UNIVERSIDAD CARLOS III DE MADRID
DEPARTMENT OF MECHANICAL ENGINEERING

Ignacio Valiente, José Luis Pérez Díaz, David Mauricio Alba Lucero y Efrén Diez Jiménez

MACHINE THEORY
ANALYSIS OF GEAR TRAINS

Course 2010/11

INTRODUCTION

The aims of this practical work are:

- to familiarize students with the use of gear trains and the arrangement of gears in it;
- introduce the students with the gear train calculations.

A gear train is any collection or set of several gears that are engaged. On a practical level, the gear trains are used when it is not possible to transmit a given motion between two shafts or trees, with only a couple of gears.

Gear trains, in its many provisions, are widely used in different industrial sectors, as well as speed reducers systems and torque multipliers (Figure 1).

The course of this practice will focus on the study of gear trains used in the automotive sector, gearboxes and differentials.

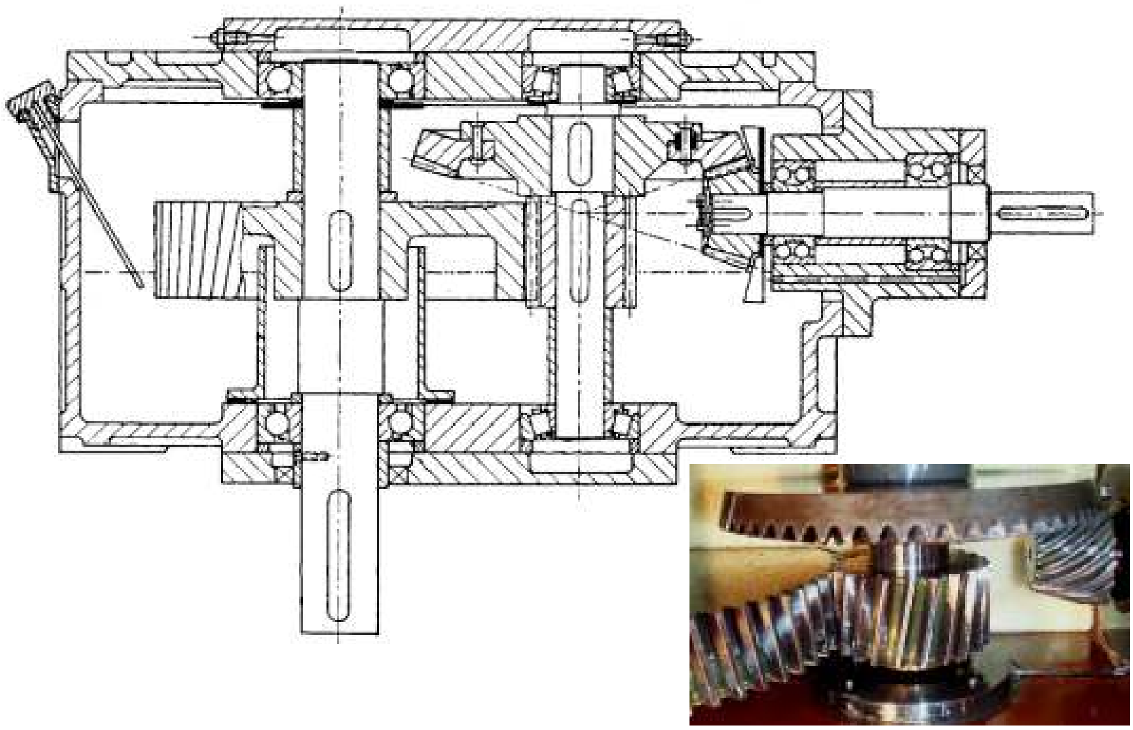


Figure 1. Diagram of a reducing box and the photo of it

GEARBOXES OF CARS

Gearboxes of cars, looking both at its construction and its operation can be classified into manual and automatic control gearboxes. The addition of electronic devices makes this classification a bit vague. The distinction between manual gearbox and automatic is just functional. Manual is the change in which the driver connects the gear ratios by a mechanical process without any other control system. Automatic is the change in which relationships can be modified without involving the human factor.

Historically, a manual transmission consists of sequences of pairs of gears that transfer different ratios depending on the progress that the driver has selected with a gear lever. Automatic gearboxes, however, consist of epicyclic gear trains, activating a hydraulic system through clutches, depending on engine speed, vehicle speed and throttle position.

EXPLANATION OF THE USE OF GEARBOXES

All cars need a gearbox because the power and torque developed by internal combustion engines vary depending on the speed. Normally, the highest torque is obtained at a lower power. Figure 2 shows the characteristic curves of power and torque depending on the speed of the motor. It is noted that the maximum torque is achieved at 3000 rpm., While the maximum power at 5800 rpm. It is said that engine operation is stable in the range 3000-5800 rpm. The speed of 3000 rpm is the lower limit of stability of this engine.

Figure 2. Characteristic power and torque curves of a combustion engine of a car

It is clear that we must make the engine work in the stable speed range, regardless of the resistance encountered by the vehicle while driving. The gearbox is a device to achieve this performance by modifying speed and torque. Neglecting the losses:

$$P = T_1 \cdot \omega_1 = T_2 \cdot \omega_2$$

$$\omega_2 = \frac{T_1 \cdot \omega_1}{T_2} = \frac{R_1}{R_2} \cdot \omega_1$$

Gearboxes are very special gear trains. From an operational standpoint, these systems are transmitters between the engine and wheels. Its mission is to connect two devices with the same output speed of the motor, but in the meawhile generate different speeds for the wheels or even reverse the rotation when needed.

The presence of the gearbox in a transmission system is essential. Otherwise, the engine would not use its resources well. For example, if a vehicle had to climb a ramp, the load torque increases and the engine would not have enough power to continue at the same speed. To avoid this and to overcome the resistance torque it is necessary to place a mechanism which can vary the torque, according to the needs of the speed.

MANUAL GEARBOXES

Manual gearboxes have been developed greatly over time. Currently, manual gearbox with helical gears is used (Figure 3) to engage the serrated axes and to transmit torque.

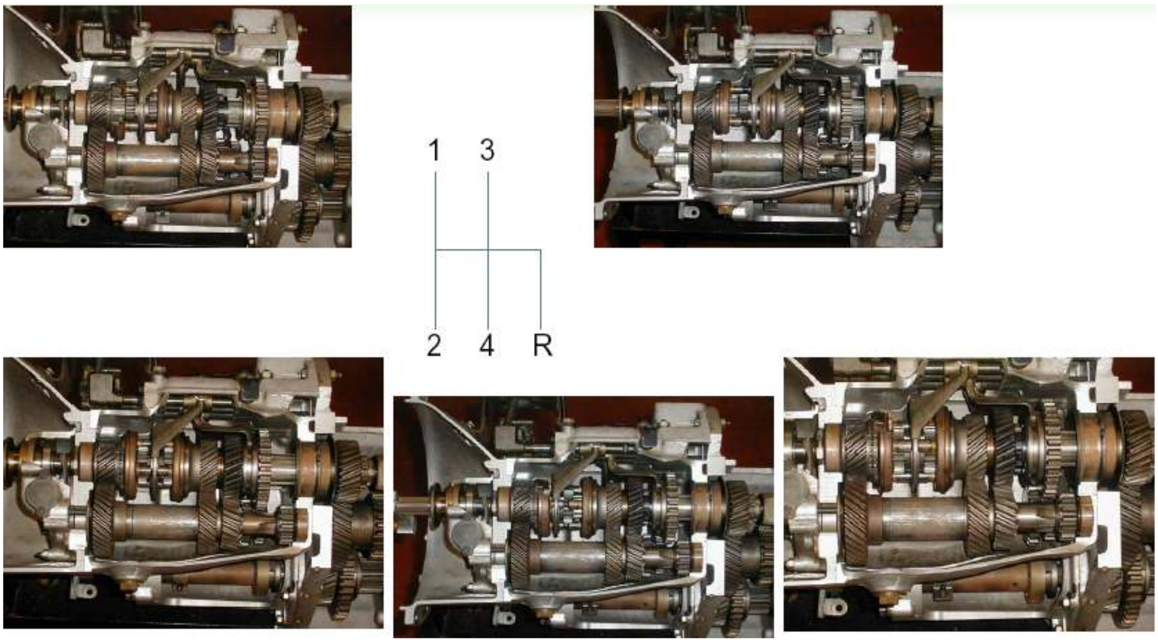


Figure 3. Photographs of different positions of a manual gearbox

The gears are constantly meshed with each other, to reduce the noise, vibrations etc while shifting gears. Synchronizers are usually arranged in any of the axes so that the total volume occupied by the gearbox is as little as possible. The operation of the synchronizers is driven by a shift linkage forks that displace synchronizers axially along the shaft.

Usually manual gearboxes consist of a series of gears placed on two, three or more axes. The whole mechanism cosists of:

- primary shaft - the recipient of the movement of the motor (normally consists of a single pinion);
- intermediate shaft - a transmitter shaft that consists of a gear that meshes with the primary shaft and the gears that mesh with the secondary shaft;
- secondary shaft - output shaft, that has the gears mounted with synchronizers, so that they can move all the time;
- reverse shaft - it is a separate wheel that stands between the secondary shaft and the intermediate shaft reversing the direction of rotation;
- displacement bars;
- synchronizers - used to match the speed of the secondary shaft gears with intermediate shaft gears, avoiding colliding teeth in the operation.

An example for calculation of gearbox speed for a Peugeot 405:

- Volume of the cylinders (cc): 1998
- Power (hp): 155
- Angular speed of the output shaft (rpm): 5600
- Maximum torque (mkgf): 19.3 / 3500
- Tires: 195/55 R14

Transmission ratio for the different speeds:

- r (1 st speed) = 13/38 = 0.342
- r (2 nd speed) = 23/43 = 0.535
- r (3 rd speed) = 25/32 = 0.781
- r (4 th speed) = 32/31 = 1.032
- r (5 th speed) = 37/28 = 1.321
- r (reverse) = 12/40 = 0.300

In addition to reductions of gearbox should consider reduction of the differential group. In this case it is:

r = 14/62 = 0.226

To obtain the whole transmission ratio for each gear it is needed to multiply the gearbox differntial ratio with the differential group ratio.

$$n_r = n_m \cdot r_t \qquad T_r = \frac{T_m}{r_t}$$

All the data is presented in Table 1.

Table 1. Transmission parameters of a Peugeot 405

Speed No.	Transmission Ratio (Gearbox)	Transmission Ratio (Differential Group)	Total Transmission Ratio	r.p.m.	Torque on the wheels (mkg)
1st gear	0.342	0.226	0.078	436.8	247.44
2nd gear	0.535	0.226	0.121	677.6	159.50
3rd gear	0.781	0.226	0.177	991.2	109.04
4th gear	1.032	0.226	0.233	1304.8	82.83
5th gear	1.321	0.226	0.299	1674.4	64.55
reverse	0.300	0.226	0.068	380.8	283.82

With these values you can calculate the rest that may interest you.

AUTOMATIC GEARBOXES

Automatic gearboxes have the same mission like manual gearboxes, but are designed so that the gear change is made without driver intervention. The change occurs in function of vehicle speed and throttle position, therefore it is not needed to press the clutch pedal and shift lever, causing the driver to be aware of fewer things. This makes it a safer driving.

The basic mechanisms used in most automatic transmissions to obtain various ratios are planetary gear trains (Figure 4).

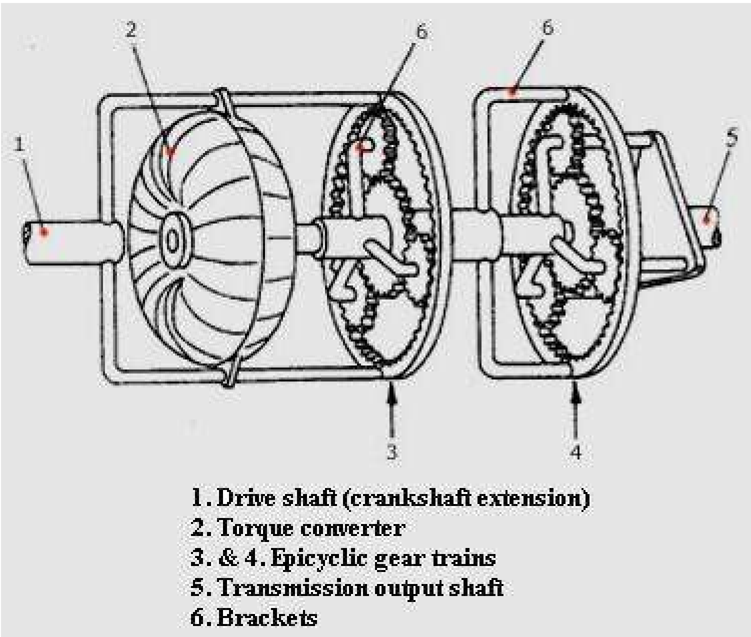


Figure 4. Simplified schematic of an automatic transmission planetary gear of two

The main advantage of these gear trains from those used in manual gearboxes is they are more compact and allow for distribution of torque at different points through the satellite and can transmit higher torques.

Planetary gear trains are composed of different elements:

- a central gear (sun);
- gears that revolve around the sun gear (planet gears);
- an outer ring with inward-facing teeth that mesh with the planet gear or gears (ring gear);

Figure 5 shows a BMW´s automatic 8-speed transmission.

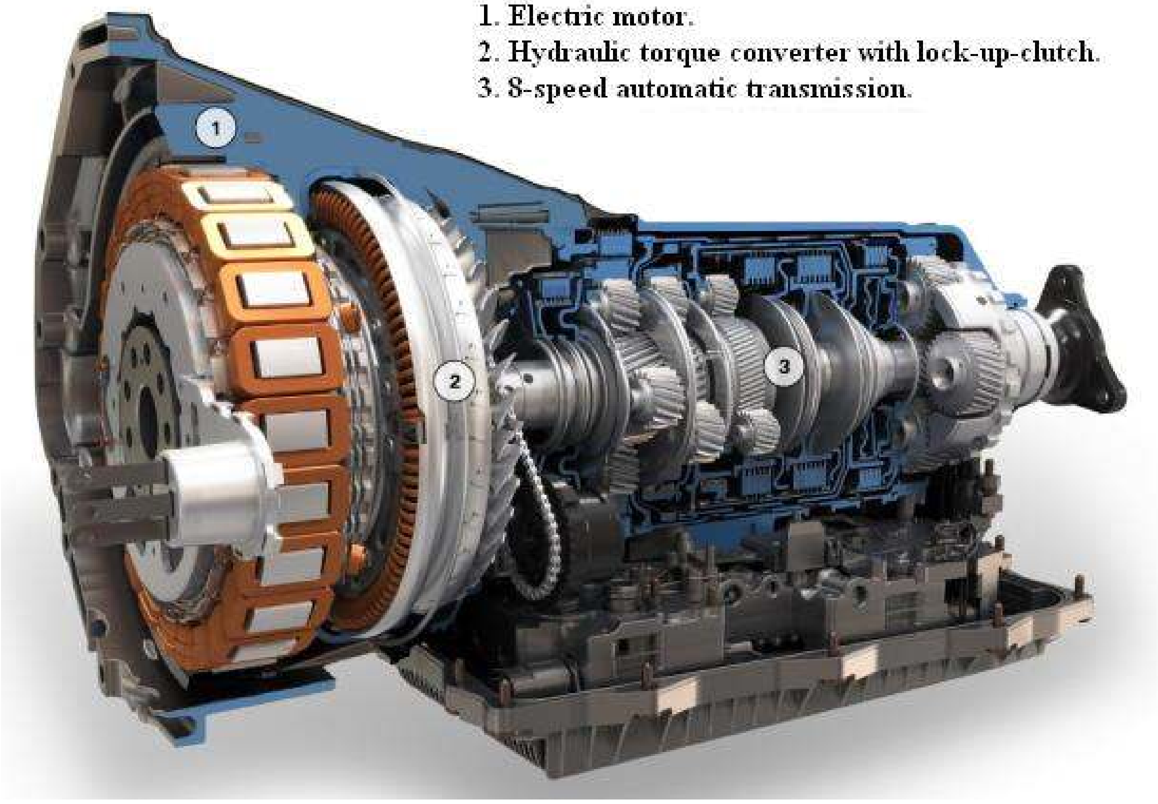


Figure 5. Automatic transmission of BMW

DIFFERENTIAL MECHANISM

When a vehicle with two wheel axles takes a curve, the outside wheel must travel a greater distance than the inside. In order to allow the wheels on the same axle move with different speeds it is needed to divide the shaft. Differential is a train of bevel gears that secures the union of the two halves (Figure 6).

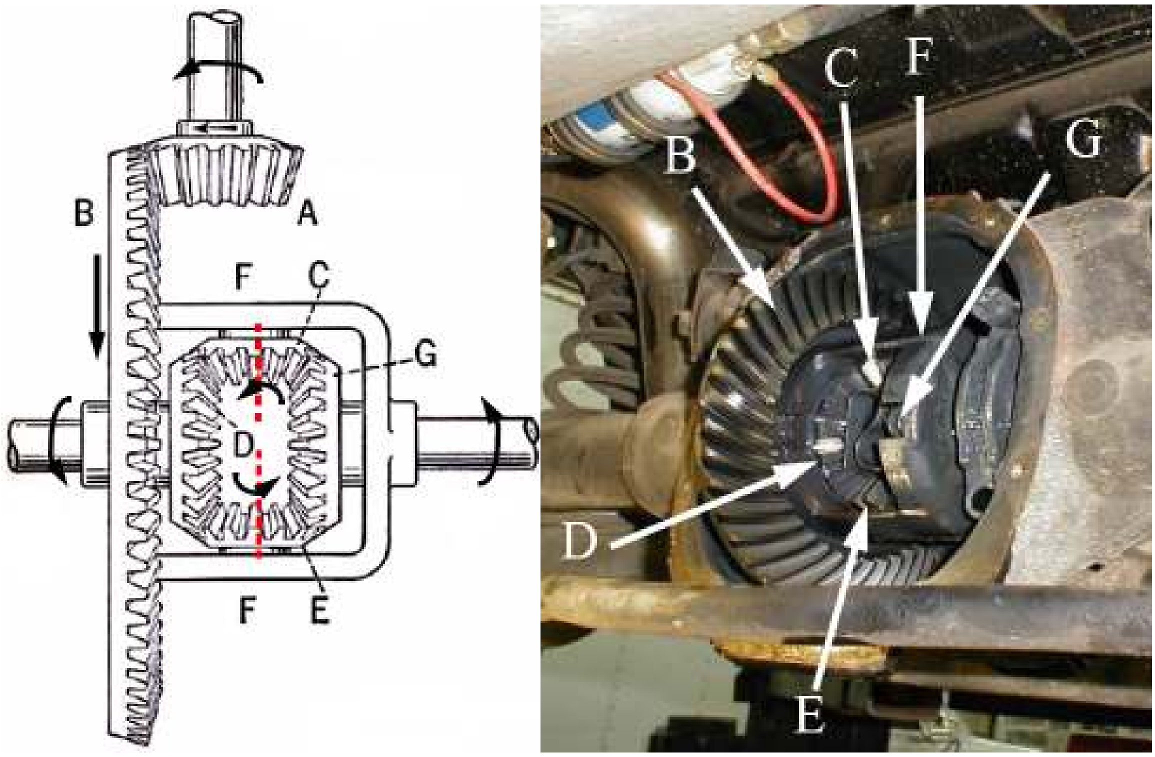


Figure 6. Schematic representation of an automobile and photograph of it

The differential mechanism (Figure 6) is composed of:

1. pinion drive shaft (A).
2. the gear (B) is attached to the housing or support (F) of the planetary gears;
3. planetary gears (C and E);
4. pinions (D and G).

The gears D and G are connected respectively to their wheels and when the vehicle is moving in a straight line both rotate at the same speed. There is no relative motion between the gears D and G and also planetary gears (C and E).

When the vehicle is running straight, the differential should behave as if it were rigid, and make both wheels turn at the same speed. This means that in this situation, the satellites do not rotate about its own axis. They act as wedges to transmit the movement of the driving shaft.

The differential divides torque to both wheels, or just to one of them depending on the need. If both wheels have the same charge differential provides the same torque to both. In case not evenly loaded, the distribution is proportional to the need.

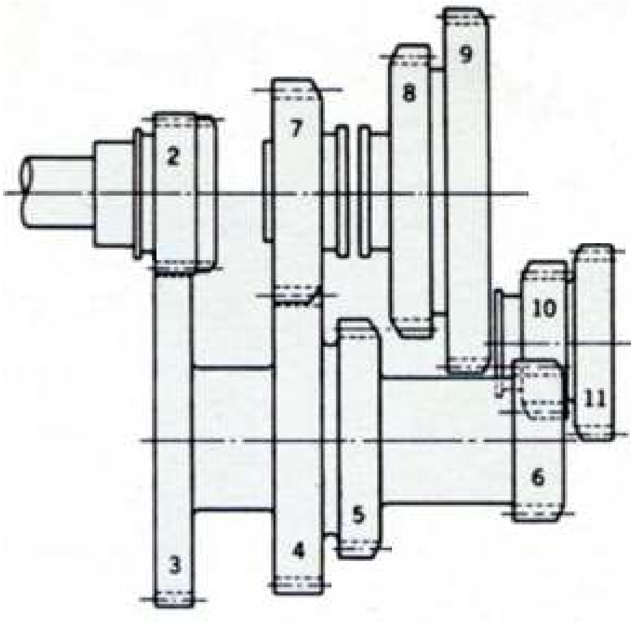
To avoid the problem of lack of torque, there are systems called self-locking differentials, which are able to block the wheel without grip, making it possible to transmit all of the torque to the wheel.

PRACTICAL APPLICATION

1. Behaviour of an automatic transmission with planetary gear.
2. Behaviour of a manual gearbox with cylindrical helical gear.
3. Behaviour of a bevel gear differential.
4. Practical study of the speed of a car depending on the selected gear: calculation of the transmission ratio of a manual gearbox with helical cylindrical gear and bevel gear differential.
   - It is proposed that a car studied achieves maximum power at 5800 rpm and has a tire diameter of 56 cm.
   - The abovementioned car has a gearbox as shown in Figure 7, with a number of gear teeth reflected in the table below.
   - It also has a differential as shown in Figure 8, with a number of gear teeth reflected in the table below.
   - The gears that can be developed by the gearbox of Figure 7 are shown in Figure 9.
   - Fill the data in Table 2.

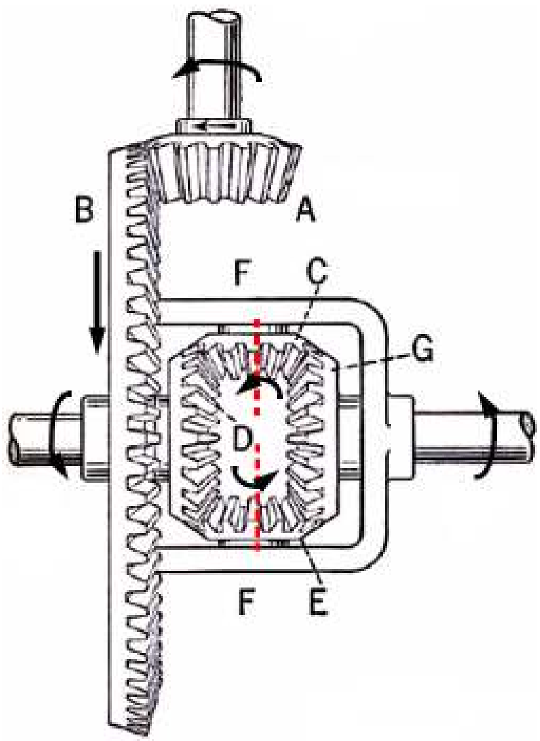
Table 2. Transmission parameters and speeds.

Speed No.	Gears Involved	Transmission Ratio (Gearbox)	Transmission Ratio (Differential Group)	Total Transmission Ratio	r.p.m.	Velocity (km/h)
1st gear						
2nd gear						
3rd gear						
4th gear						
Reverse						



GEAR	Nº of teeth
2	17
3	43
4	36
5	27
6	17
7	23
8	33
9	43
10	18
11	22

Figure 7. Representation of the gearbox of a car.



GEAR	Nº of teeth
A	12
B	48
C	12
D	18
E	12
G	18

Figure 8. Representation of a Differential of a car.

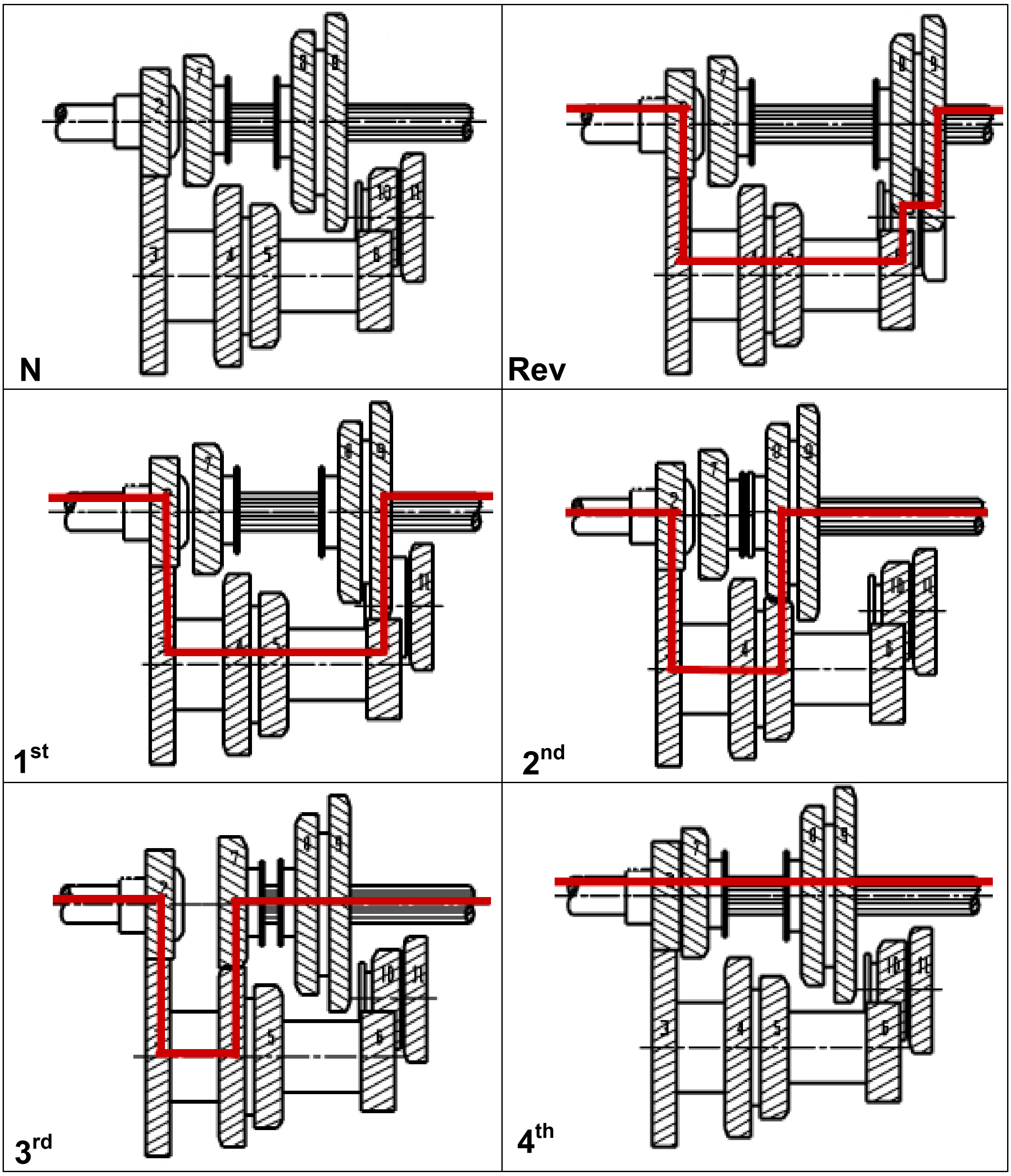


Figure 9. Representation of the gearbox of a car in different gears: Neutral, Reverse, and four speeds.