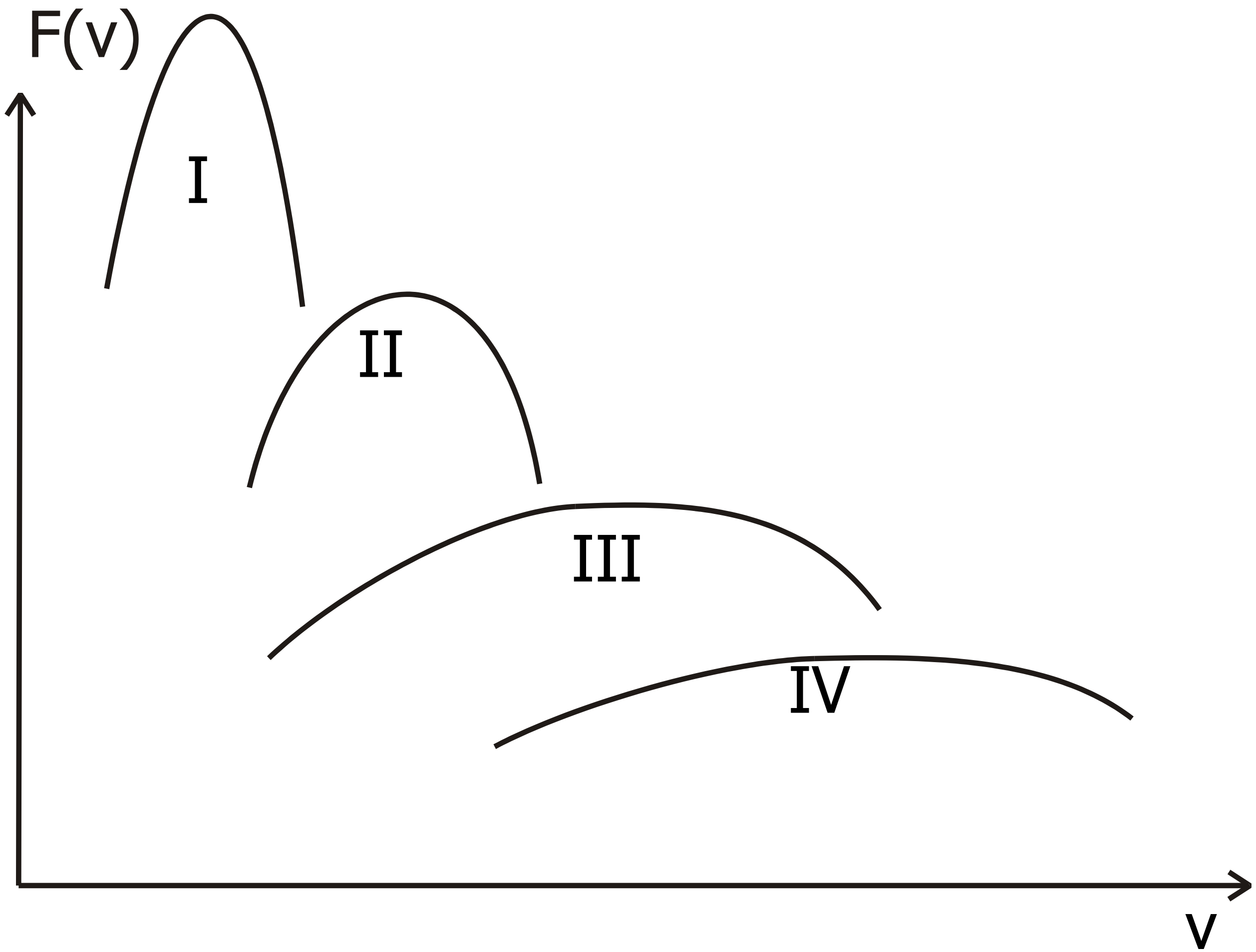
$$F_w\, v \;=\; \eta\;\, C_p\, \omega_p$$

$$F_w \;=\; \eta\;\, C_p\, \frac{\omega_p}{v}$$

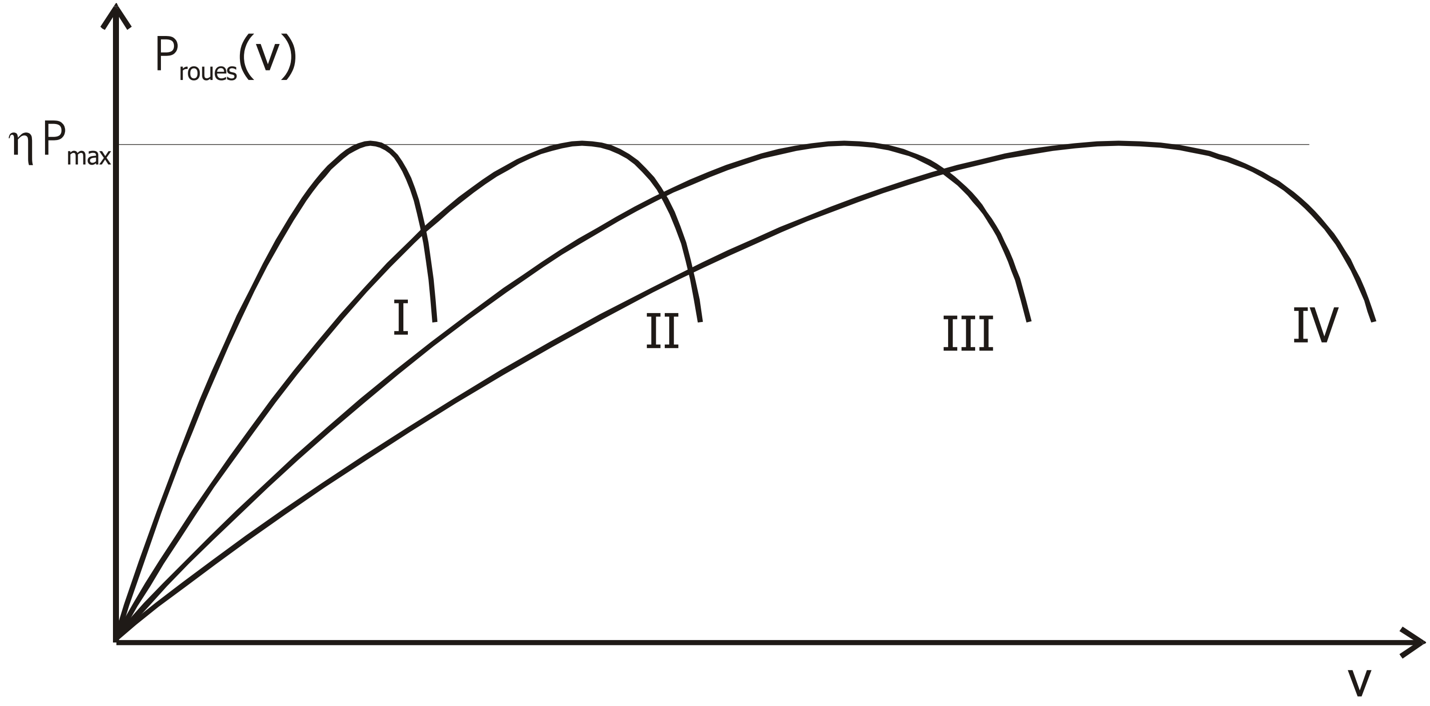
- So we get the tractive force at wheels

$$\boxed{F_w \;=\; \eta\;\, C_p\, \frac{\omega_p}{\omega_w R_e} \;=\; \eta\;\, C_p\, \frac{i}{R_e}}$$

Traction power and forces at wheels



Traction power and forces at wheels



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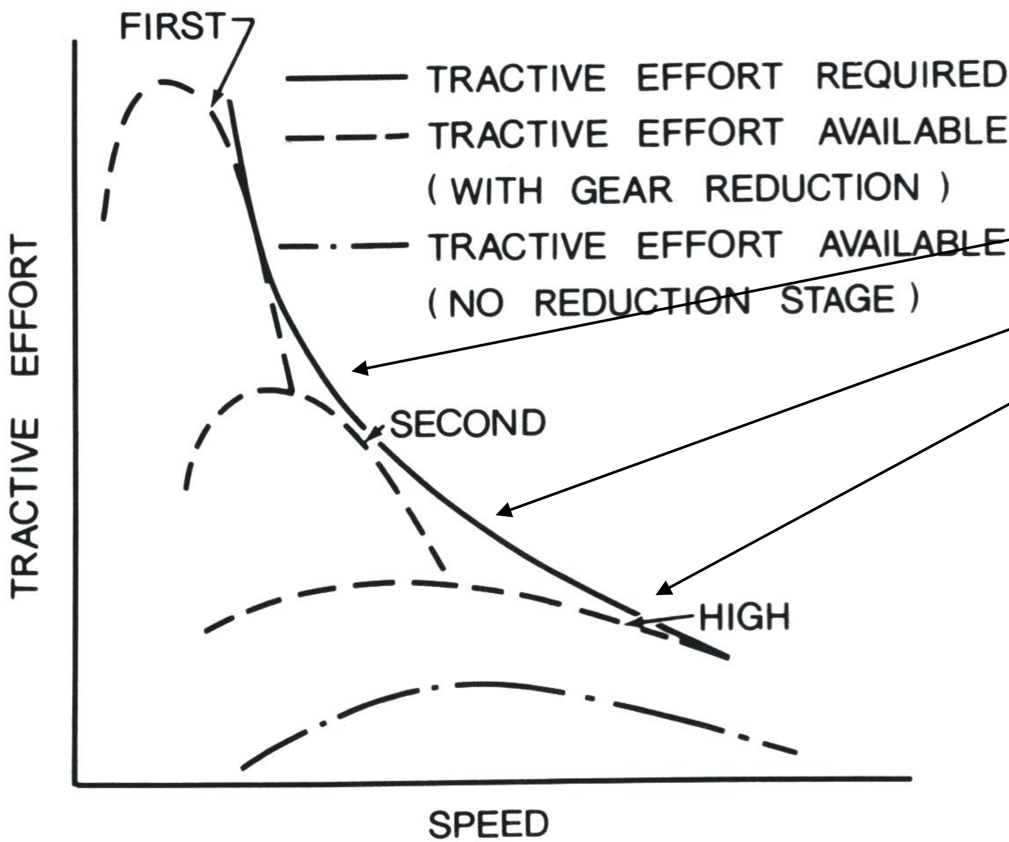
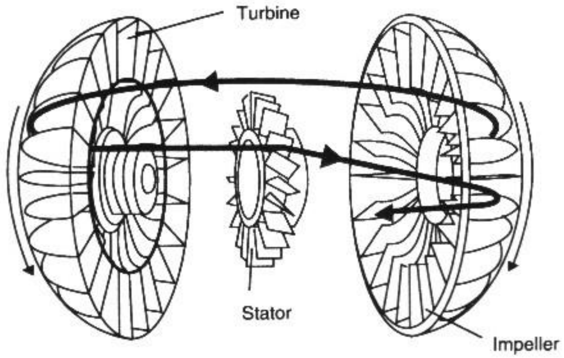
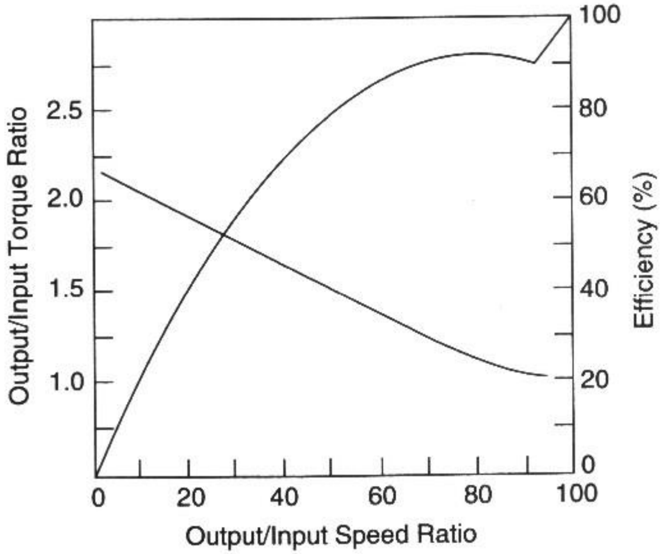


Envelop of the tractive forces for the different gear rations → max constant power ~P_{max}/v

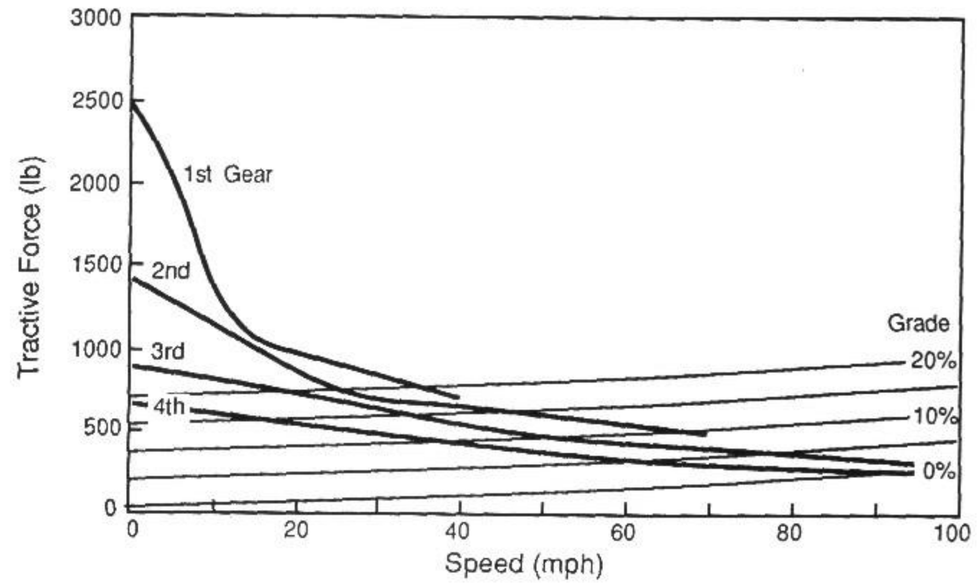
Tractive forces for a car
Wong Fig 3.25

Traction power and forces at wheels



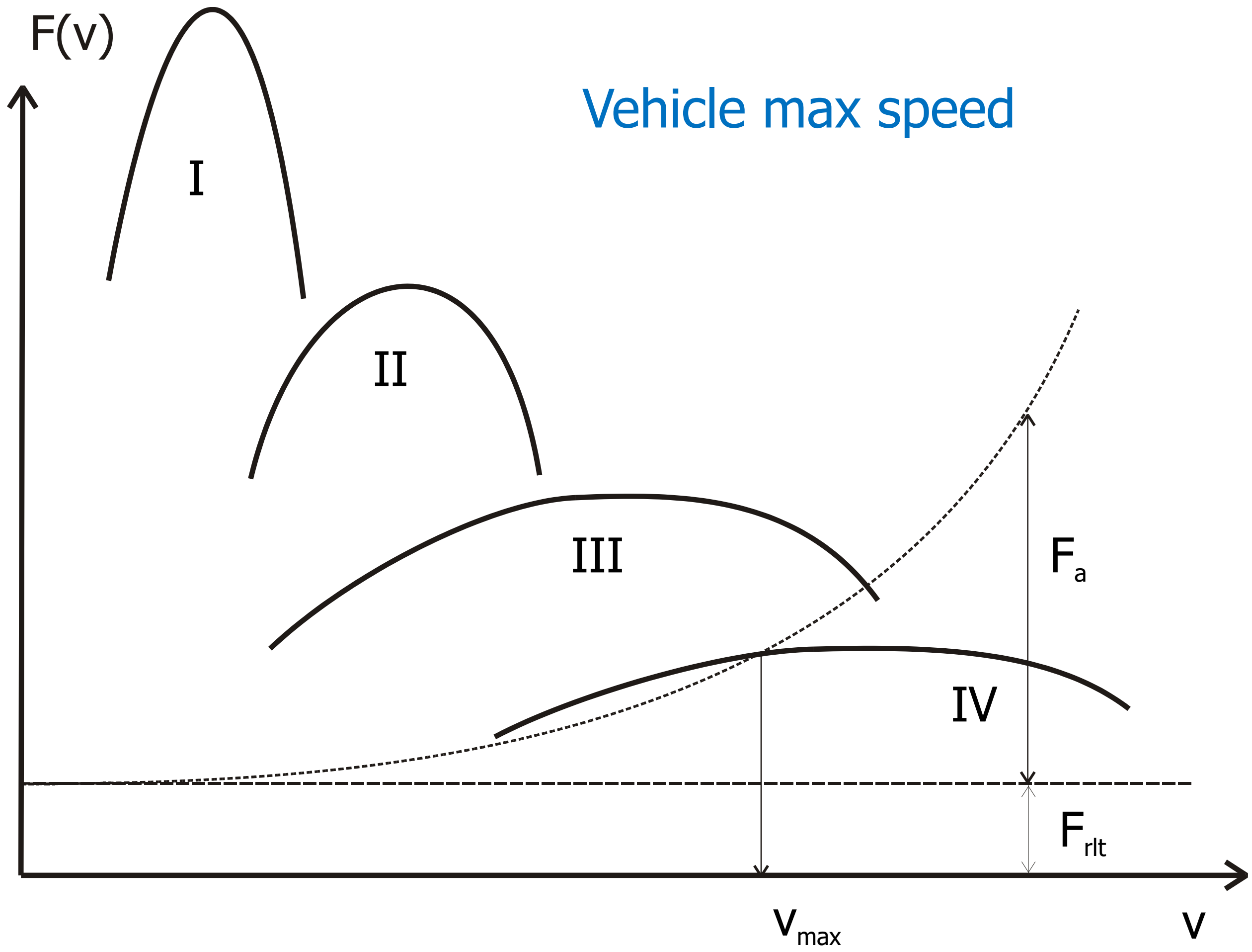


Automatic gear box



Gillespie, Fig 2.5, 2.6

Vehicle performance of the force diagram



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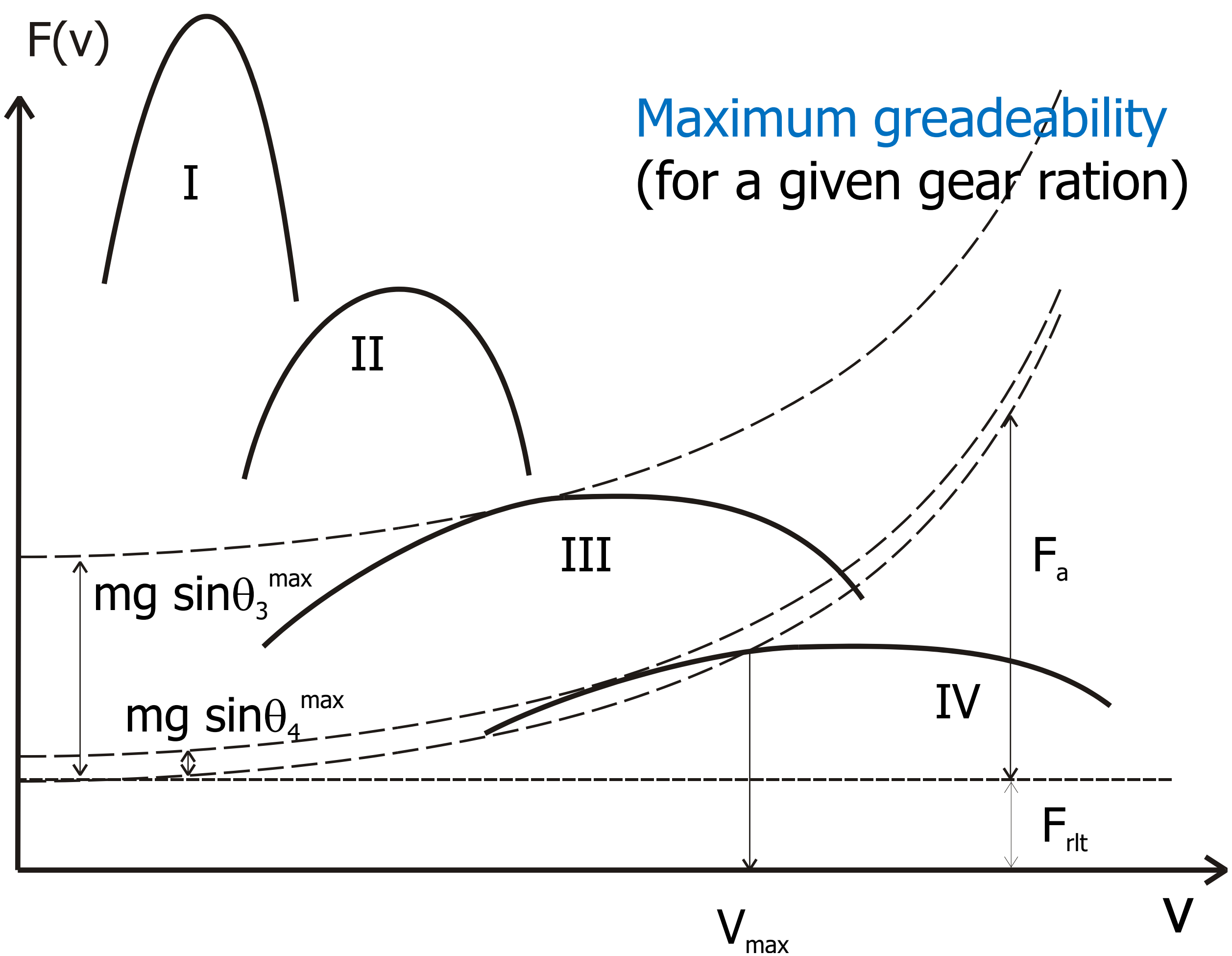

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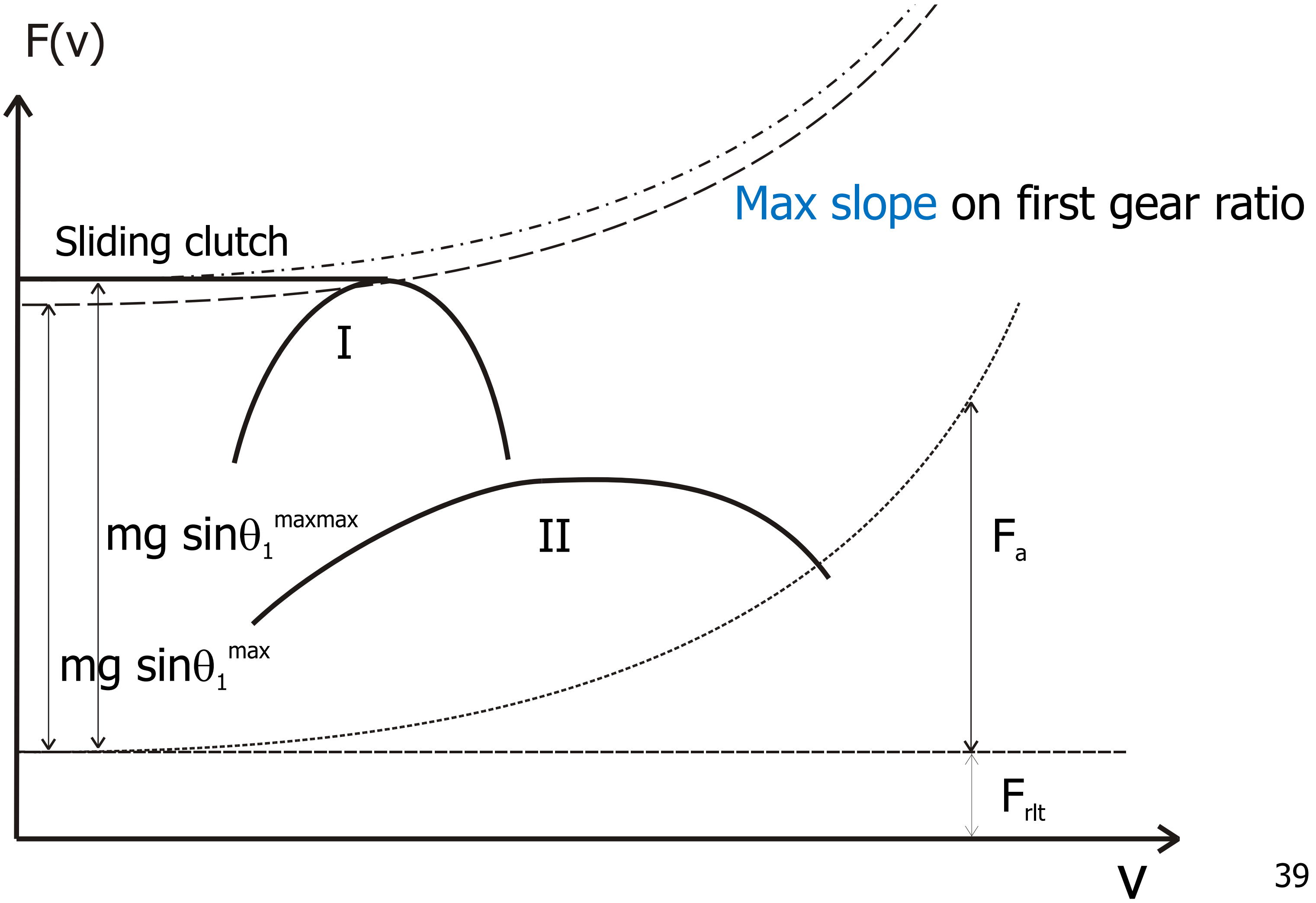
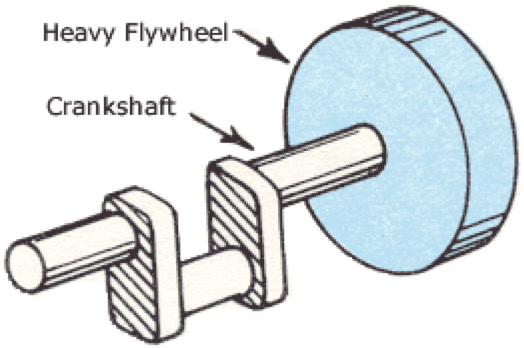
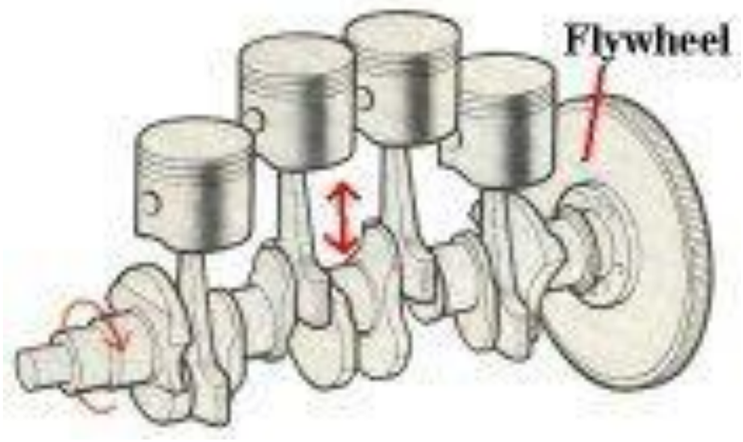


ENGINE FLYWHEEL

ENGINE FLYWHEEL

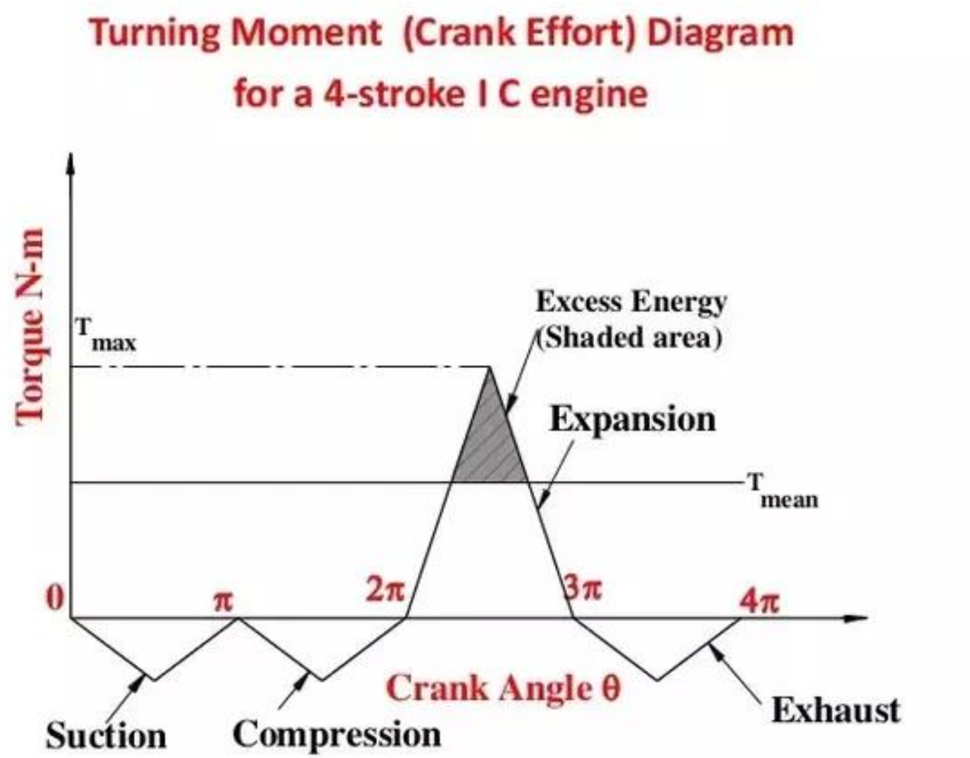
- The engine flywheel is involved in several functions of the engine and of the driveline
- It enables a certain leveling of the engine rotation speed due to uneven engine working strokes
- It is also a connection offered to the starter electric motor
- It is also the foundation for several other parts
- For dry friction clutches, the friction plate is directly engaged onto the flywheel





ENGINE FLYWHEEL

- Fly wheel enables the leveling of the engine rotation speed due to uneven engine working strokes



ENGINE FLYWHEEL

- It is also a connection offered to the starter electric motor
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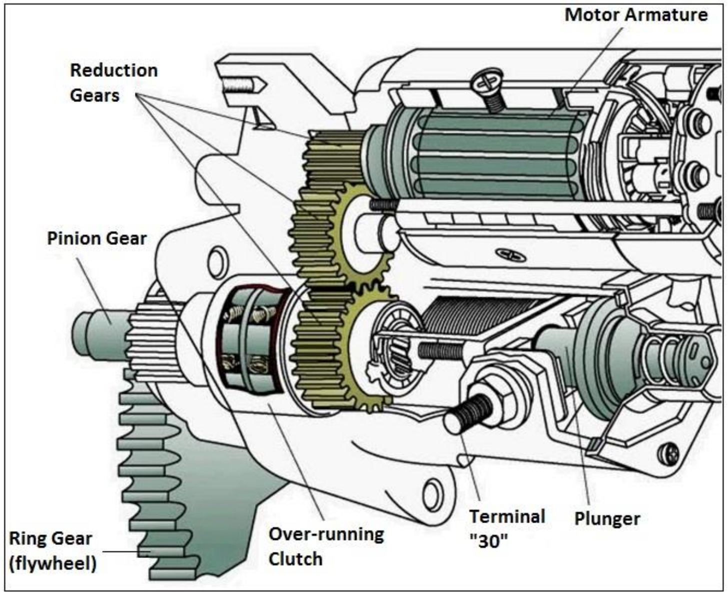
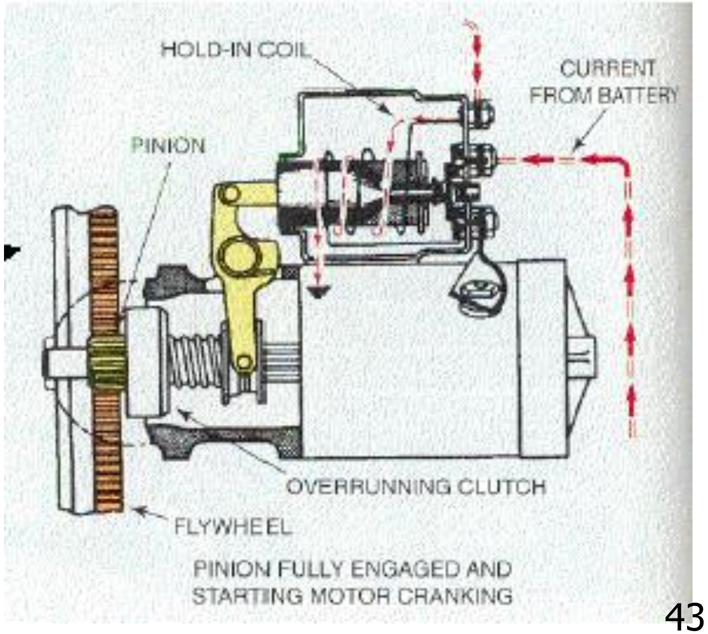
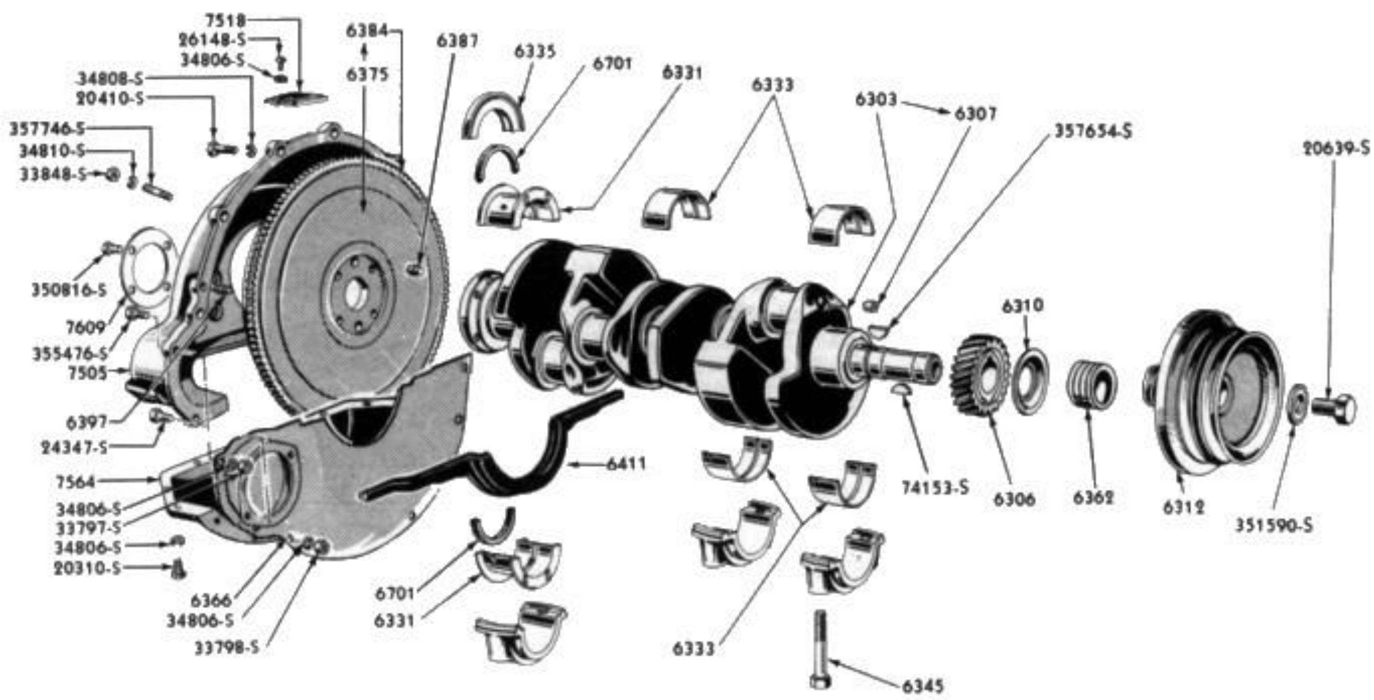




ENGINE FLYWHEEL

Ford Truck Crankshaft & Flywheel Assembly

1953 Trucks with 239 Flathead V8



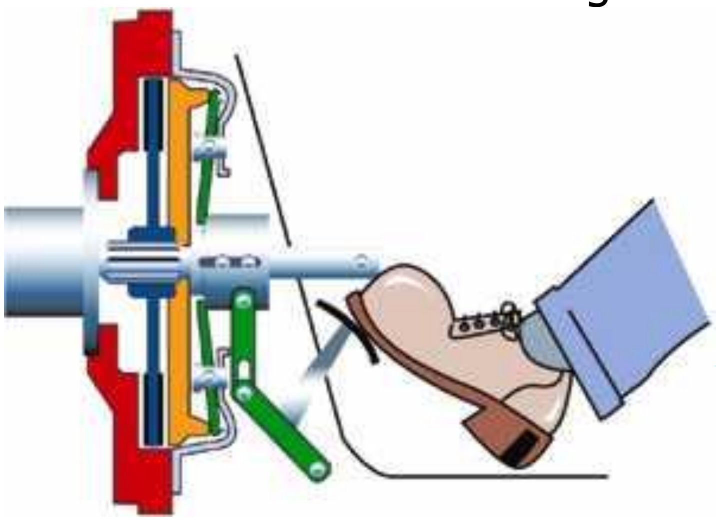
CLUTCH SYSTEMS

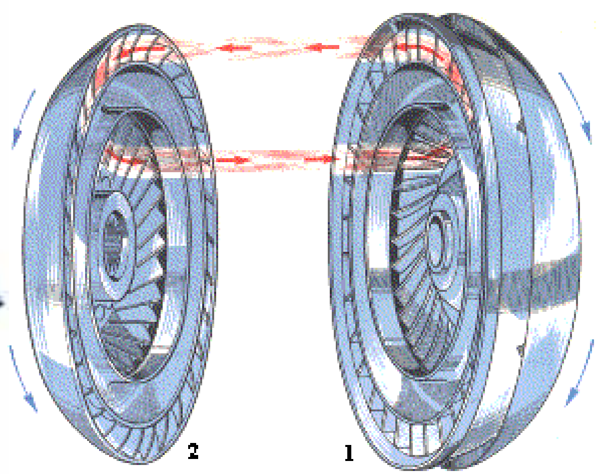
CLUTCH

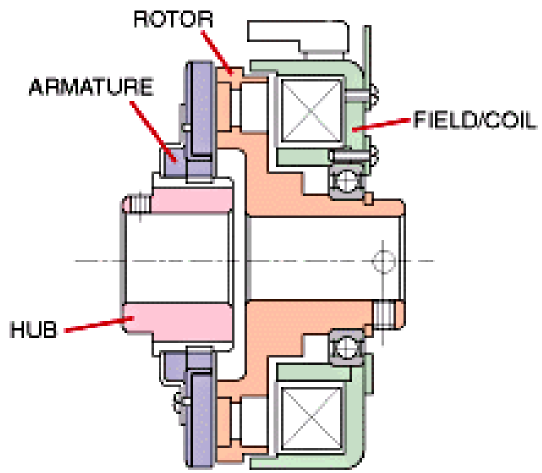
- Functions:
  - The clutch is necessary to connect / disconnect the engine and the wheels
  - In a vehicle, the clutch is used to transmit the power flowing from the engine to the wheels while enabling to disconnect it during gear changes
  - The clutch enables also to comply with engine idling speed while the vehicle is at rest without using the neutral position of the gear box

CLUTCH

- Different technologies of clutches
  - Friction clutches
    - With a manual command or with robotized command systems
    - Dry friction / Lubricated
    - Centrifugal coupler
  - Hydraulic torque converter
  - Electromagnetic clutches



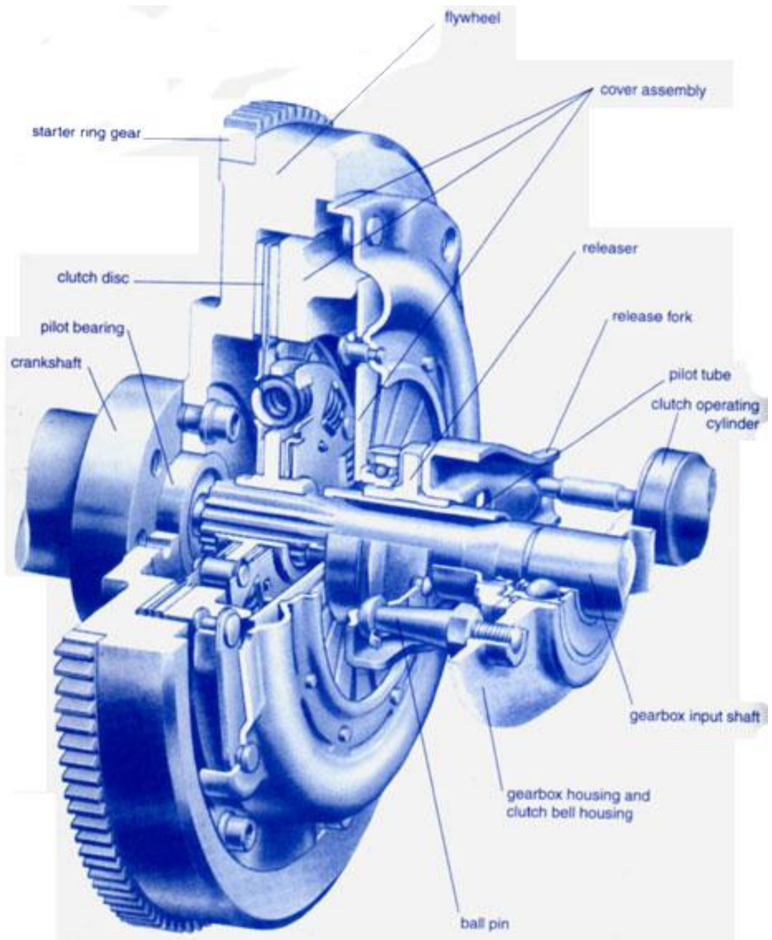




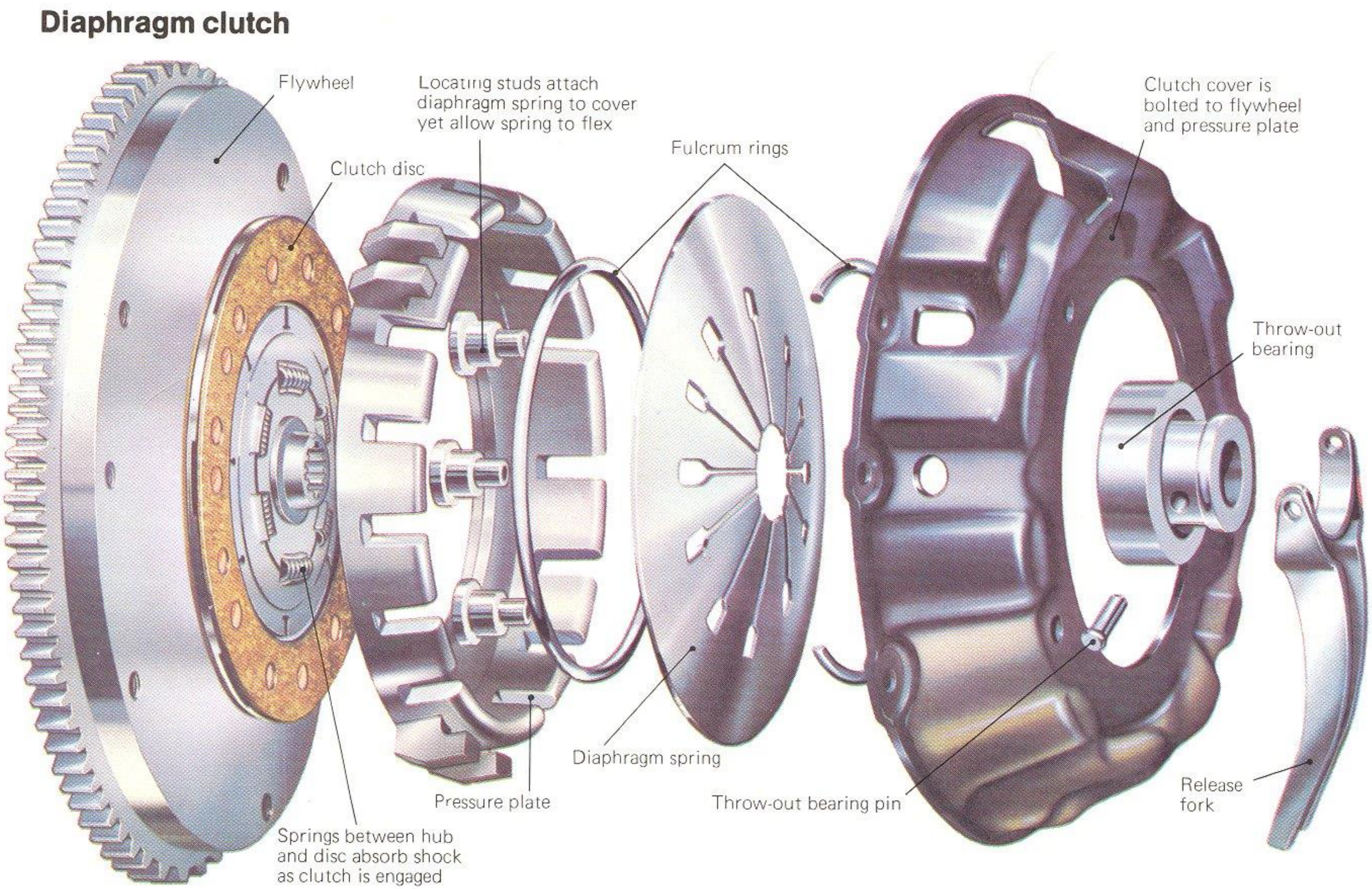
Dry friction clutch

- Components
  - Engine flywheel
  - Friction disk
  - Pressure plate
  - Actuation mechanism

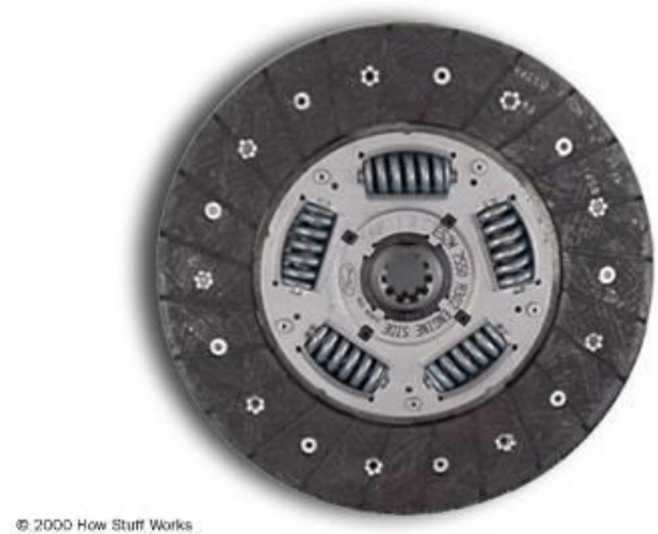
- Advantage:
  - Simplicity
  - High efficiency =100% when closed



Dry friction clutch



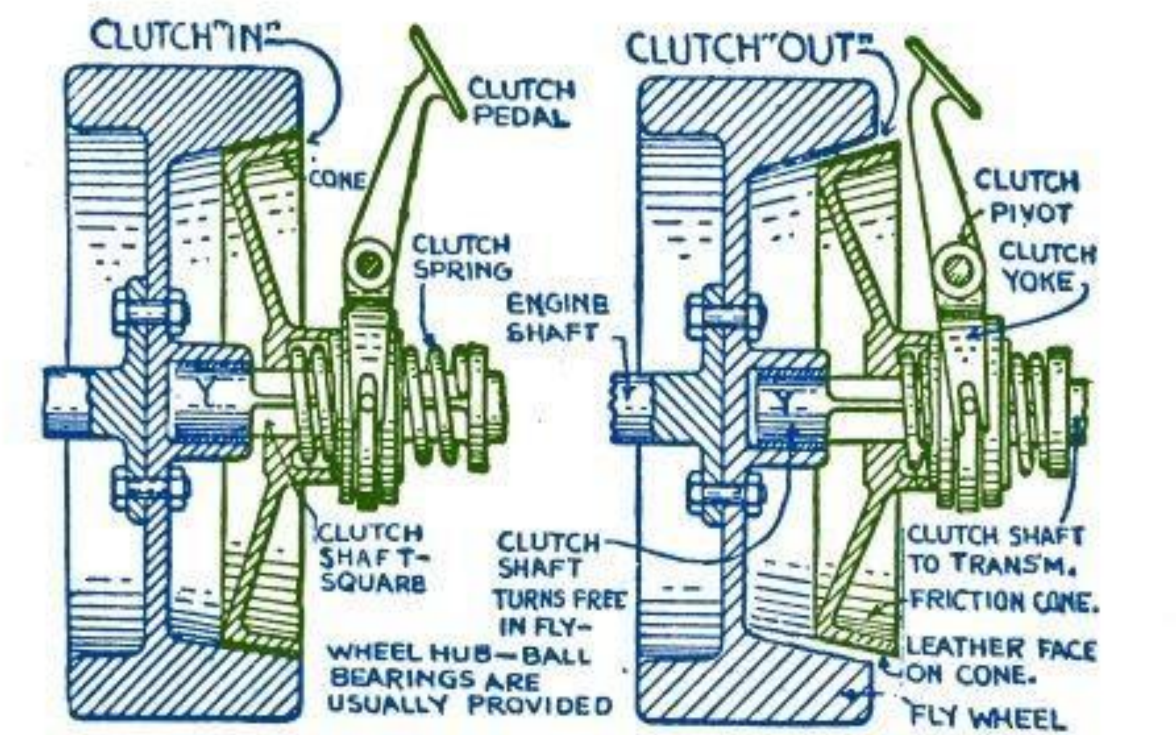
Dry friction clutch



Diaphragm spring and pressure plate

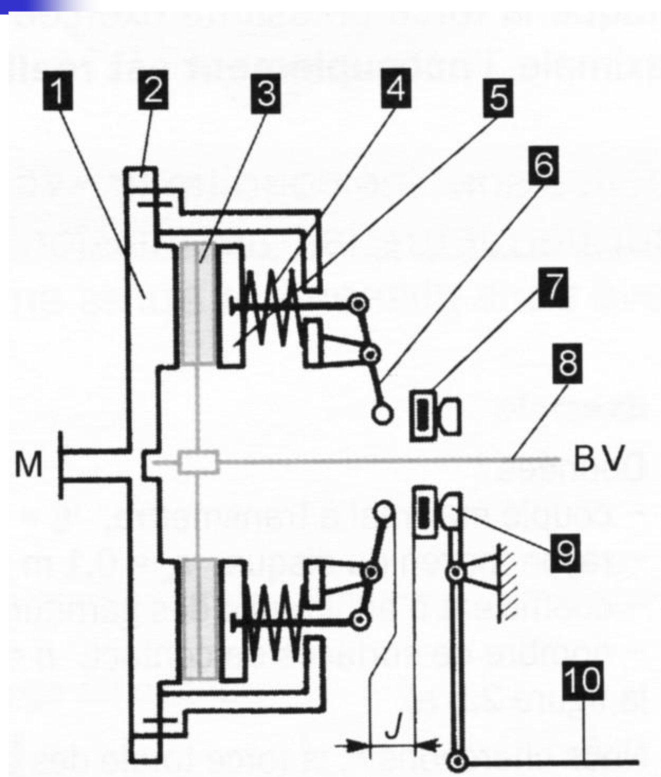
Friction plate

Dry friction clutch

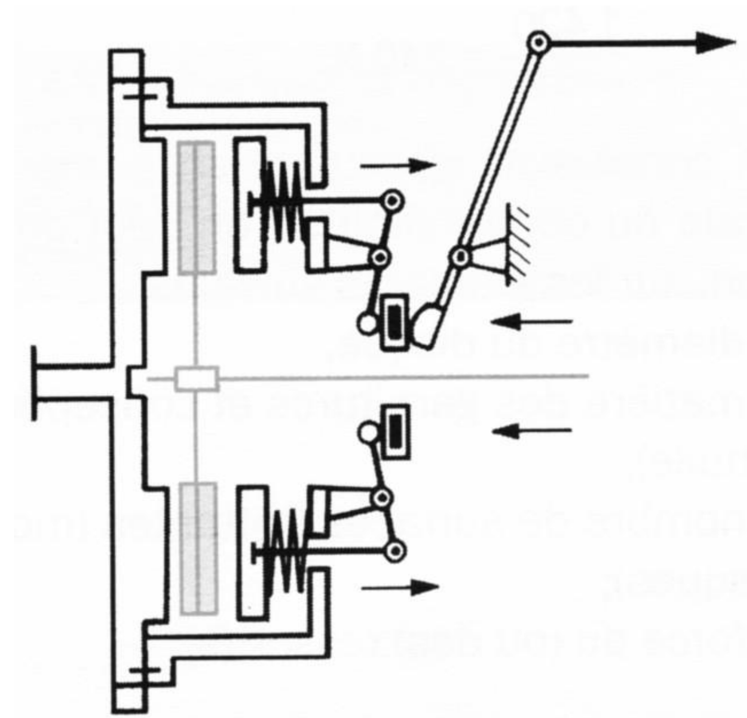


Conic clutch device : Old system

Dry friction clutch



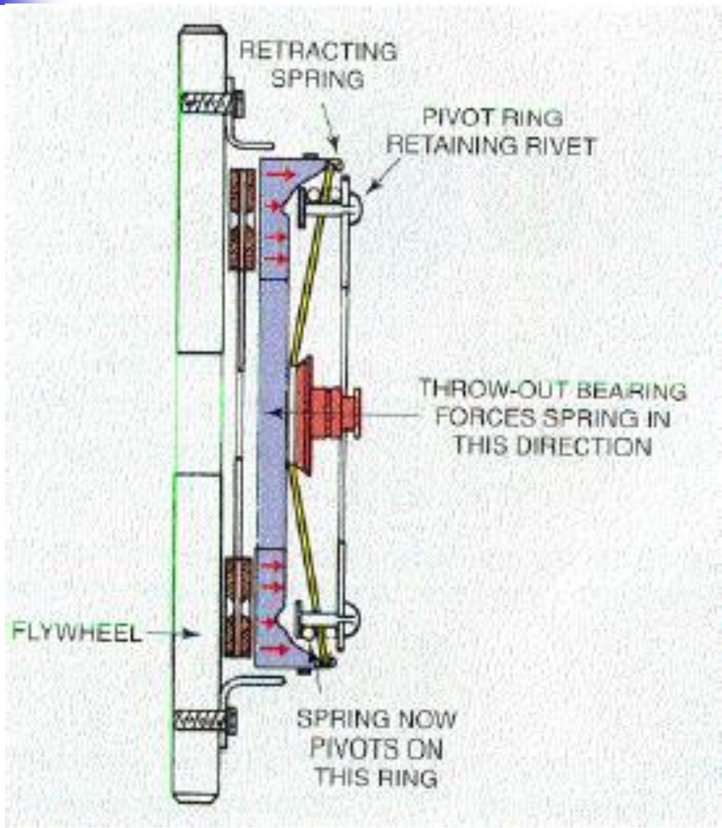
Clutch closed



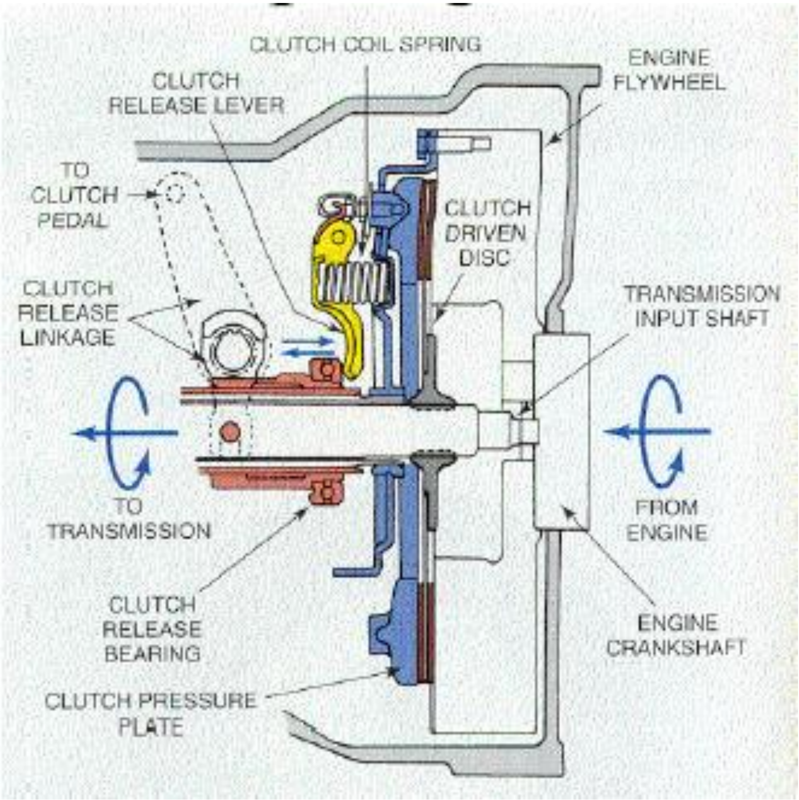
Clutch open

Plate clutch device : Modern system

Dry friction clutch



Diaphragm spring



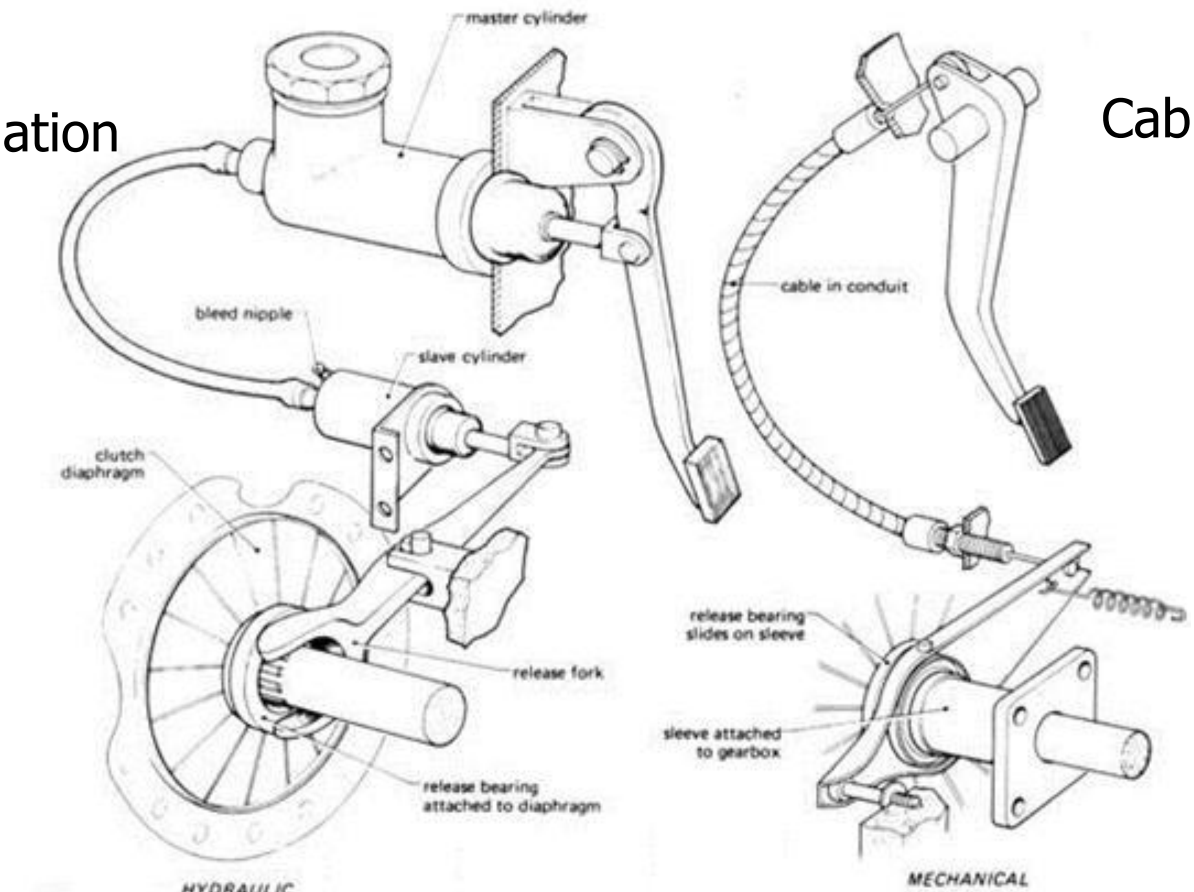
Helical spring system

Spring technologies: diaphragm vs helical springs

Dry friction clutch

Hydraulic actuation

Cable actuation

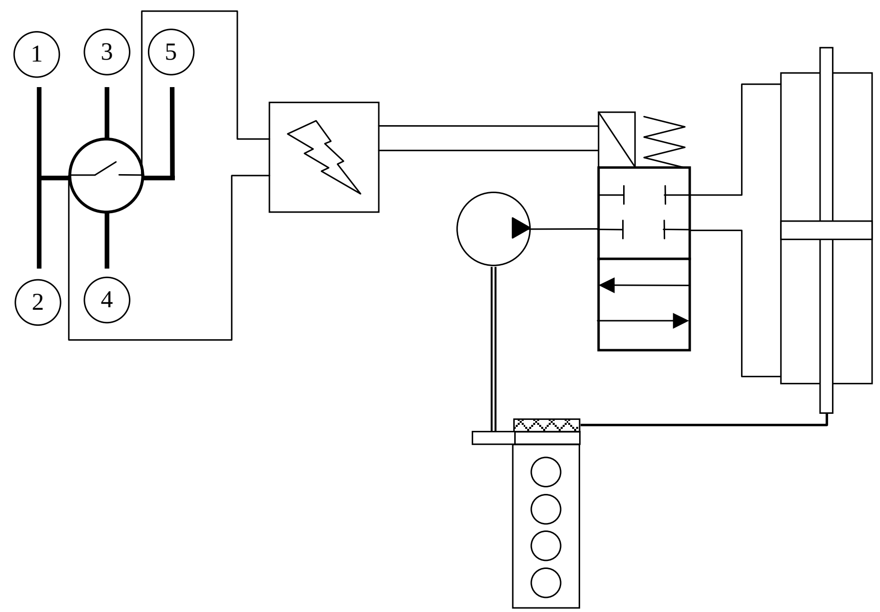


Clutch operating systems

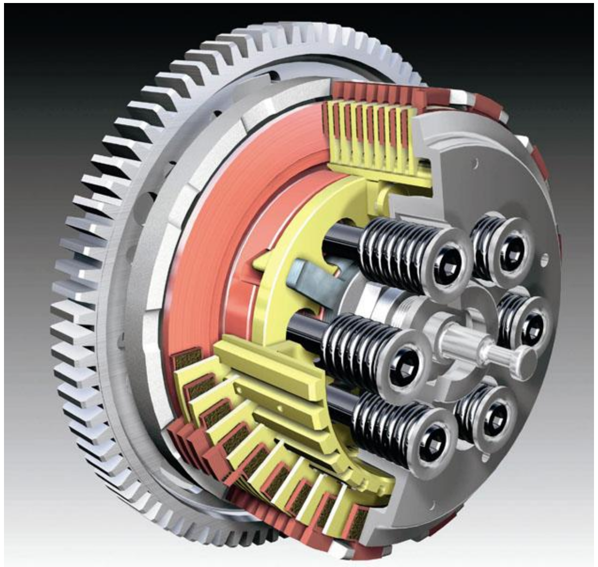
Actuation mechanism

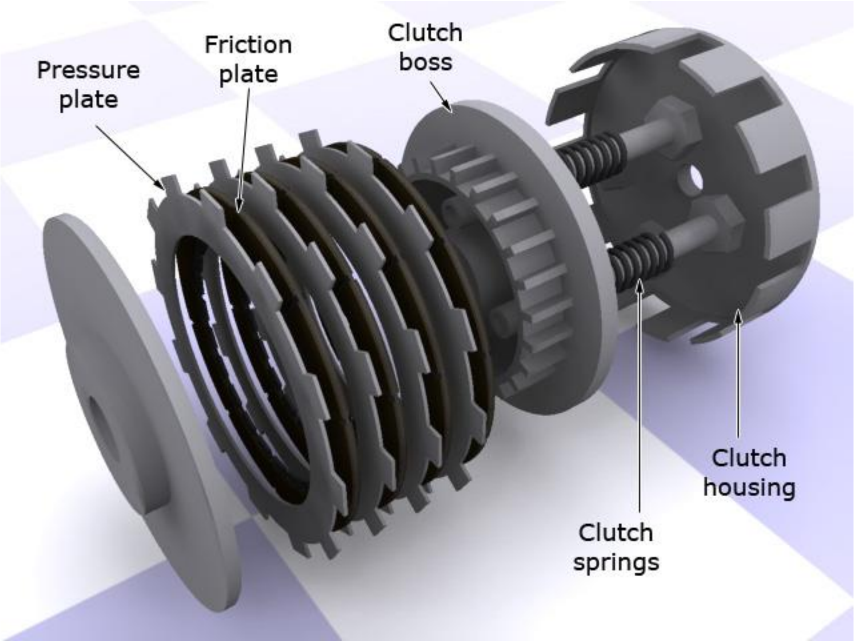
Dry friction clutch – robotic actuation

- Principle: replace the rigid body mechanism by an electric or hydraulic actuation system controlled by electro valves
- Advantages:
  - Simplicity
  - High efficiency = 100%
  - No clutch pedal
- Drawbacks:
  - Energy consumption of the actuation system
  - Feeling of a slow gear change time



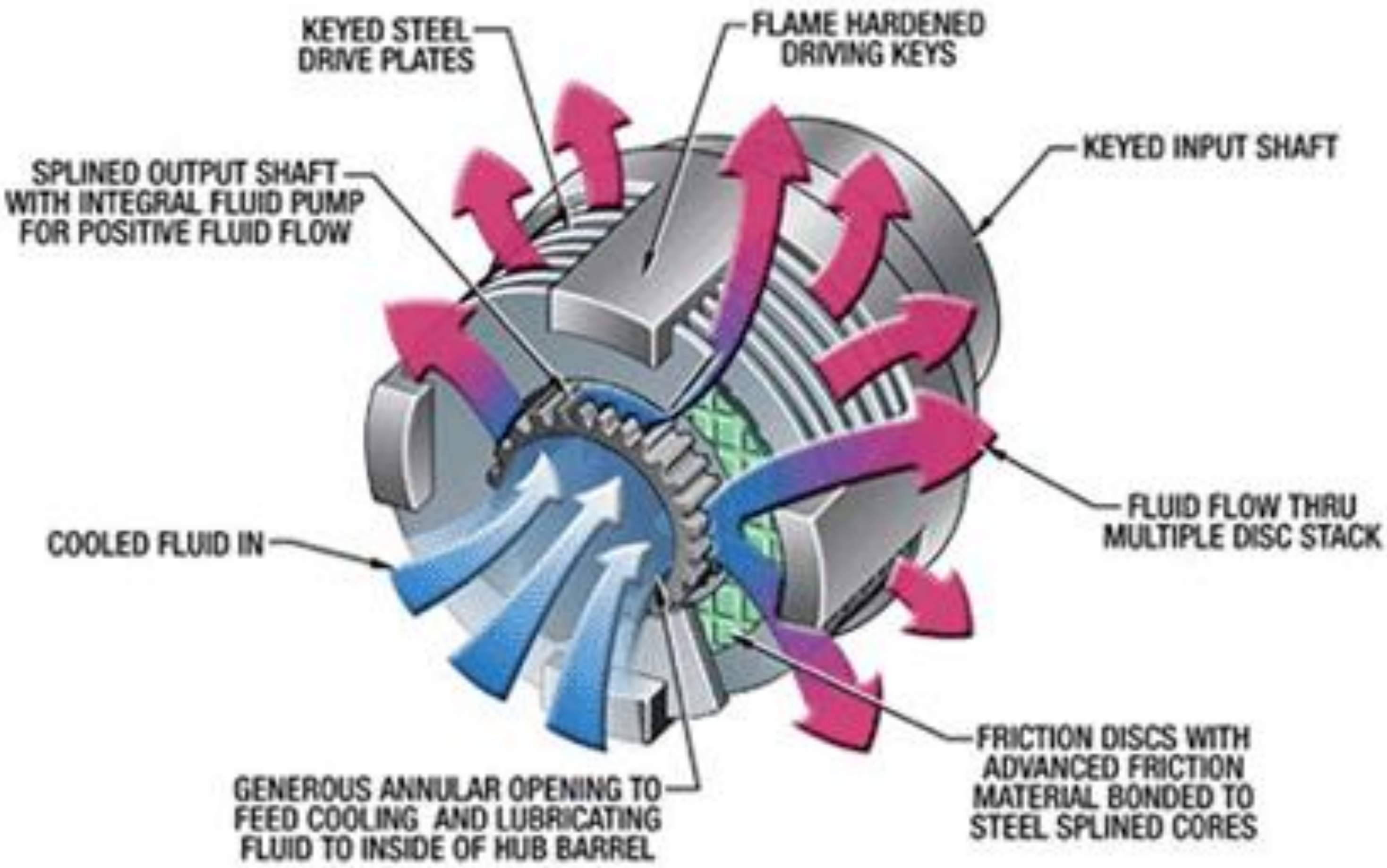
Multidisc clutch





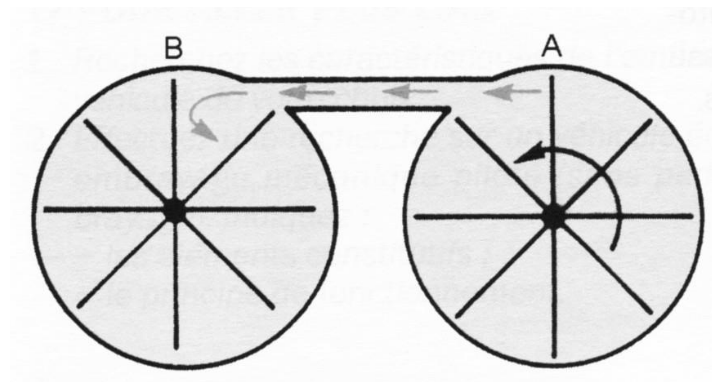
- Often used on motorbikes
- Can be lubricated or not
- More compact
- Oil ensures the evacuation of the heat generated

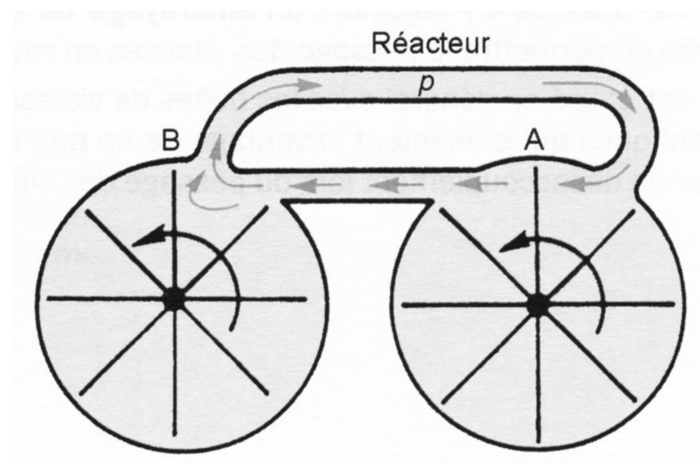
Multidisc clutch



Hydraulic transmission

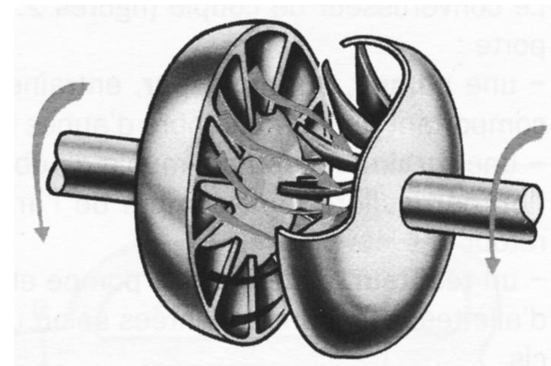
- Using the kinetic energy of the fluid (oil) to transfer without shock the power from the engine to the wheels while magnifying the torque
- The input wheel, the impeller acts as a pump and provides some kinetic energy and momentum to the working fluid
- The output wheel connected to the wheels acts as a turbine and recovers the kinetic energy from the fluid



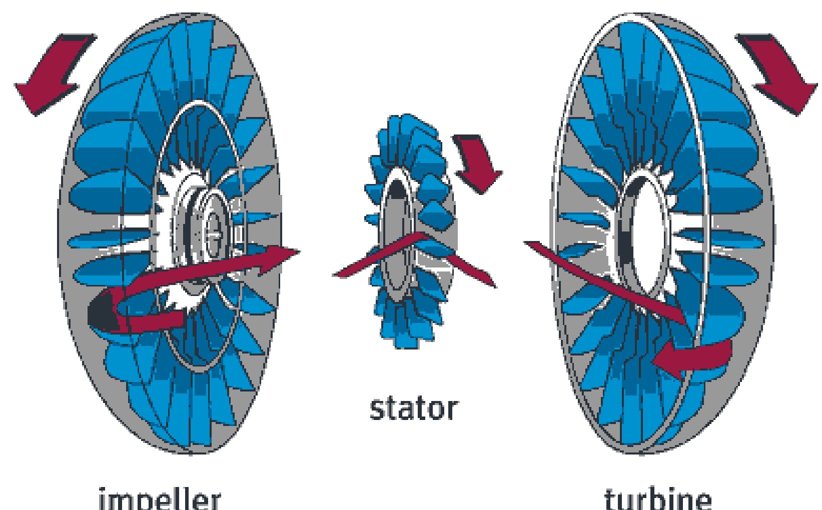


Hydraulic transmission

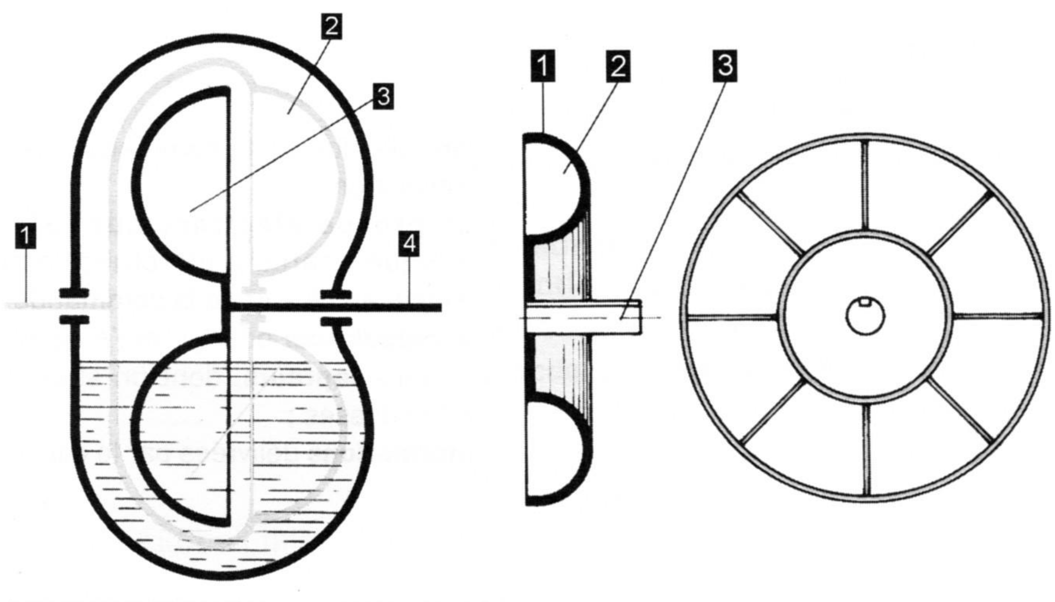
- One distinguishes:
- Torque couplers or hydraulic clutches:
  - Two identical elements facing each other: a pump and a turbine
  - Input and output torques are identical

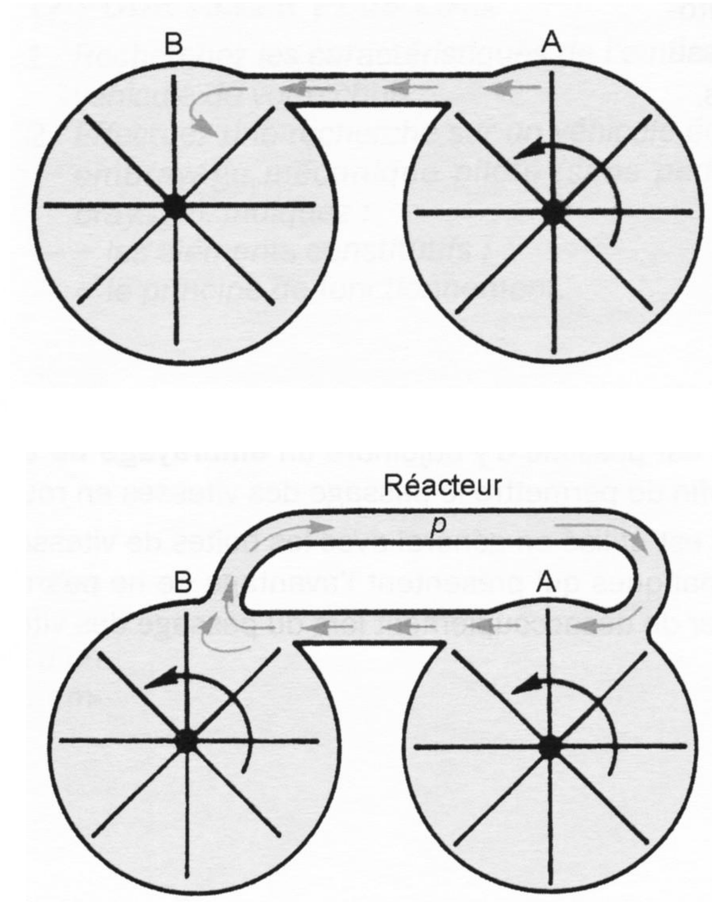


- Torque converters:
  - Include a pump and a turbine
  - A third element, the stator that creates a reaction torque when fixed, and free to rotate over a certain speed (free wheel).
  - Torque is magnified between input and output



Hydraulic coupling

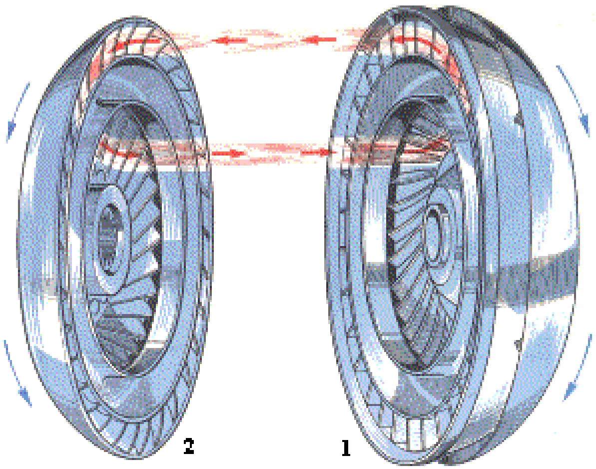




Principle of basic torque converter

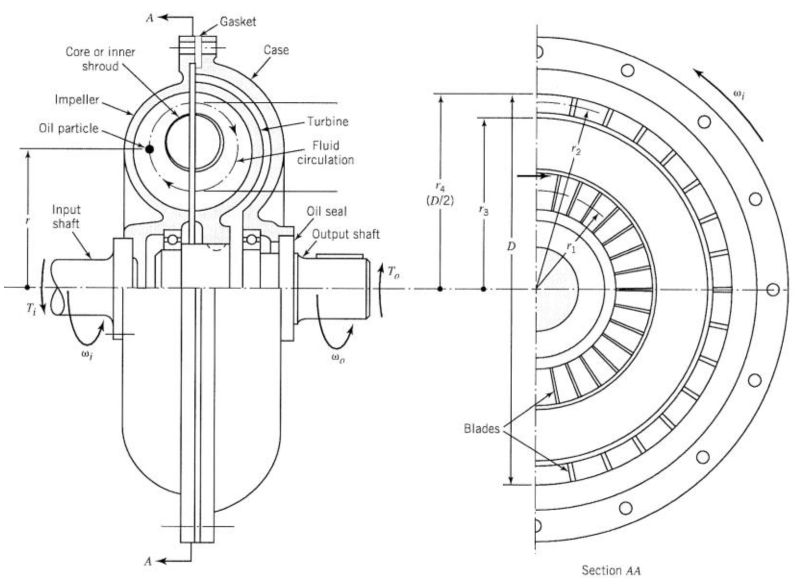
Hydraulic coupling

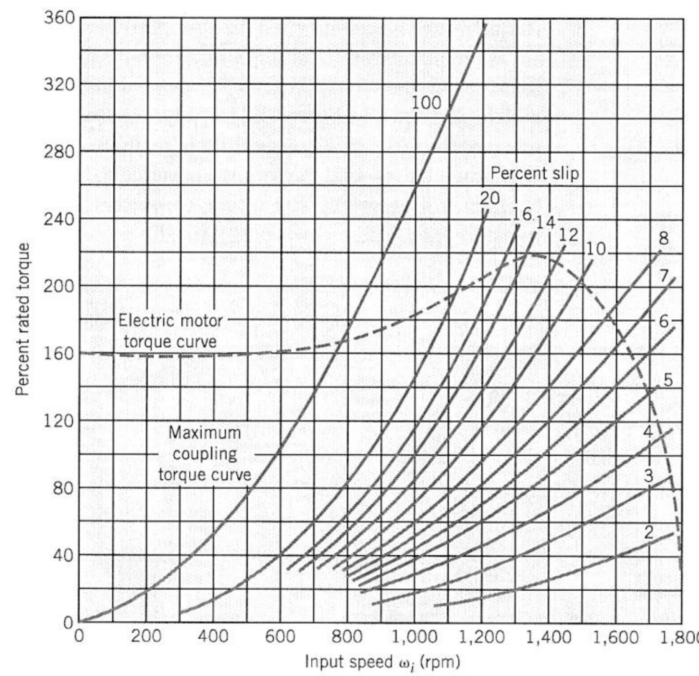
- The pump is driven by the engine.
- Oil is sent to the external diameters and leaves the pump with an axial speed V_a and a tangential speed V_t due to the velocity of the wheel.
- The fluid hits the blades of the turbine wheel and drives the rotation of the output shaft
- The kinetic energy produces a circumferential force F_t and an axial force F_a
- The oil follows the turbine walls and flows back to the pump through the central path



Hydraulic coupling

- Because of its working principle, the torque coupler naturally involves a slippage, that is difference of rotation speed between the input and output shafts
- Thus, it is well adapted to start functions.





Juvinal. Fig.19.10 and 19.11

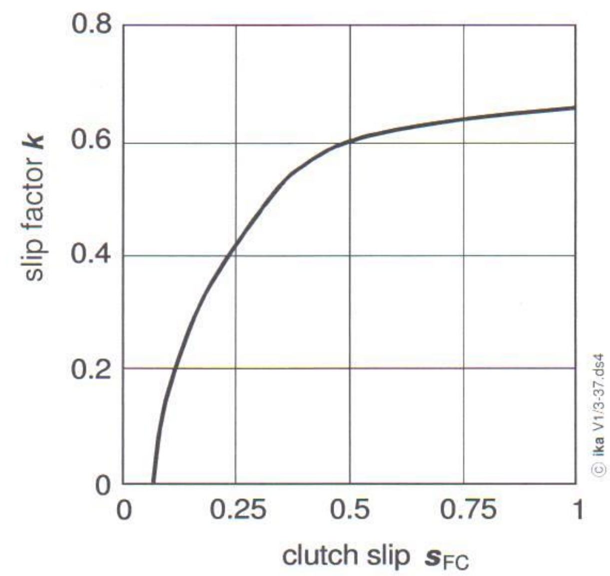
Hydraulic coupling

- The torque that can be transferred by the coupler is given by:

$$T = k\,\rho\,\omega_p^2\,D^5$$

  - k : sliding factor
  - ρ : fluid density (oil=870 kg/m³)
  - ω_p : rotation speed of the pump
  - D : clutch diameter

- The sliding factor depends on the design and on the slip of the clutch



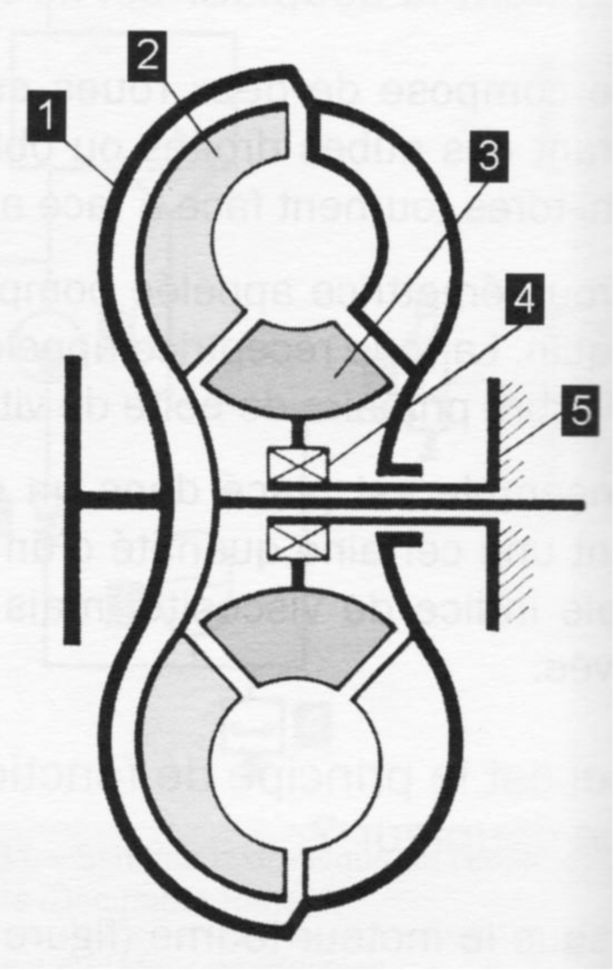
Hydraulic torque converter

1: Impeller
2: Turbine
3: Stator device

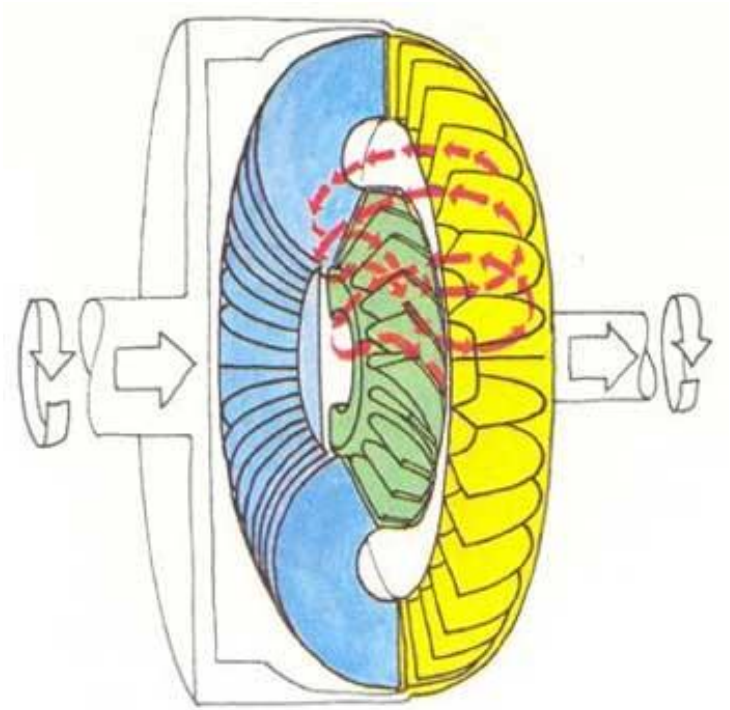
- To increase the output torque beyond the input torque, it is necessary to add a third torque-contributing element: the stator
- The stator acts a reaction element
- The reaction torque of the stator is there to magnify the output torque

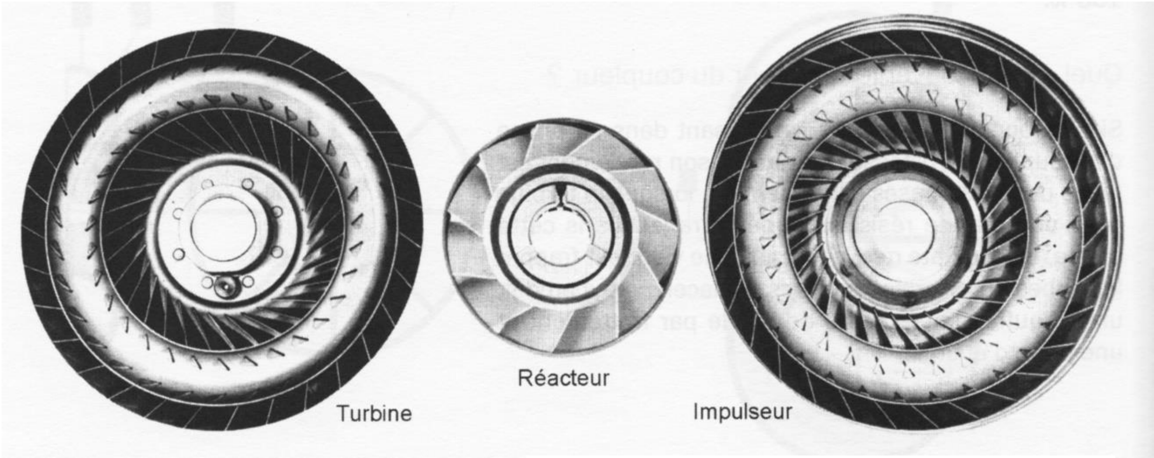
$$T_o + T_i + T_r = 0$$

- It also contributes to improving the efficiency of the converter

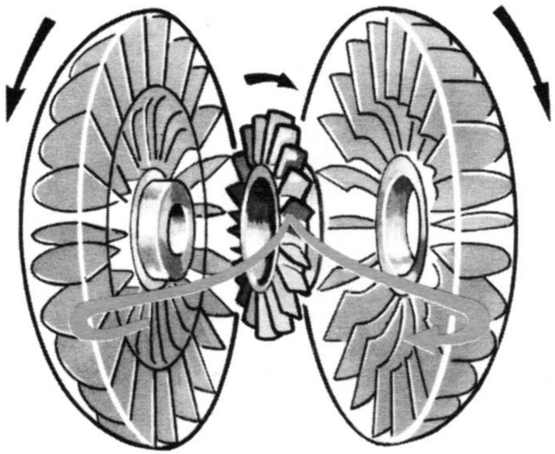


Hydraulic torque converter

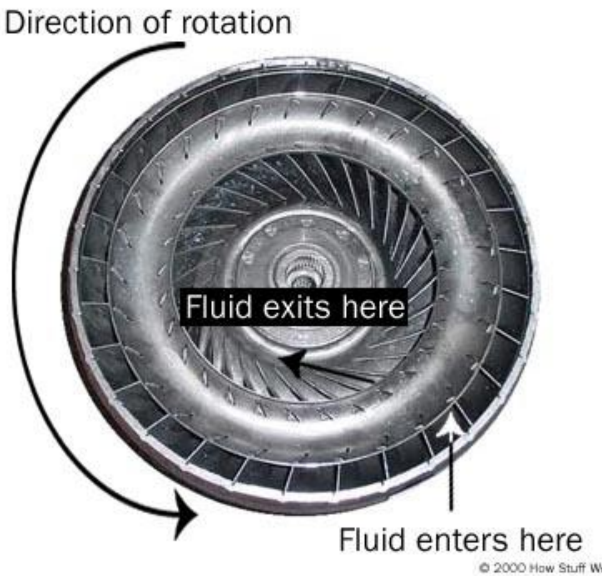


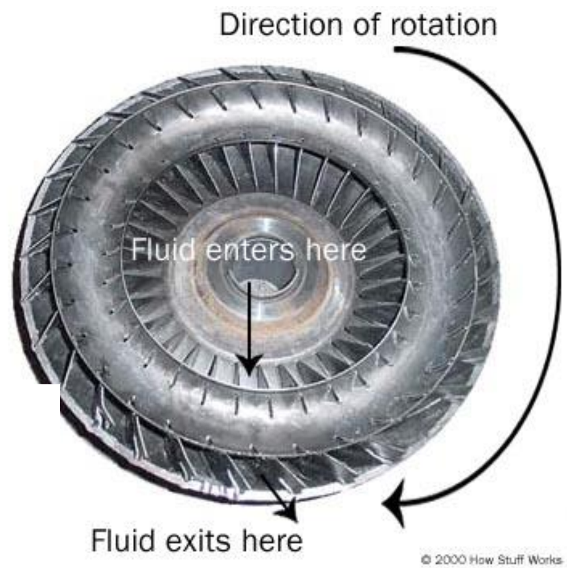


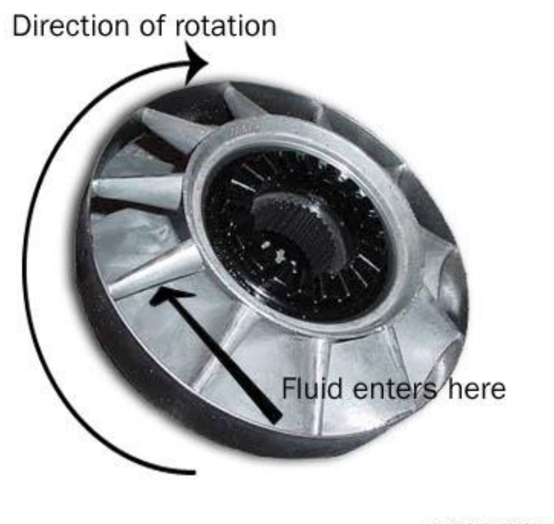
Torque converter
with three elements



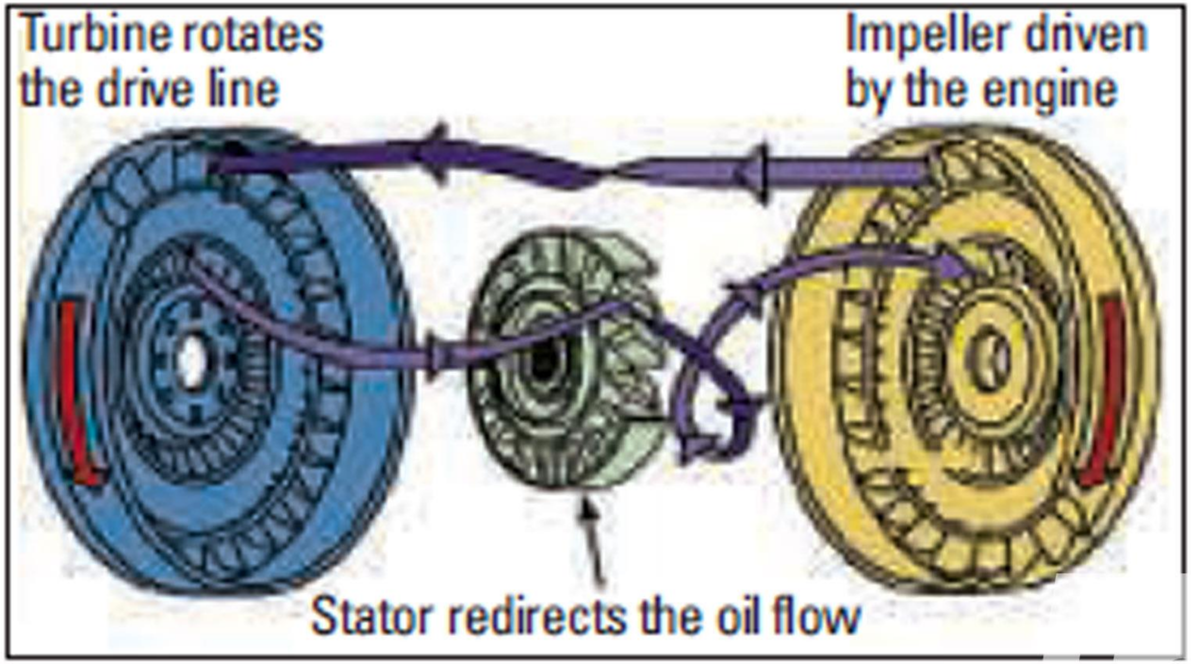
Hydraulic torque converter





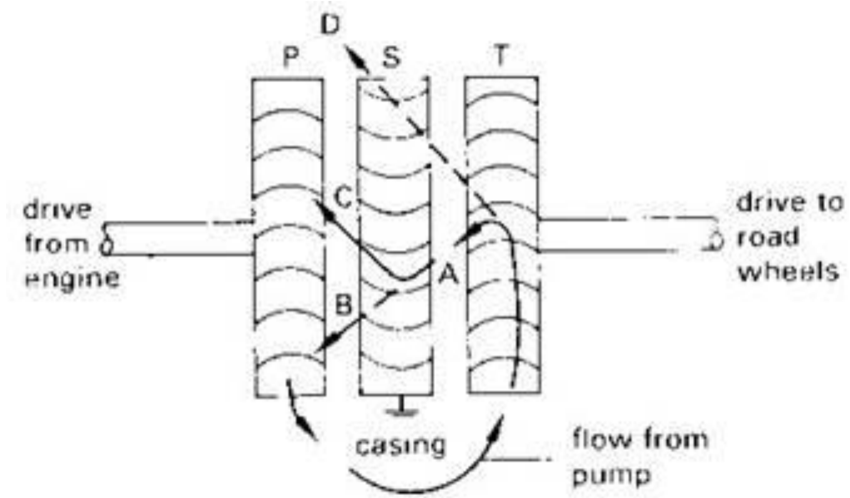


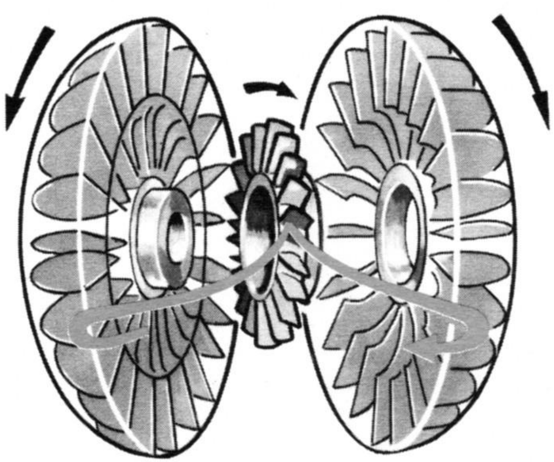
Hydraulic torque converter



This diagram shows how fluid flows through the various parts of a torque converter.

Hydraulic torque converter





- The stator device realizes a flux directional control.
- The bended stator walls act as supports for the fluid filets reducing the turbulence and losses.
- Because of the control of the fluid flow in the stator, the fluid returns to the impeller with a higher and a better orientation of velocity, saving some energy, so improving the efficiency

Hydraulic Torque Converter

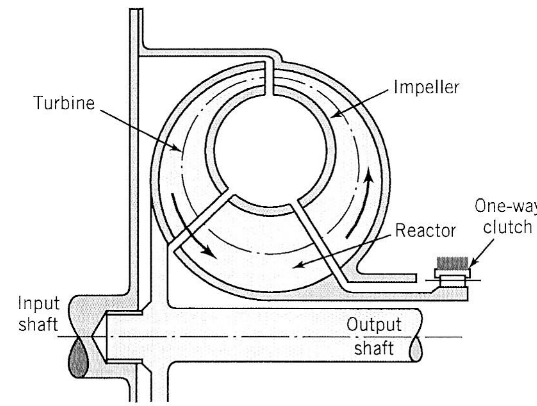
- At low speed the stator is blocked due to the free wheel and there is a magnification factor

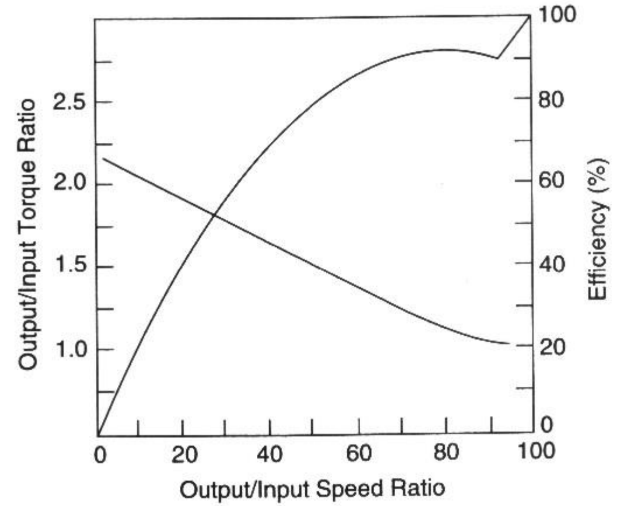
$$C_{tr} = \frac{T_{out}}{T_{in}} > 1$$

- Over a certain speed, the fluid flow is such that the reaction disappear and the stator free to spin. The torque converter operates as a hydraulic coupling

$$C_{tr} = \frac{T_{out}}{T_{in}} \simeq 1$$

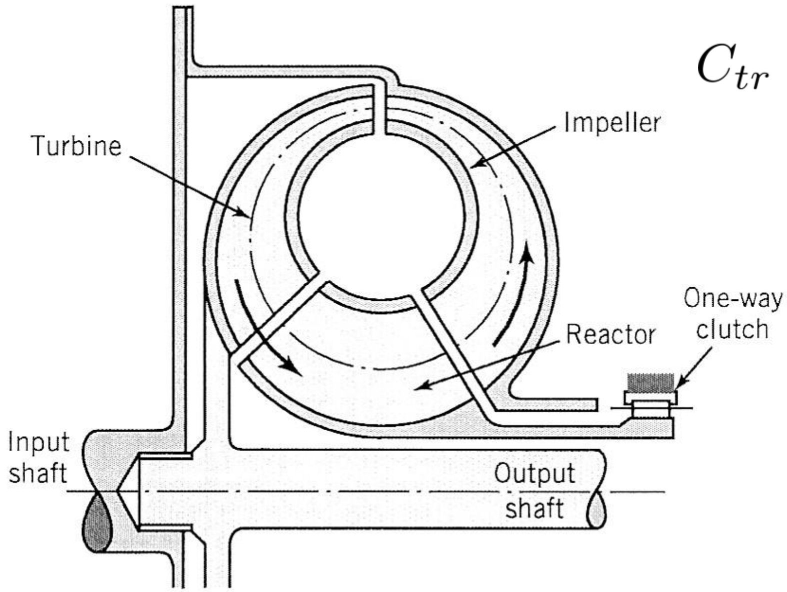
$$C_{sr} = \frac{\omega_{out}}{\omega_{in}}$$



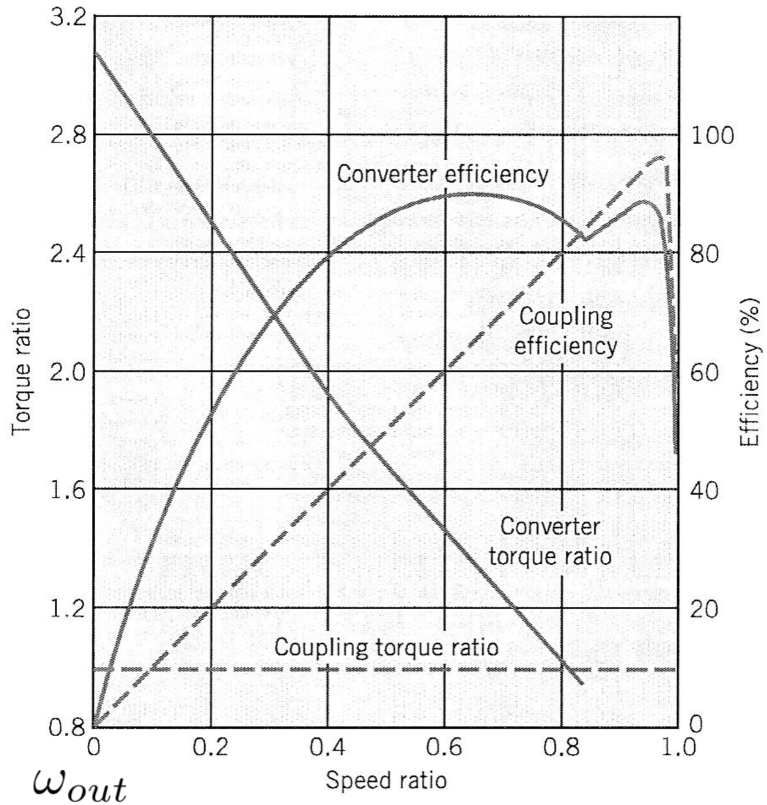


Hydraulic torque converter

$$\eta_c = \frac{P_{out}}{P_{in}} = \frac{T_{out}}{T_{in}} \frac{\omega_{out}}{\omega_{in}} = C_{tr} \times C_{sr}$$



$$C_{tr} = \frac{T_{out}}{T_{in}}$$

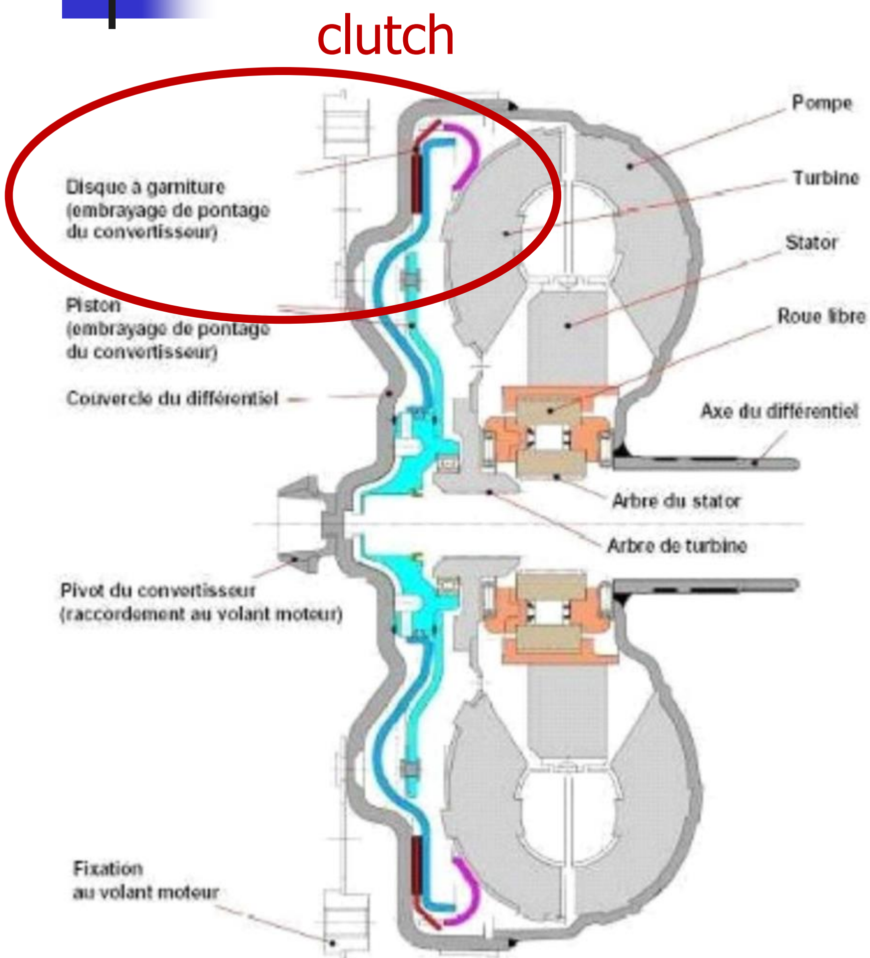


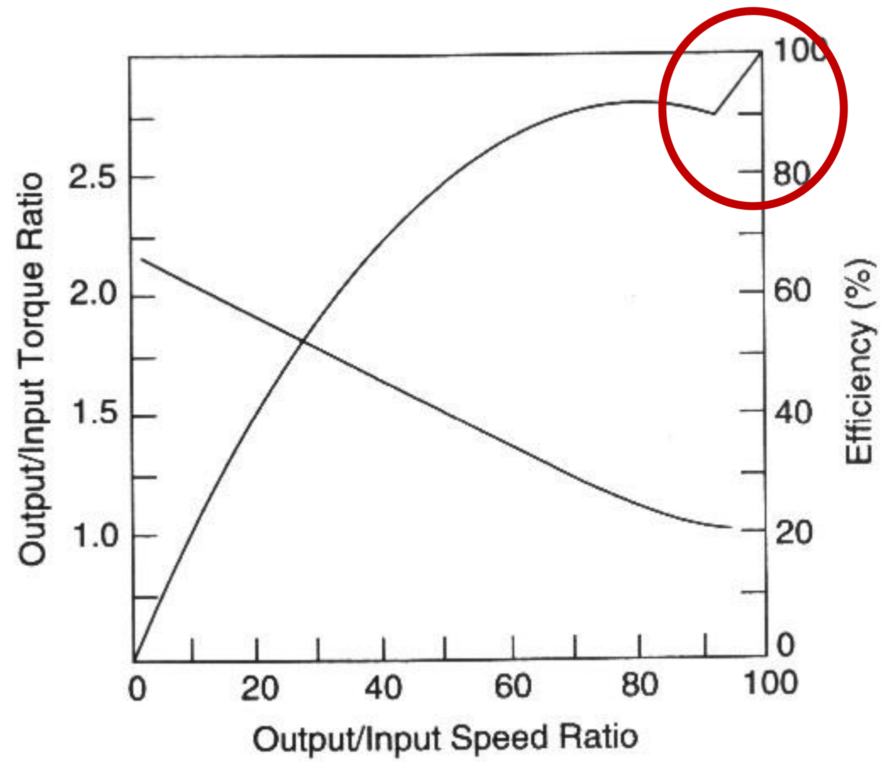
Characteristic curves of a torque converter with 3 parts

Juvinal Fig. 19.13 & 19.14

$$C_{sr} = \frac{\omega_{out}}{\omega_{in}}$$

Hydraulic torque converter



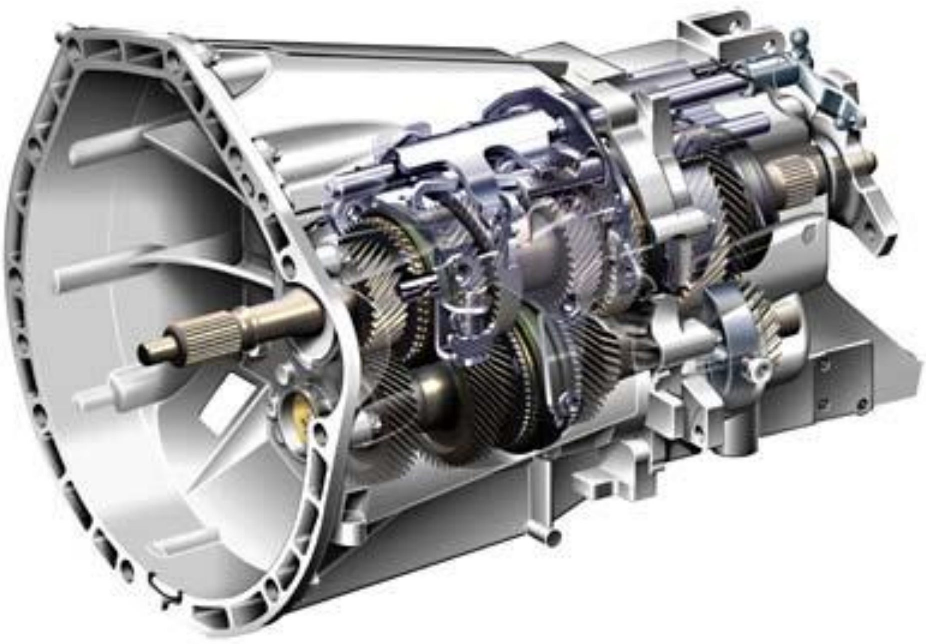


Blocking the rotation of the input and output wheel → 100% efficiency

Hydraulic torque converter

- Advantages:
  - Simplicity of the working principle
  - Suppression of the clutch pedal
  - Higher progressivity compared to dry friction clutches
  - Magnification of the torque for high load torques and low rotation speed of the output shaft
  - No contact, no wear → Longer lifetime
- Drawbacks:
  - Lower efficiency because of the presence of a velocity slip even when closed. Zero efficiency when the output shaft experiences high slip
  - Irreversible character: no torque transmitted when the output shaft spins in the reverse way. So, no engine brake is possible
  - Higher weight

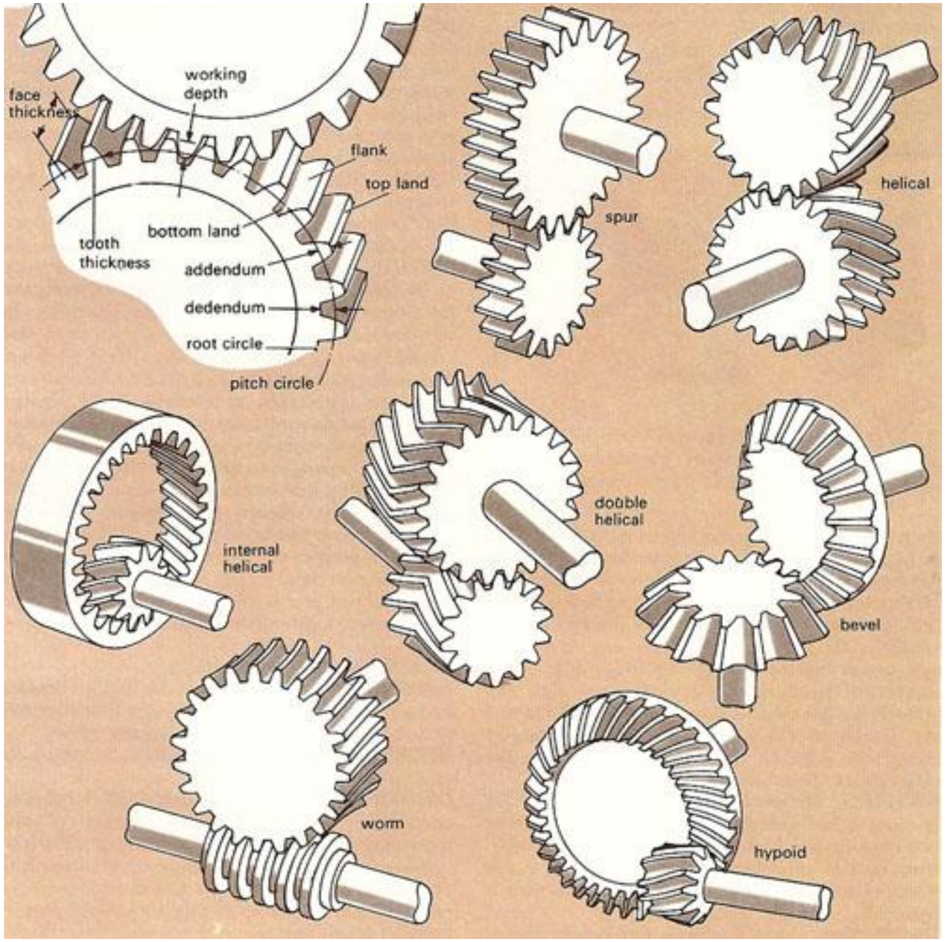
MANUAL GEAR BOXES



GEAR BOXES

- Adapt the rotation speed and the torque to driving conditions
  - To be able to deliver the maximum power of the power plant whatever be the driving speed
  - To be able to match the operating range of ICE with the range of the wheel rotation speeds under various driving conditions from rest to maximum speed
    - Idle regime
    - Maximum speed regime
- The gear box is not the sole element to introduce a reduction ratio. The differential generally provides a fixed (final) gear ratio. This reduces the size and the weight of the gear box.
- The gear box is often the sole component to have a variable gear ratio

GEAR BOXES


working depth
face thickness
flank
top land
bottom land
tooth thickness
addendum
dedendum
root circle
pitch circle
spur
helical
internal helical
double helical
bevel
worm
hypoid

GEAR BOXES

- Several types of gear pairs
  - Spur gears
  - Helical gears
  - Synchromesh
  - Epicyclical

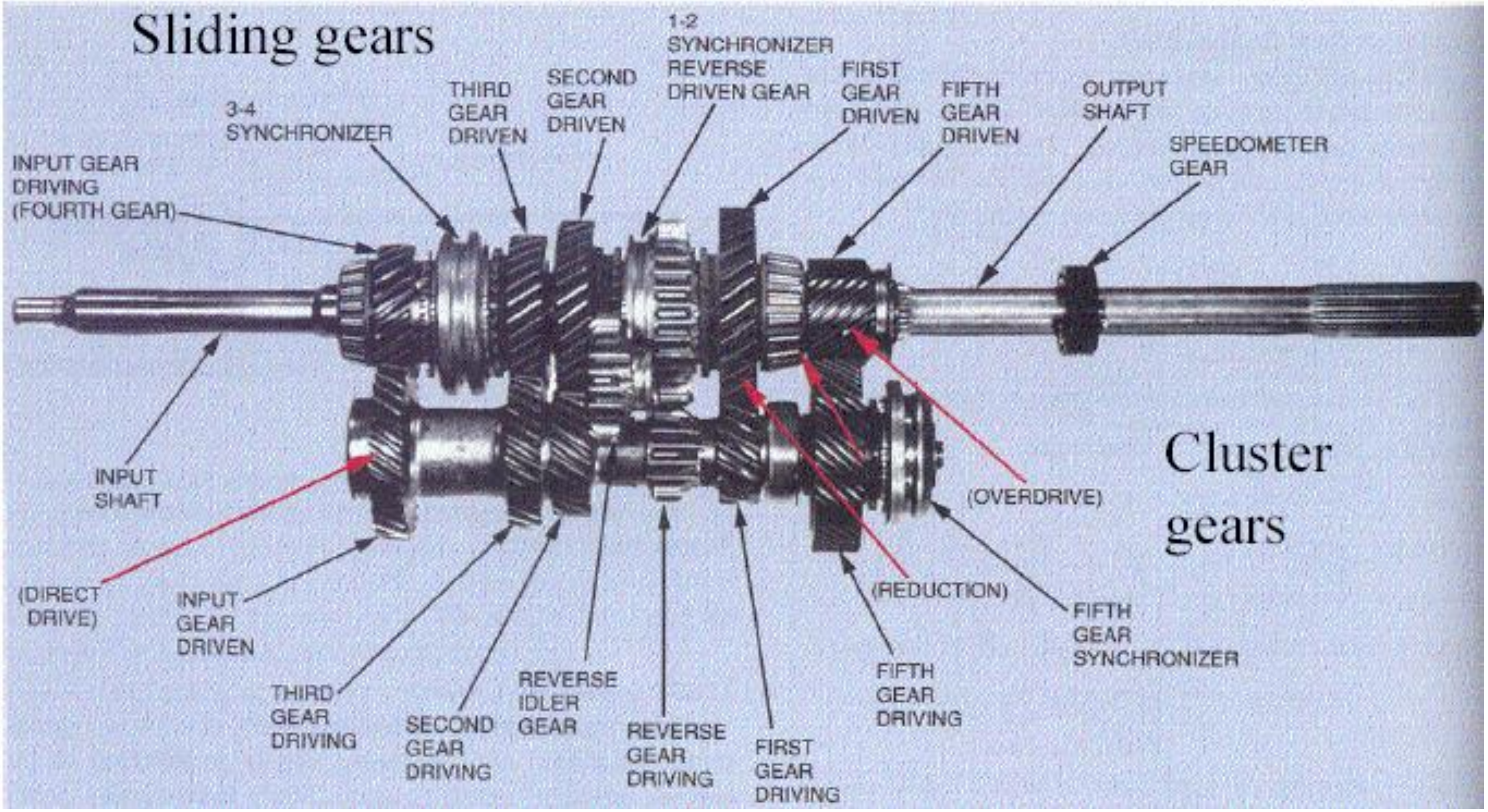
- Several types of gear boxes
  - Manual gear boxes (MT)
  - Automatic gear boxes (AMT)
  - Continuous Variable Transmission (CVT)

MANUAL GEAR BOXES

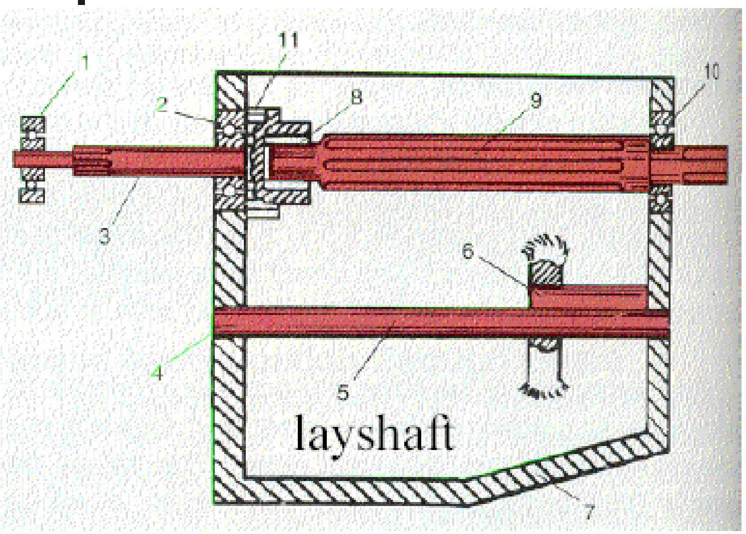
- Typical gear ratios for automobiles

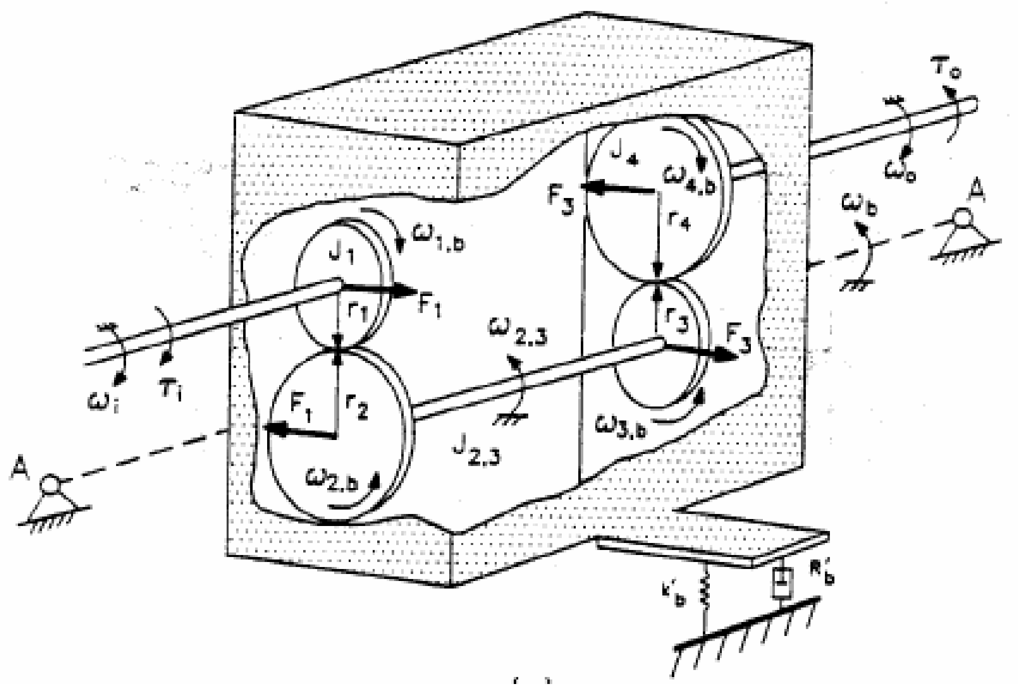
3 Gear Ratio	4 Gear Ratio	5 Gear Ratio
1st gear : 3:1	1st gear : 3,5:1	1st gear : 3,2:1
2nd gear : 2:1	2nd gear : 2:1	2nd gear : 2:1
3rd gear : 1:1	3rd gear : 1,5:1	3rd gear : 1,4:1
Reverse gear: 2,5:1	4th gear : 1:1	4th gear : 1:1 (direct drive)
	Reverse gear : 3:1	5th gear : 0,853:1 (overdrive)
		Reverse gear : 3:1

MANUAL GEAR BOXES



MANUAL GEAR BOXES





- Input Shaft
- Intermediate or layshaft
- Output shaft

Gear box with spur gears

- Working principle: Changing the gear ratio is operated by opening the clutch, then by sliding one gear and separating the meshes. Then one selects another gear element and pushes it along the spline shaft to mesh with another pair
- Advantages:
  - Simplicity
  - Robustness
- Inconvenient:
  - Noisy when operating
  - Lower efficiency (spur gear)
  - Difficult to operate for large gears
  - Need to stop to change the gear

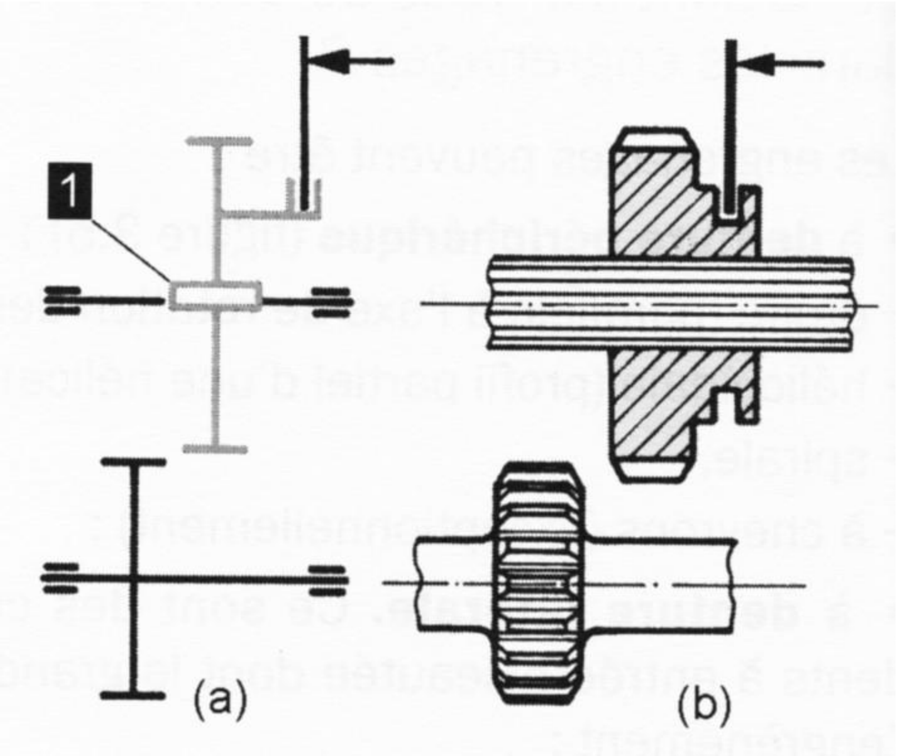


Fig. Memeteau

Helical gear boxes

- Because of helical geometry, the two gear elements are in constant mesh.
- For each pair, the pinion spins freely generally about the secondary shaft. The gear change is operated by sliding a drive hub so that dog teeth can mesh into the flanks of the gear wheel.
- Advantage:
  - Reduction of the noise emissions
  - A clutch is necessary
- Inconvenient:
  - The pinions and wheels can not be meshed easily
  - Usual solution in agricultural vehicles

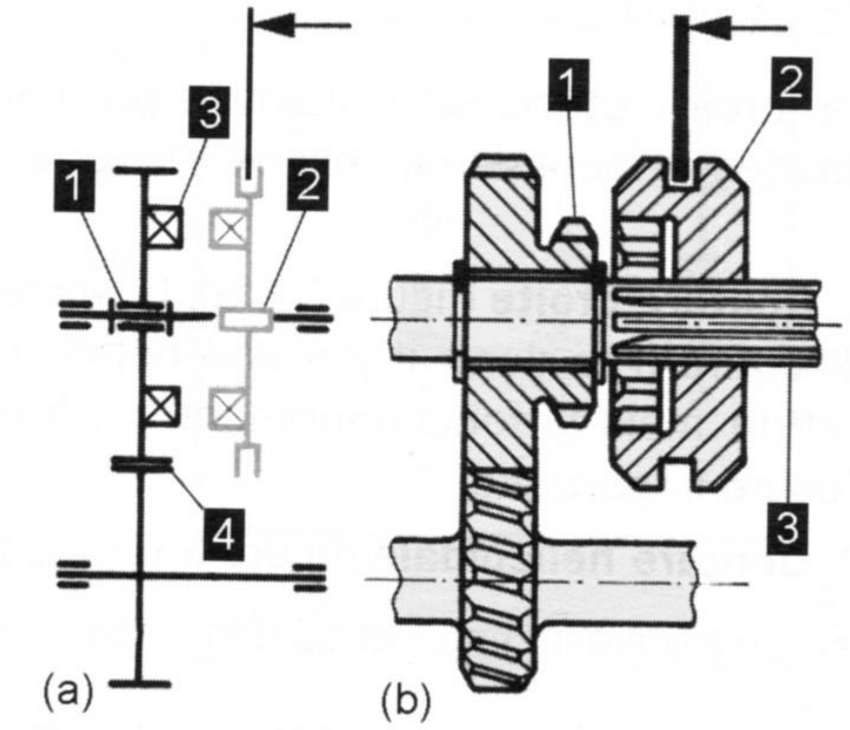
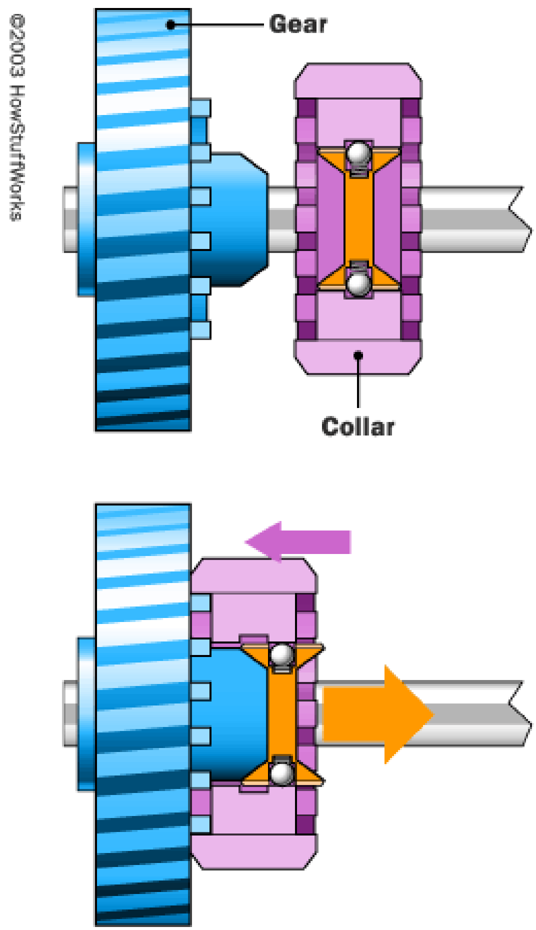


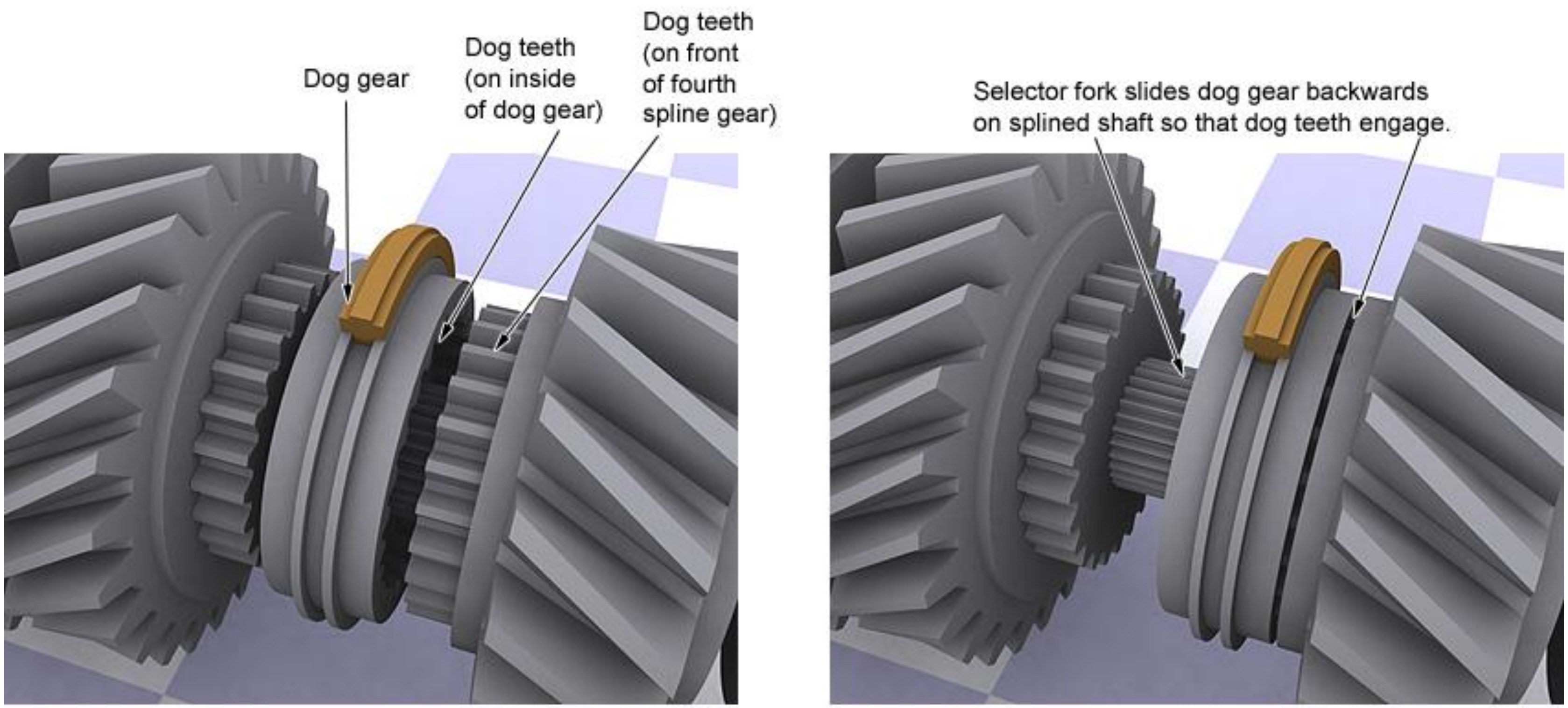
Fig. Memeteau

The synchromesh

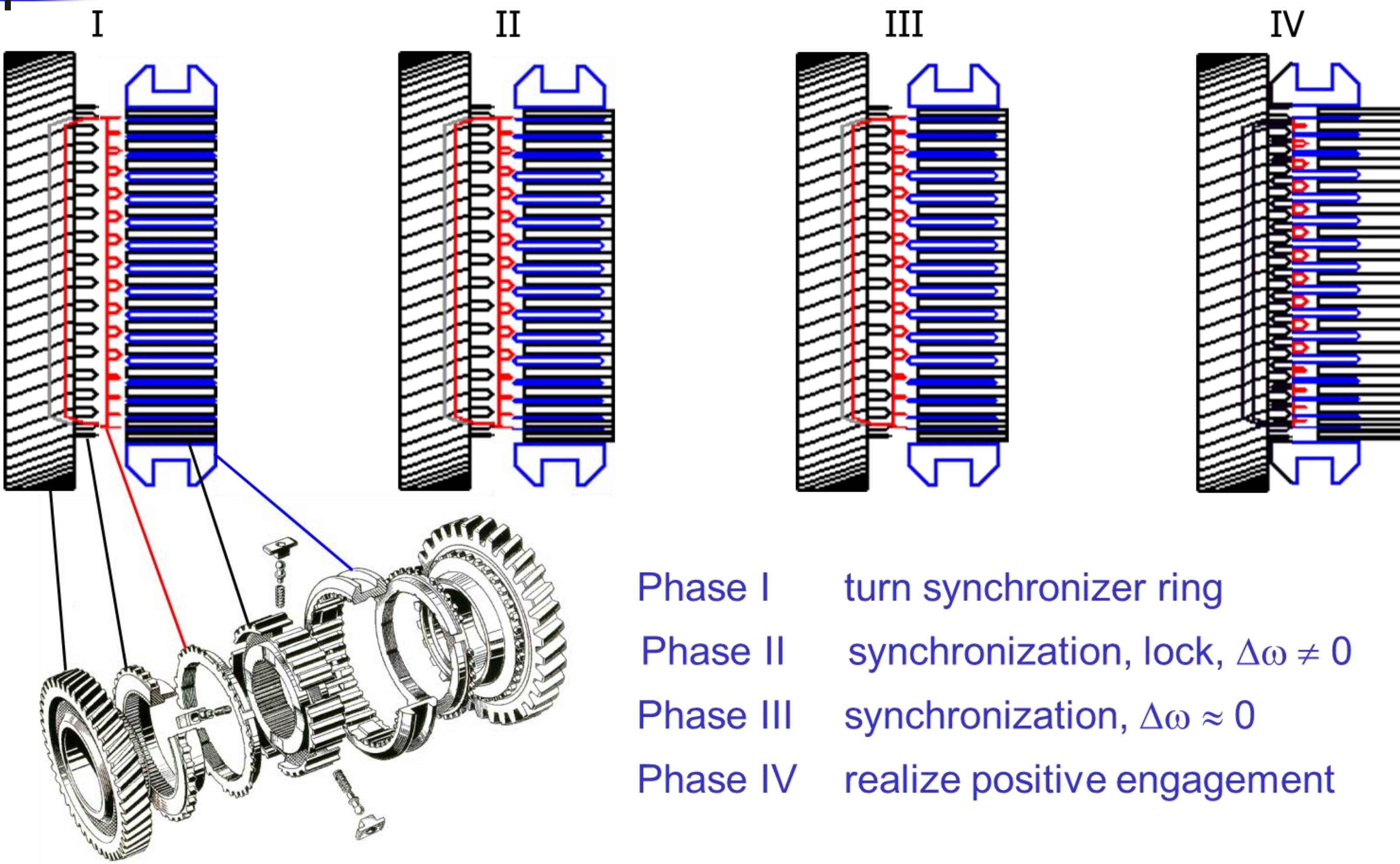


- During the gear change, the initial rotating speed of the two gear elements are generally different.
- To avoid the shocks and grinding noise when contact is engaged, one has to synchronize the rotating speeds before meshing the dog teeth.
- This is the aim of the synchromesh
- This device is a small conical clutch placed on the collar and the flanks of the gear wheel
- When the clutch has synchronized the rotation speed of the two elements, the two dog teeth can penetrate each other with grinding

The synchromesh



4 phases of synchronization



Phase I — turn synchronizer ring

Phase II — synchronization, lock, $\Delta\omega \neq 0$

Phase III — synchronization, $\Delta\omega \approx 0$

Phase IV — realize positive engagement

The synchromesh

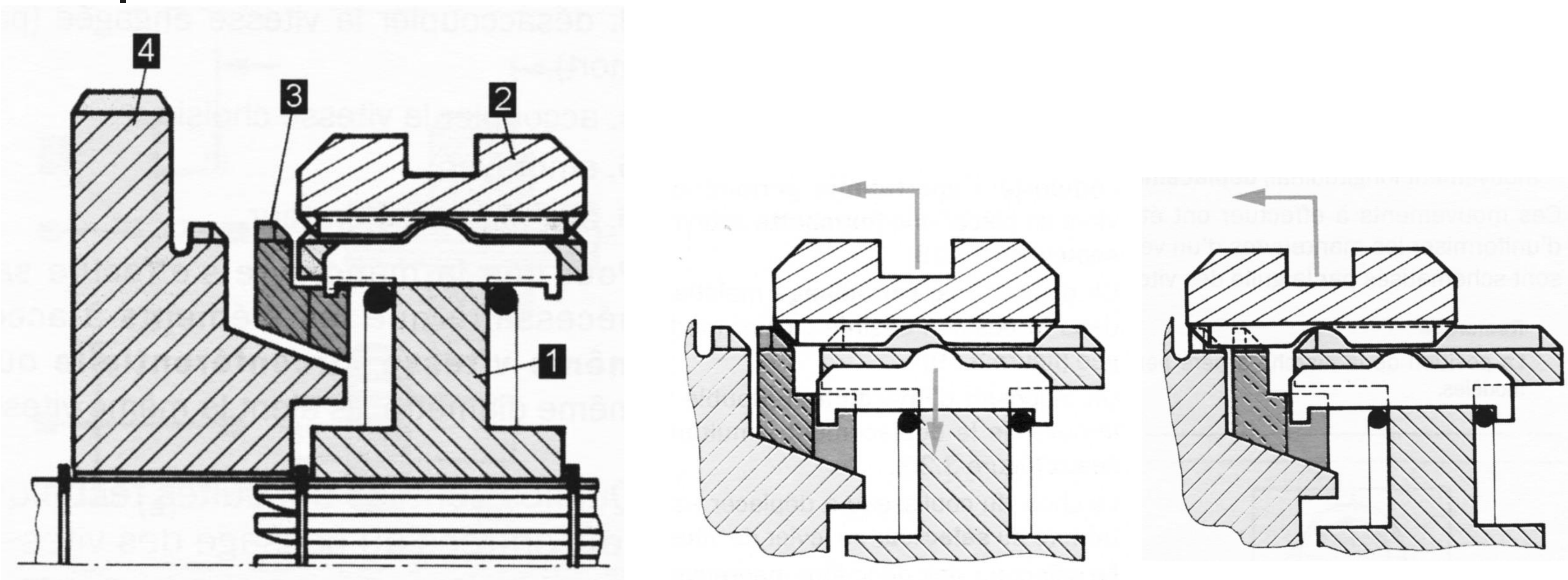


Fig. Memeteau

The synchromesh

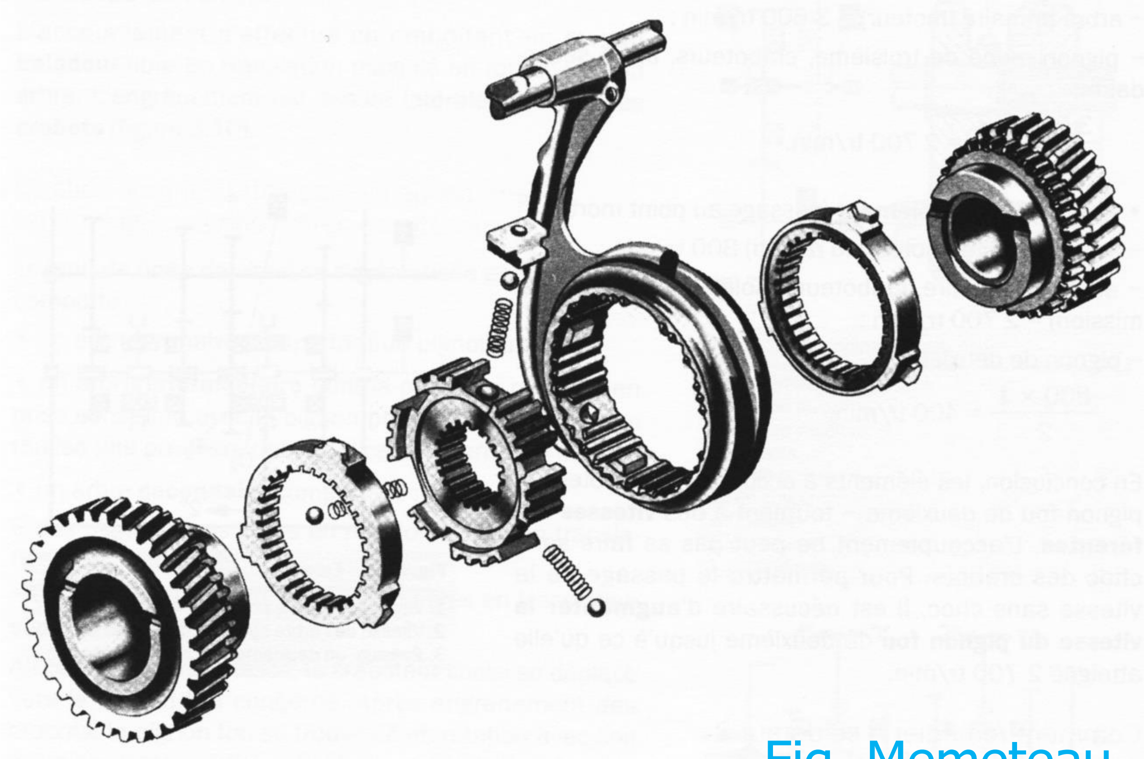
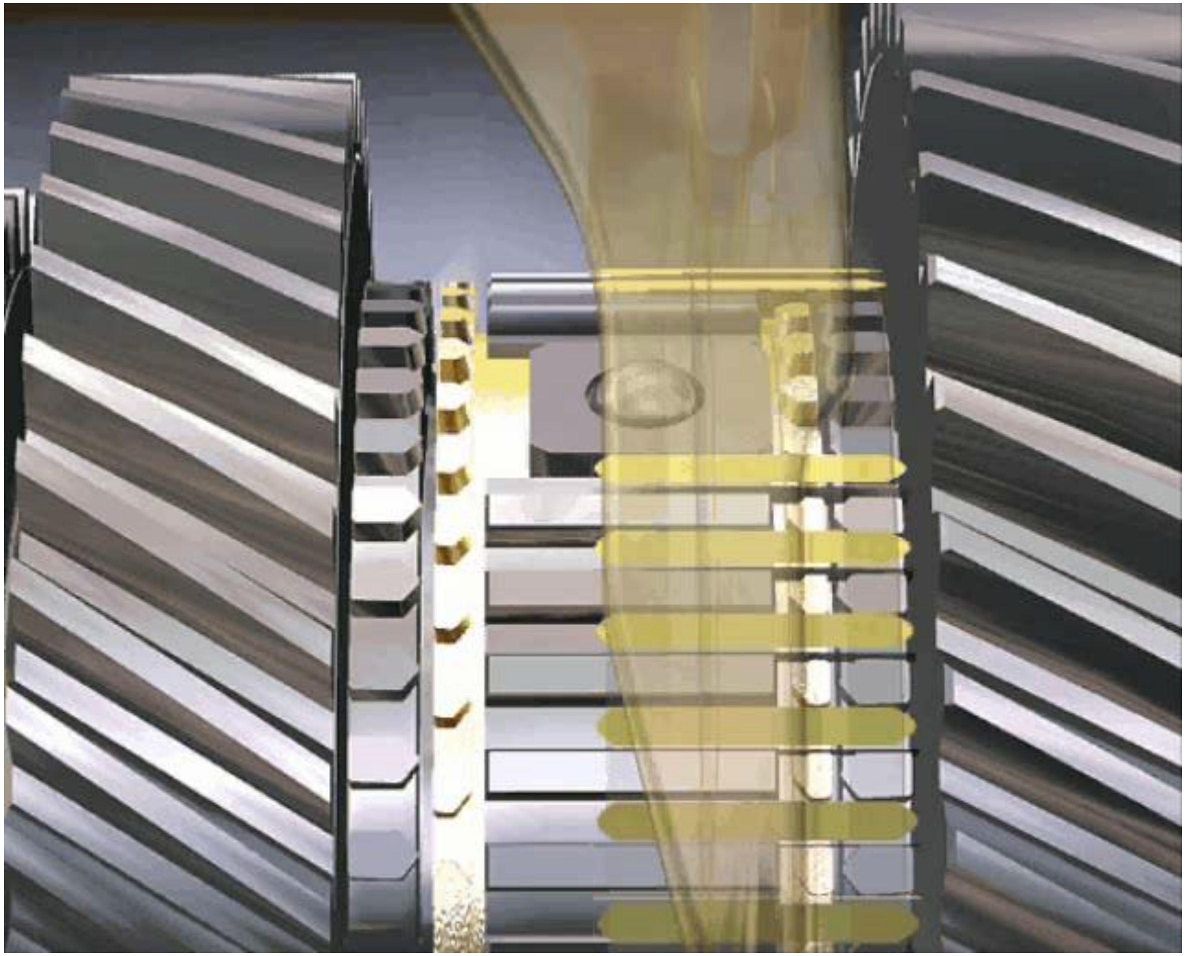
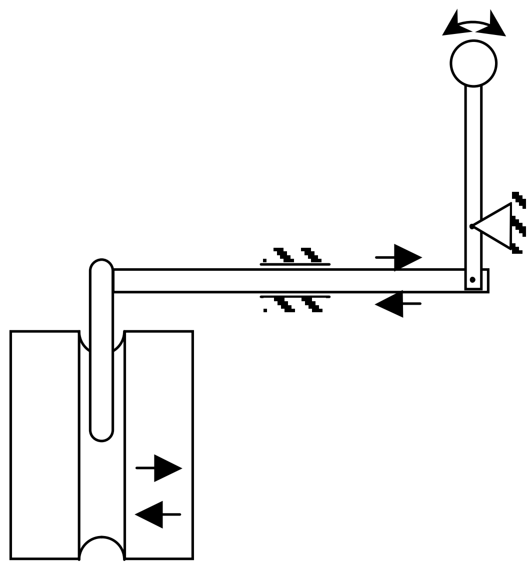


Fig. Memeteau

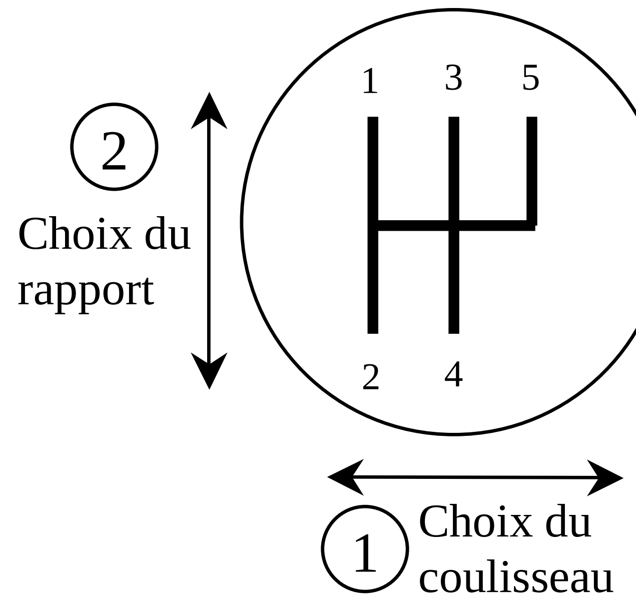
The synchromesh



Gear box selection mechanism

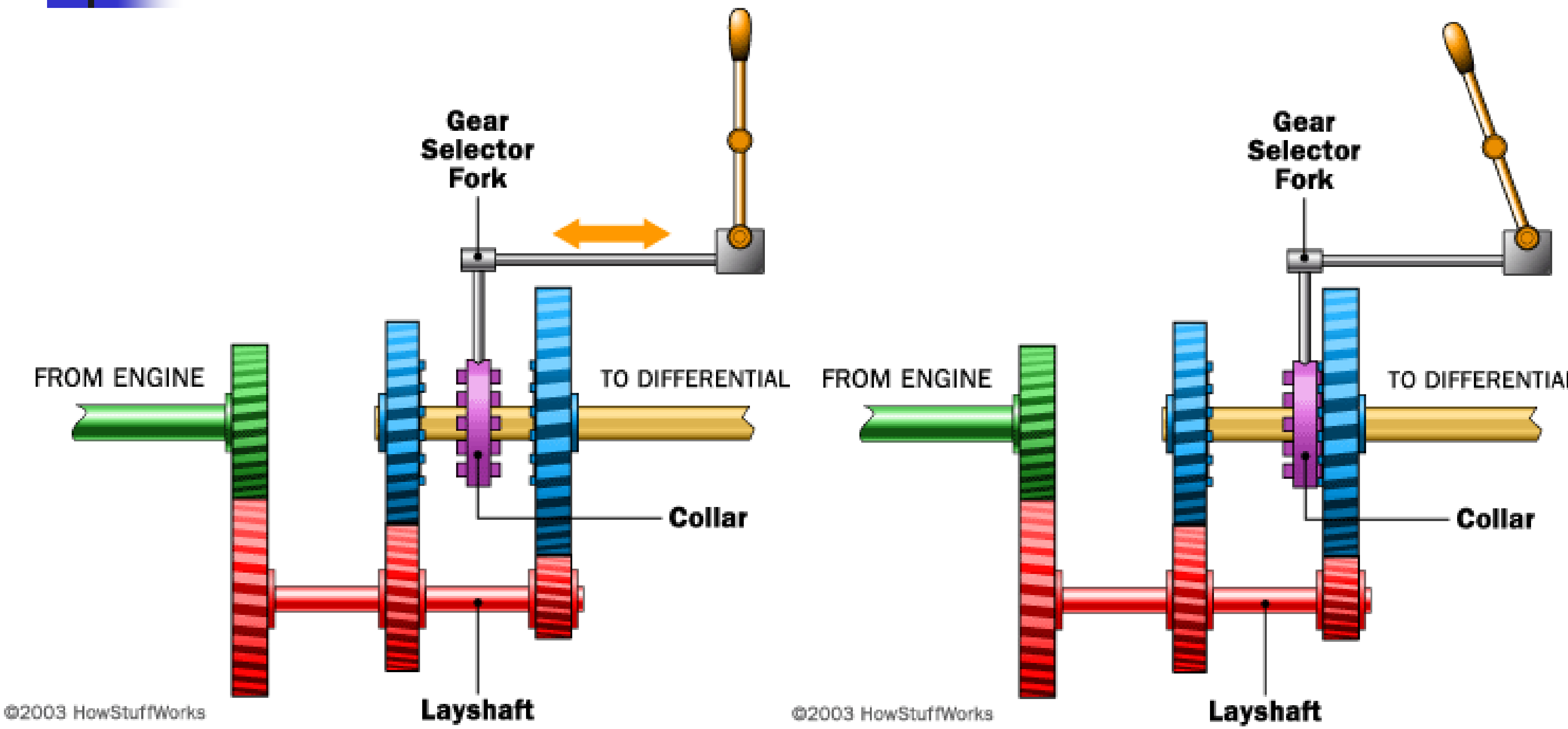


Fork and selector mechanism



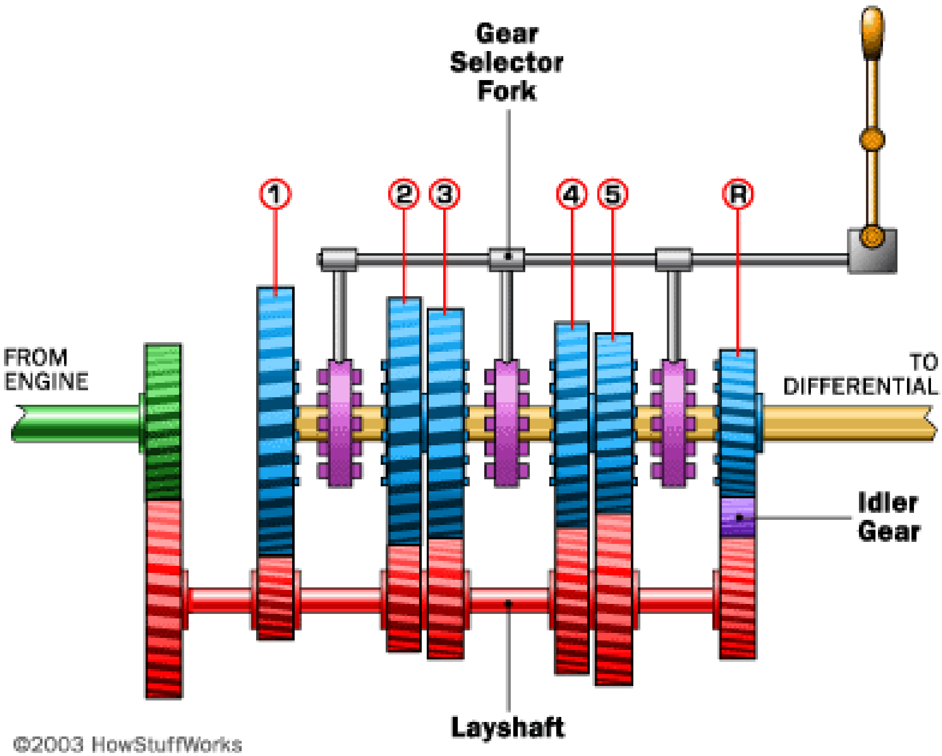
Selection of the fork

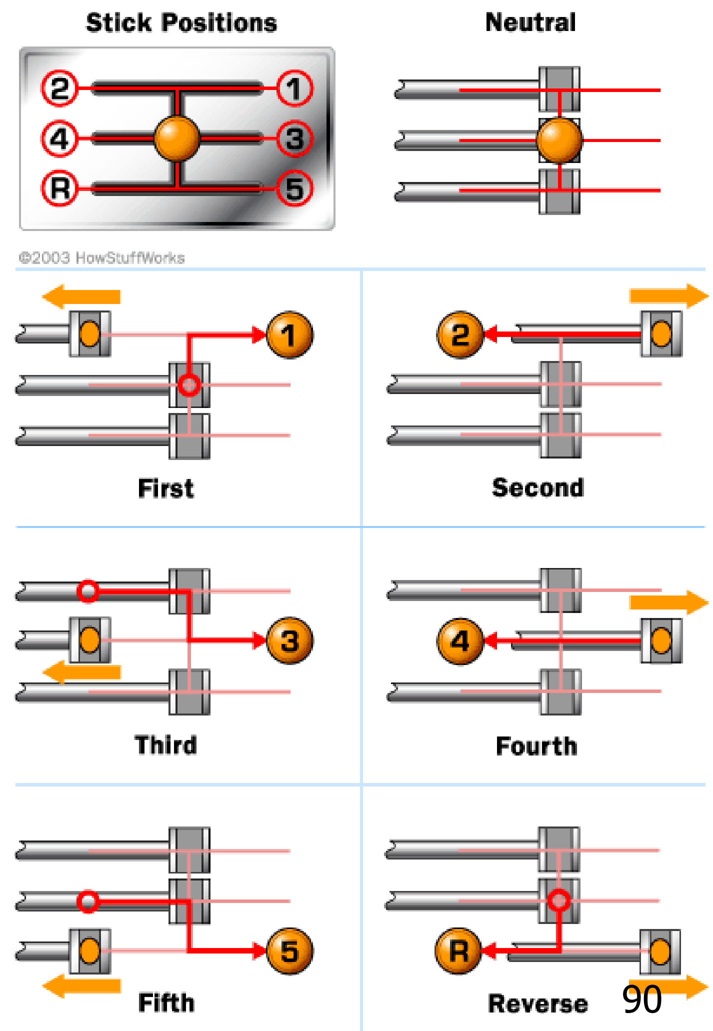
Gear selection mechanism



Gear selection mechanism

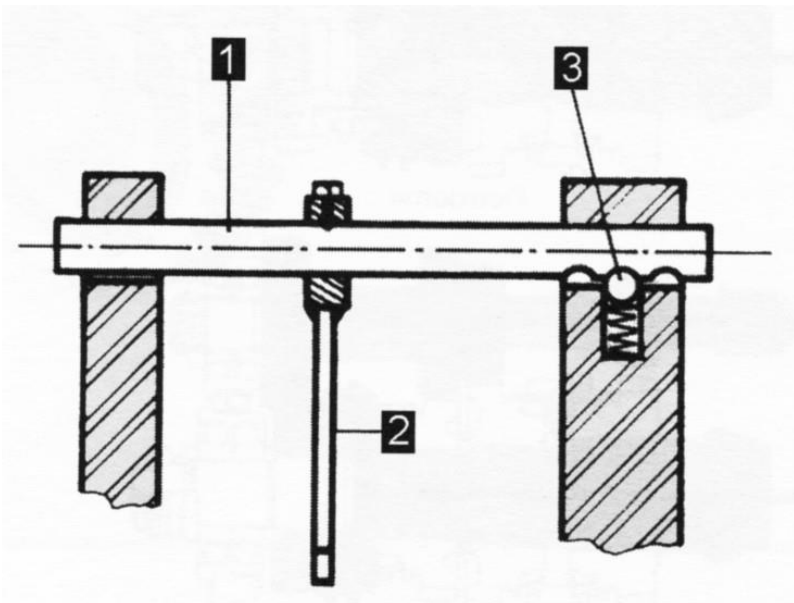
Gear box selection mechanism





Selection of gear and of a selection stick

Gear box selection mechanism



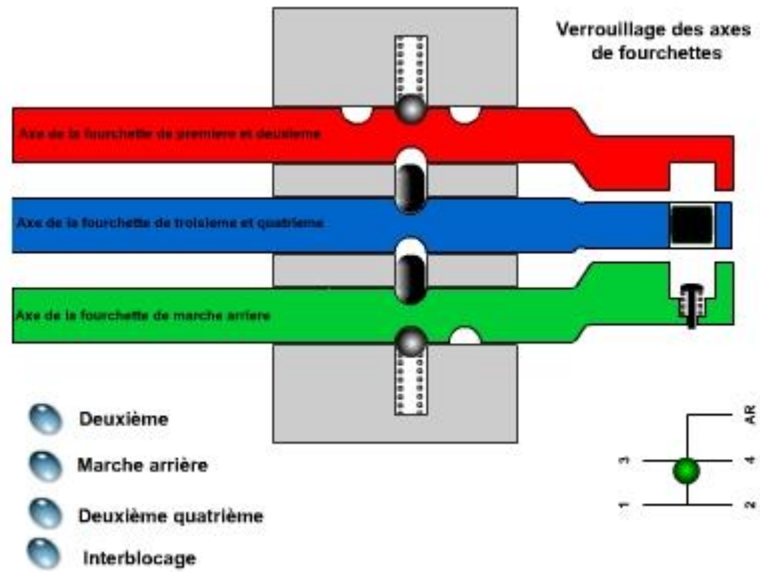
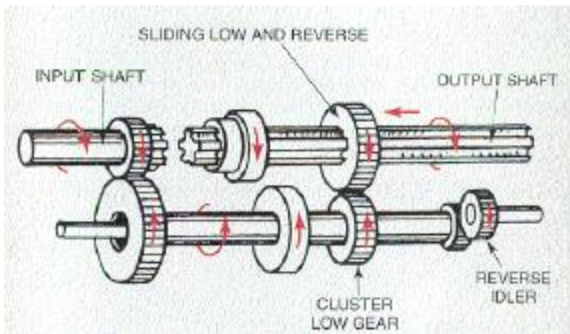


Fig. Memeteau

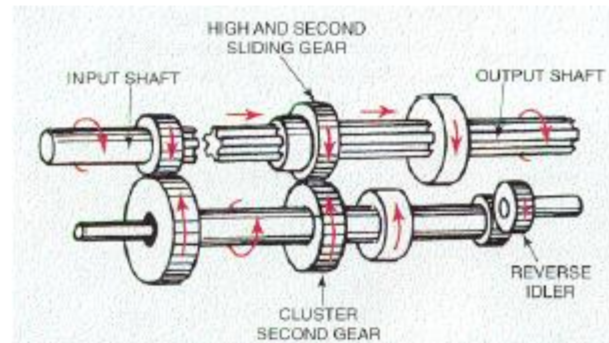
Locking of the selection mechanism: location spring and ball system

Path of the power for the different gear ratios

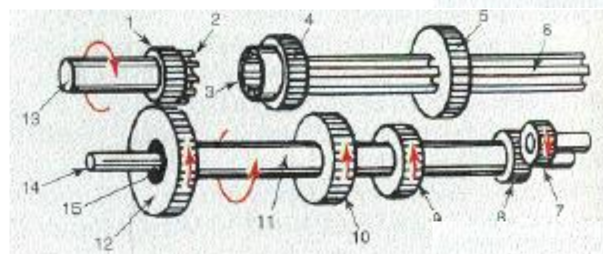
1st



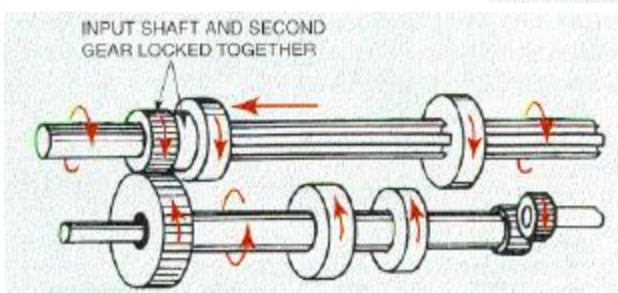
2nd



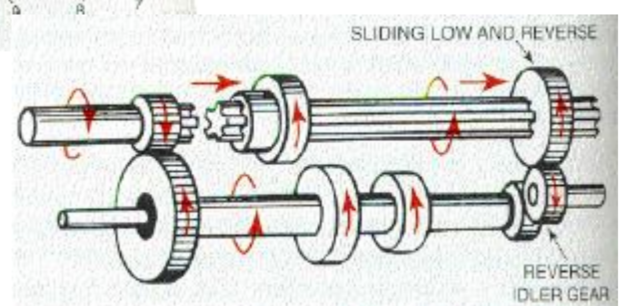
Neutral point



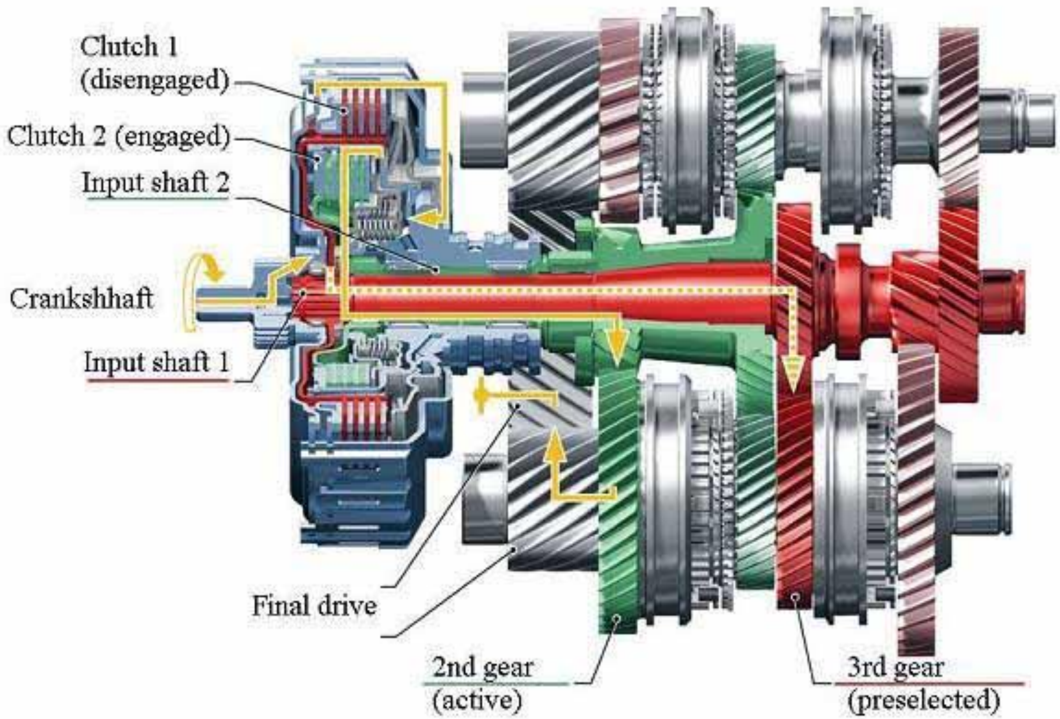
3rd

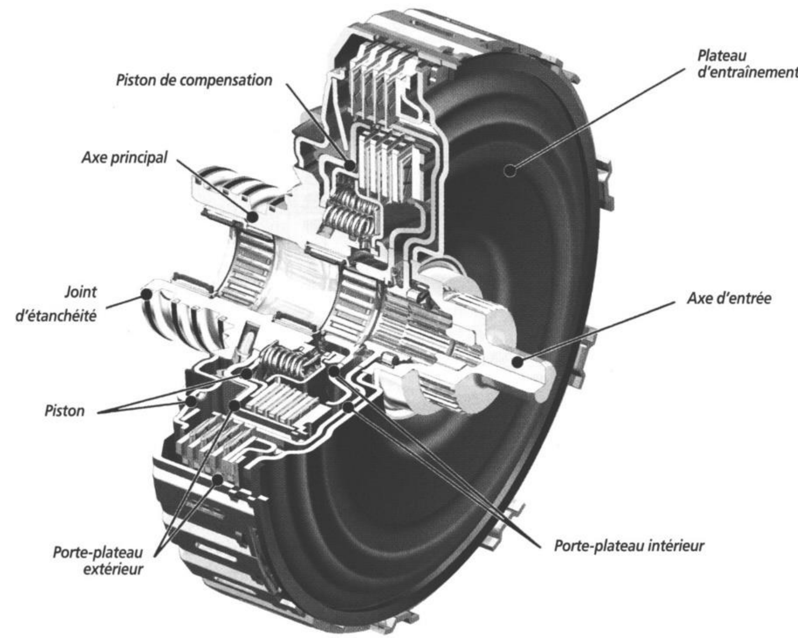


R



DUAL CLUTCH GEAR BOX





Principle: two coaxial shafts are powered by two clutches and operated by a hydraulic system

GEAR RATIO SELECTION

- The choice of the gear ratios is realized on the following bases:
  - <u>The highest ratio</u> is calculated to match the <u>maximum speed</u> of the vehicle
  - <u>The first gear ratio</u> is based on the <u>maximum gradeability</u> and on the drawbar pull specifications
  - The <u>selection of the intermediate gear ratios</u> are made following a strategy
    - Geometric distribution
    - Fuel consumption minimization

Maximum speed

- For a given vehicle, tires, and engine, one can calculate the transmission ratio that gives the greatest maximum speed
- Solve equality of tractive power and dissipative power of road resistance

$$\mathcal{P}_w = \mathcal{P}_{res}$$

  - with $\mathcal{P}_{res} = Av + Bv^3 \quad A,\ B > 0$

- As the power of resistance forces is steadily increasing, the maximum speed is obtained when using the maximum power of the power plant

$$Av + Bv^3 = \eta \mathcal{P}_{max}$$

Maximum speed

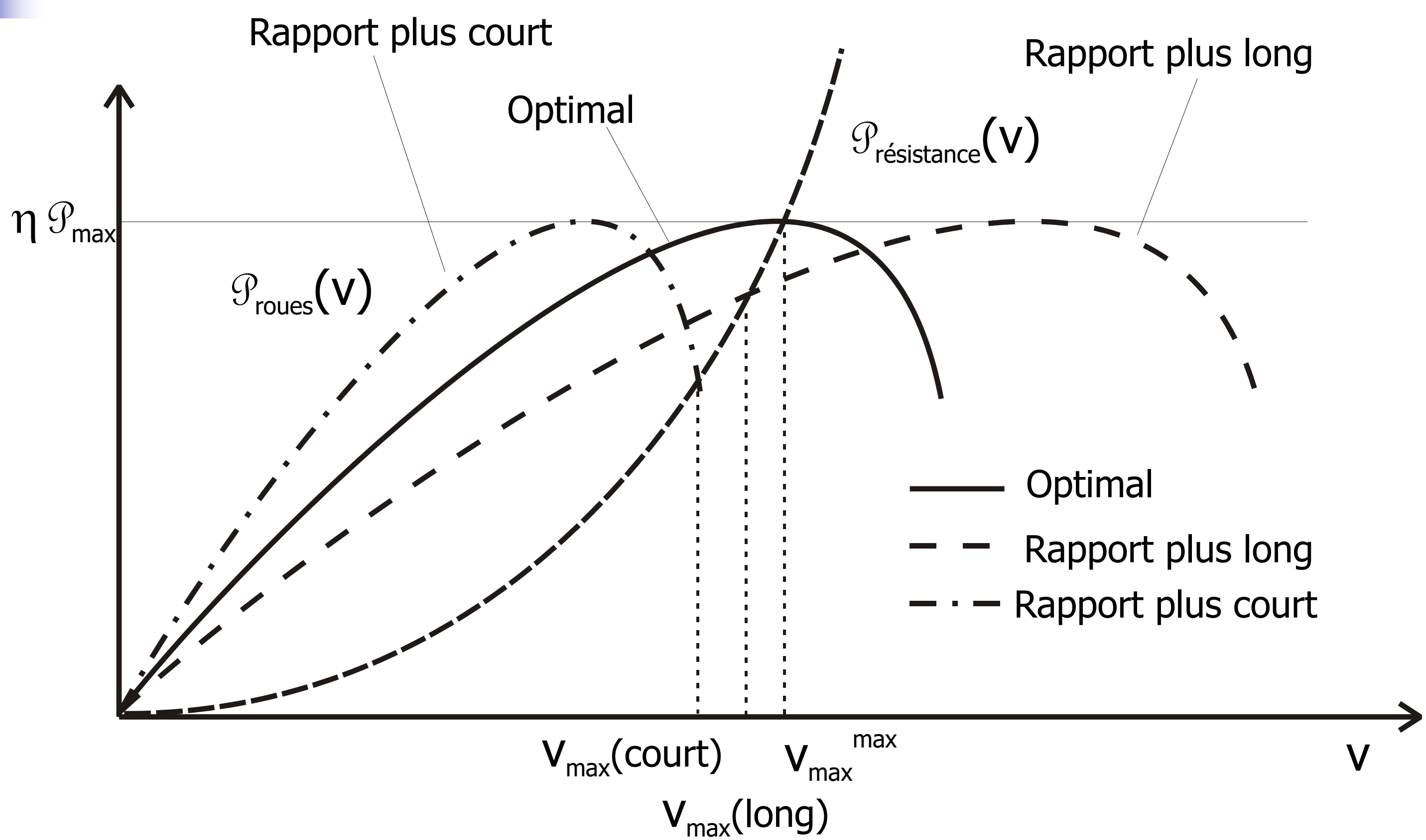
- Iterative scheme to solve the third order equation (fixed point algorithm of Picard)

$$\begin{aligned} v_0 &= 0 \\ v_{n+1} &= \left(\frac{\eta \mathcal{P}_{max} - A v_n}{B} \right)^{1/3} \end{aligned}$$

- Once the maximum speed is determined the optimal transmission ratio can be easily calculated since it occurs for the nominal rotation speed:

$$\left(\frac{R}{i} \right)^* = \frac{v_{max}^{max}}{\omega_{nom}}$$

Max speed for a given reduction ratio



Max speed is always reduced compared to v_{max}^{max}

Selection of a gear ratio for a given max speed

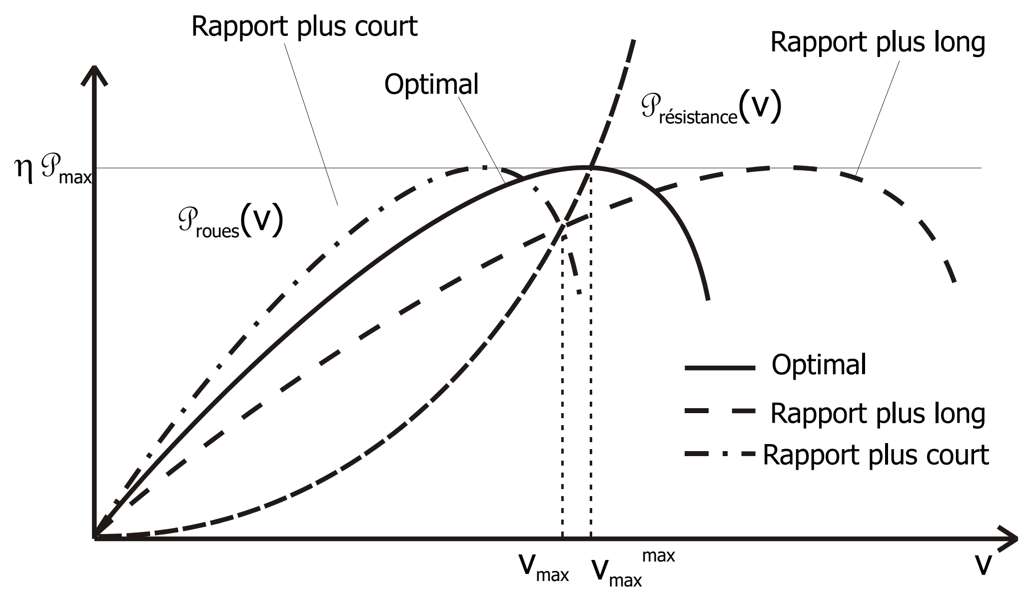
- There are two solutions : one over the nominal speed and one below the nominal speed.

$$\omega_p = \omega_{nom}(1 \pm \alpha)$$

$$\bar{\mathcal{P}}_p = \frac{\mathcal{P}_{RES}}{\eta} = \frac{1}{\eta}\left(A\bar{v}_{max} + B\bar{v}_{max}^3 \right)$$

$$\left| 1 - \frac{\omega_p}{\omega_{nom}} \right| = \alpha > 0 \quad \Leftrightarrow$$

$$\bar{v}_{max} \leq v_{max}^{max}$$

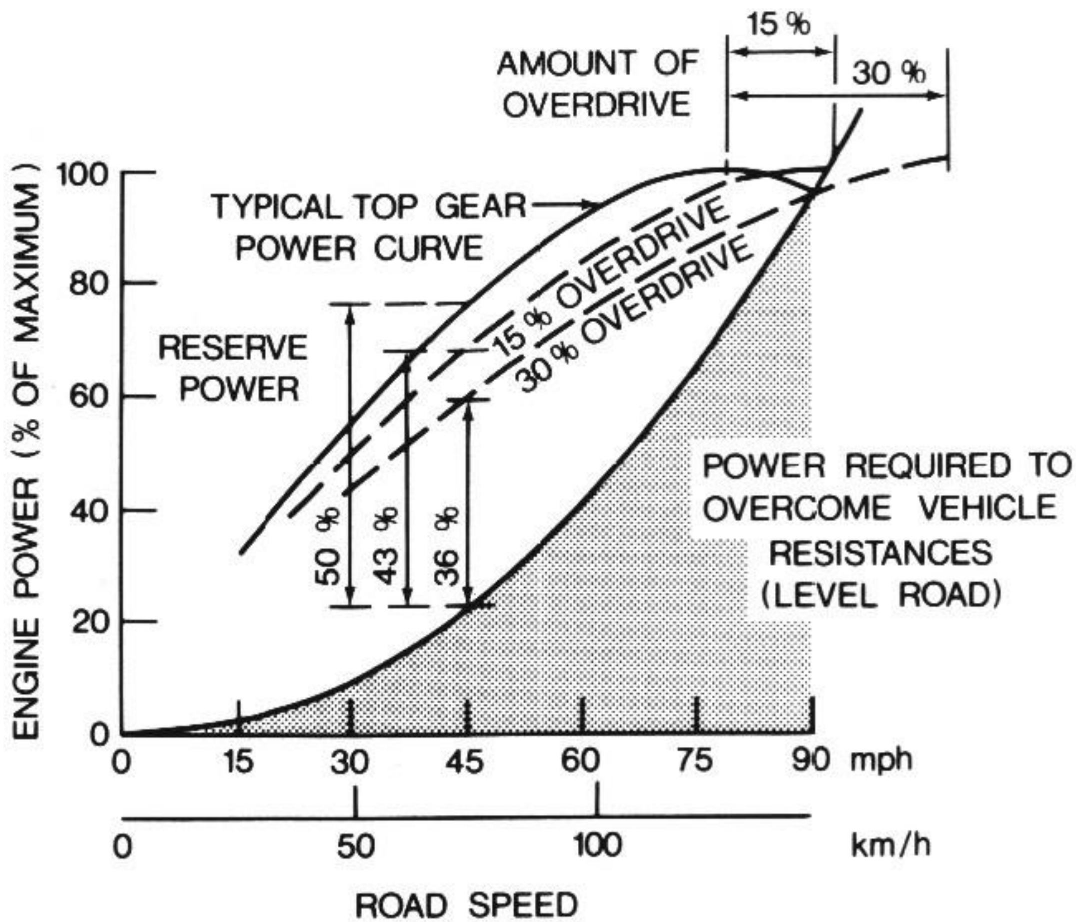


Selection of the final gear ratio

- Design specifications related to the maximum speed (from Wong)
  - To be able to drive at the maximum speed with the given engine
  - To be able to keep a constant speed between 88 and 96 kph while climbing a slope of at least 3% on the final gear ratio
- These specifications enable to calculate the final gear ratio
  - The specification about the maximum speed gives a final gear ratio
  - If two choices are possible, one will choose the gear ratio that is a bit above the nominal speed in order to keep a certain power reserve against the ageing or the engine, gust winds, etc.

Selection of the final gear ratio

Influence of the overdrive of the final gear ratio
Wong, Fig. 3.26



Maximum slope

- For the maximum slope the vehicle can climb, two criteria must be checked:

- The maximum tractive force available at wheel to balance the grading force

$$F_{slope} = mg\sin\theta$$

- The maximum force that can be transmitted to the road because of the limited tire-road friction and the weight transfer

$$F_{w,f} \leq \mu W_f \qquad F_{w,r} \leq \mu W_r$$

Selection of first gear ration

- Maximum slope to be overcome, for instance θ_{max} = 33%

$$F_{\mathrm{RES}} = mg\ \sin\theta_{max} + mg\ f_{RR}\ \cos\theta_{max}$$

- Tractive force at wheels

$$F_w \ = \ \eta \frac{i}{R_e} C_p$$

- Sizing of first gear ration

$$i_{max} \ = \ \frac{R_e\ F_{res}}{\eta\ C_{max}} \qquad i_{max} \ = \ \frac{R_e\ mg\ \sin\theta_{max}}{\eta\ C_{max}}$$

Selection of first gear ration

- The first gear ratio

$$i_{max} = \frac{R_e \, F_{rés}}{\eta \, C_{max}}$$

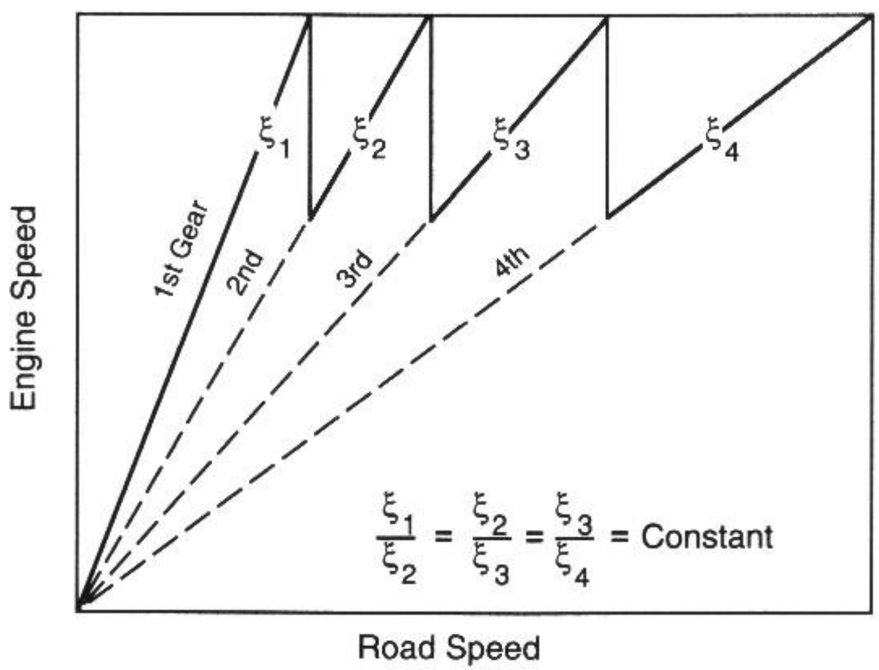
- If we neglect the rolling resistance

$$i_{max} = \frac{R_e \, mg \, \sin\theta_{max}}{\eta \, C_{max}}$$

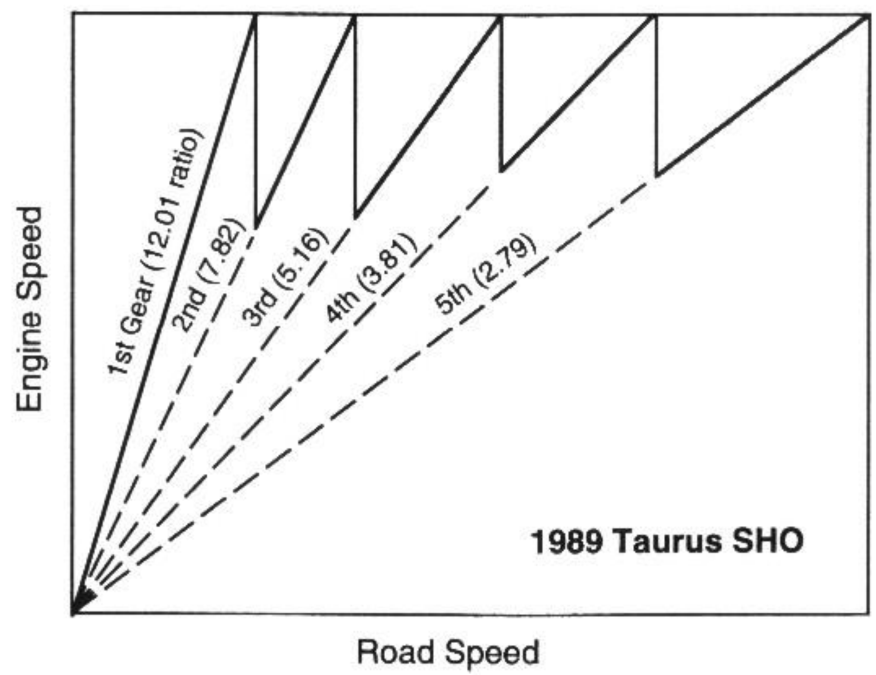
- May be generally a bit too large. One then has to moderate the proposed value:

$$i_1 \approx 0.8 \, i_{max}$$

Selection of intermediate gear ratios



Gillespie. Fig. 2.7 Selection of intermediate gear ratio following a geometry ratio



Gillespie. Fig. 2.8 Selection of the gear ration for a Ford Taurus

Selection of intermediate gear ratios

- As a first guess, one can assume that the engine operates in the constant range of speed between a minimum rotating speed N_L and a high rotating regime N_H.

- The gear change between ratio 1 and 2 happens at the following speed :

$$v_{1\to 2} = \omega_H \frac{R_e}{i_1} = \omega_L \frac{R_e}{i_2}$$

so

$$\frac{i_2}{i_1} = \frac{\omega_L}{\omega_H} = K$$

Selection of intermediate gear ratios

- It comes

$$\frac{i_3}{i_2} = \frac{\omega_L}{\omega_H} = K$$

$$\frac{i_4}{i_3} = \frac{\omega_L}{\omega_H} = K$$

etc.

that is

$$i_2 = K\, i_1$$

$$i_3 = K\, i_2 = K^2\, i_1$$

$$i_4 = K\, i_3 = K^3\, i_1 \quad \text{etc.}$$

- This shows that the gear ratios follow a geometric progression with a ratio $K = N_L/N_H$:

$$i_k = K^{k-1}\, i_1$$

Selection of intermediate gear ratios

- If we know the first and the final gear ratios, we can determine the ratio K:

$$K = \sqrt[n-1]{\frac{i_n}{i_1}}$$

- This rule is generally rather well followed by light-duty vehicles that have a large number of gear ratios.

- Conversely it is not verified by passenger cars that have a small number of gear ratios. The gaps between the highest gear ratios are shrinking to compensate the loss of vehicle speed while changing the gear

Selection of intermediate gear ratios

TABLE 3.4 Gear Ratios of Transmissions for Heavy Commercial Vehicles

Gear	Allison HT70	Eaton Fuller RT-11608	Eaton Fuller RT/RTO-15615	Eaton Fuller RT-6613	ZF Ecomid 16S 109
1	3.0	10.23	7.83	17.93	11.86
2	2.28	7.23	6.00	14.04	10.07
3	1.73	5.24	4.63	10.96	8.40
4	1.31	3.82	3.57	8.61	7.13
5	1.00	2.67	2.80	6.74	5.71
6	0.76	1.89	2.19	5.26	4.85
7		1.37	1.68	4.11	3.97
8		1.00	1.30	3.29	3.37
9			1.00	2.61	2.99
10			0.78	2.05	2.54
11				1.60	2.12
12				1.25	1.80
13				1.00	1.44
14					1.22
15					1.00
16					0.85
Value of K_g Calculated from Eq. 3.29	0.76	0.717	0.774	0.786	0.839

TABLE 3.5 Gear Ratios of Transmissions for Passenger Cars

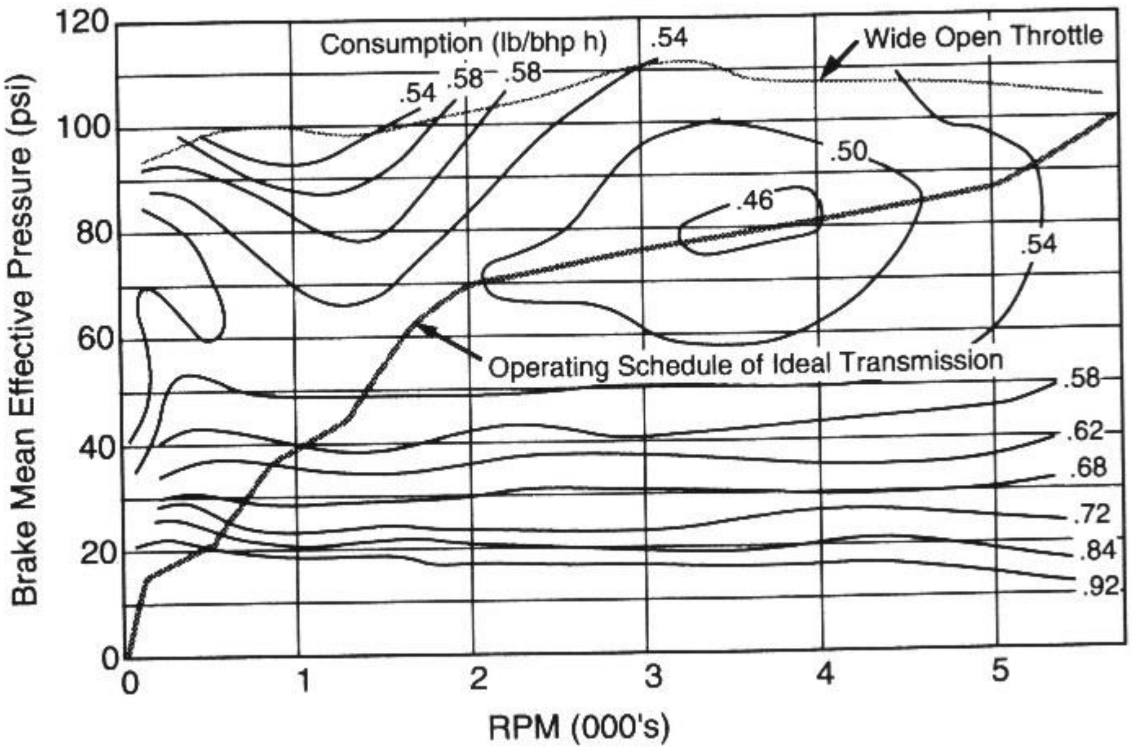
Vehicle	Transmission Type	Transmission Ratios 1st	2nd	3rd	4th	5th	Final Drive Ratio
Audi 80 1.8S	Manual	3.545	1.857	1.156	0.838	0.683	4.111
100	Manual	3.545	2.105	1.429	1.029	0.838	4.111
100 Quattro 2.8E	Manual	3.500	1.842	1.300	0.943	0.789	4.111
BMW 325i	Manual	4.202	2.49	1.67	1.24	1.00	3.15
535i	Manual	3.83	2.20	1.40	1.00	0.81	3.64
750i	Automatic	2.48	1.48	1.00	0.73		3.15
Buick Park Avenue	Automatic	2.92	1.57	1.00	0.70		2.84
Cadillac Seville	Automatic	2.92	1.57	1.00	0.70		2.97
Chrysler Voyager SE	Automatic	2.84	1.57	1.00	0.69		3.47
Ford Mustang GT	Manual	3.97	2.34	1.46	1.00	0.79	3.45
Crown Victoria	Automatic	2.40	1.47	1.00	0.67		3.08
Honda Accord GT2.2i	Manual	3.307	1.809	1.230	0.933	0.757	4.266
Mazda 323 1.6i GLX	Manual	3.42	1.84	1.29	0.92	0.73	4.11
929 3.0i GLX	Manual	3.48	2.02	1.39	1.00	0.76	3.73
Mercedes-Benz 230CE	Manual	3.91	2.17	1.37	1.00	0.81	3.46
300E	Automatic	3.87	2.25	1.44	1.00		3.27
600SEL	Automatic	3.87	2.25	1.44	1.00		2.65
Mercury Cougar LS	Manual	2.40	1.47	1.00	0.67		3.27
Nissan Micra LX	Manual	3.41	1.96	1.26	0.92	0.72	3.81
Toyota Camry 2.0G i	Manual	3.285	2.041	1.322	1.028	0.820	3.944
Volkswagen Passat GT	Manual	3.78	2.12	1.43	1.03	0.84	3.68
Volvo 960	Automatic	2.80	1.53	1.00	0.75		3.73

Wong Table 3.4 & 3.5:
typical gear ratios

Selection of intermediate gear ratios

- However nowadays, the selection of the gear ratios has become a very complex problems because of its strong impact on fuel consumption and emissions, because of the driving comfort.

Selection of intermediate gear ratios



Gillespie. Fig. 2.9 Selection of the gear ratio to follow the curve of maximum fuel economy