MECHANICAL MAINTENANCE

TRANSMISSION SYSTEMS

TRAINING MANUAL
COURSE EXP-MN-SM070
Revision 0

MECHANICAL MAINTENANCE

TRANSMISSION SYSTEMS

CONTENTS

1. GOALS

- Provide an overview of the various types of flexible couplings in the perspective of a maintenance operation.
- Be capable of differentiating between belts and chains to attempt to anticipate any possible problems.
- Be capable of recognising the various types of reduction gears.
- Understand how the different types of variable speed transmissions function.
- Understand how gearboxes function and their positioning.

2. INTRODUCTION TO TRANSMISSION SYSTEMS

2.1. THE FUNCTION OF TRANSMISSION SYSTEMS

Transmission is one of the most common functions of mechanical systems, that is to say mechanical devices designed to replace the hand of man.

The main function of a coupling is to link two shafts together to transmit power.

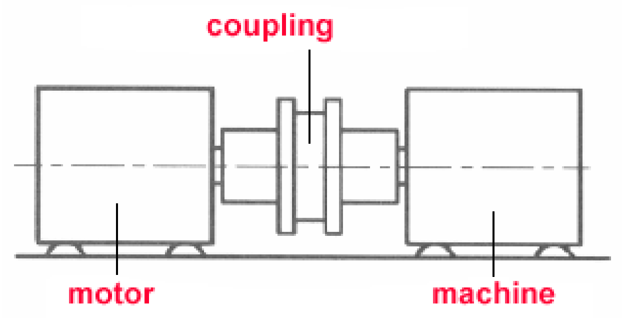


Figure 1: Schematic coupling diagram

A coupling may also fulfil other functions, such as correcting an incorrect axial positioning, or serving as a damper between two parts.

Depending on the mechanisms, transmission may concern:

- position
- movement
- force
- power

2.2. TRANSMISSION MODES

Several different modes of transmission can be used to ensure the link between two shafts.

- **Solid-contact transmission:**
  - by pressure: rope, belt
  - by obstacles: chain, notched belt, gears
  - by friction: wheel, belts, clutch

- **Fluid transmission:**
  - pneumatic: compressed air
  - hydraulic: water, oil
- **Contact-free transmission:**
  - electromagnetic: magnets, electro-magnets
- **Transmission with additional functions:**
  - elastic (flexible) coupling: to absorb shocks
  - universal joint, Oldham coupling: to overcome unwanted movements

3. COUPLINGS

3.1. THE FUNCTIONS OF COUPLINGS

The purpose of couplings is to ensure the transmission of power in rotation in a permanent way between two shafts that are more or less aligned, while keeping the same overall rotation speed and maintaining torsion stiffness.

In most cases, we will use a flexible coupling to compensate for any misalignment between the two shafts to be linked. A perfect alignment between two shafts will be extremely difficult to achieve. Without a flexible coupling, a poor alignment of the shafts will create loads that will damage the bearings.

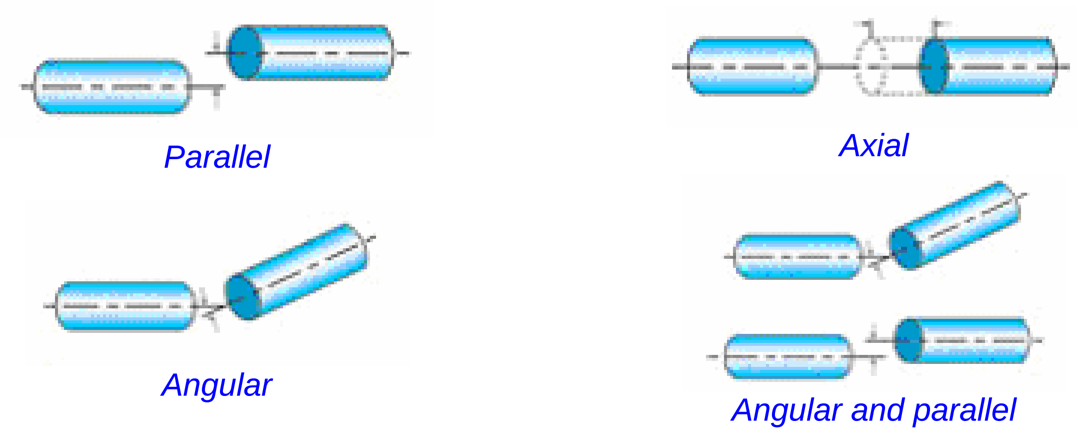


Figure 2: Possible misalignments

One of the other functions of flexible couplings is to damp the shocks and vibrations generated by the installation in operation, which will significantly limit the potential damage.

Caution: a coupling does not provide protection against overloading.

The choice of coupling must be made according to several criteria:

- Type of motor installation
- Power to be transmitted
- Coupling rotation speed
- Nature of the load
- Environment
- Shaft diameter

3.2. MAIN FLEXIBLE COUPLINGS

3.2.1. The function of flexible couplings

Flexible couplings must ensure the transmission of power in rotation in a permanent way between two more or less well aligned shafts, without changing the overall rotation speed and while keeping the torsion stiffness.

3.2.2. Internal teeth couplings

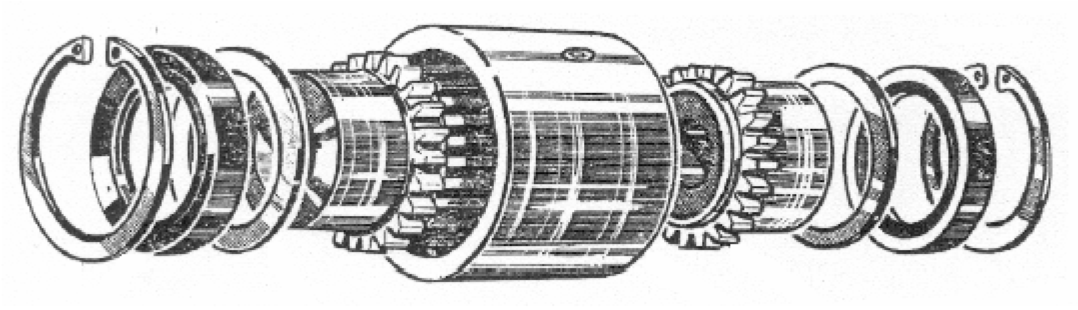


Figure 3: Internal teeth coupling

The two coupling plates are geared wheels with convex teeth completely linked to the shafts to be coupled.

These two plates mesh with the internal teeth of a sleeve (removable or one-piece) made of steel or a polyamide.

This association of steel and polyamide makes it possible to ensure maintenance-free operation without the need for any lubrication. Steel couplings, however, must obligatorily be greased.

These couplings are used when the misalignment between the two shafts to be linked must be compensated for.

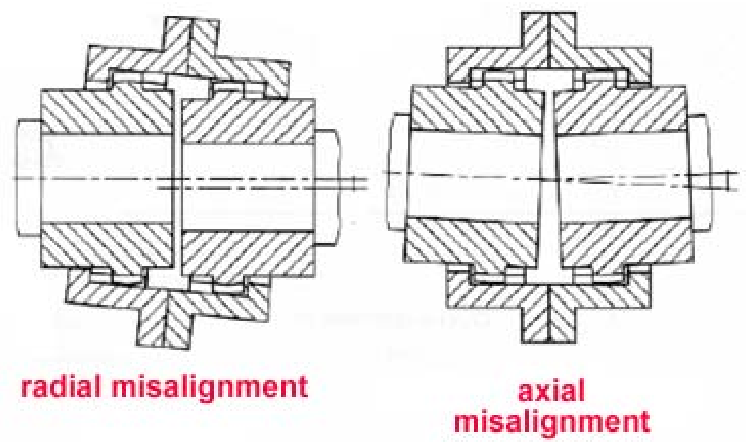


Figure 4: Cases of misalignment

Figure 5: Some examples of internal teeth couplings

3.2.3. Membrane couplings

With his type of coupling, the flexible element is a deformable membrane, that is rigid in terms of torsion. It is made either of a plastic material or of a steel sheet.

The coupling consists of two flanges and one or more membranes, attached to two flanges with screws.

Figure 6: Examples of membrane couplings

This type of coupling does not require any maintenance. It can be used for very high rotation speeds.

The membrane has six holes in it, which make it possible to ensure the link with the two flanges (three holes per flange).

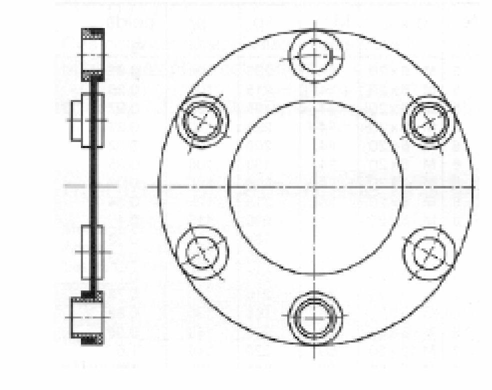


Figure 7: Detail of a membrane

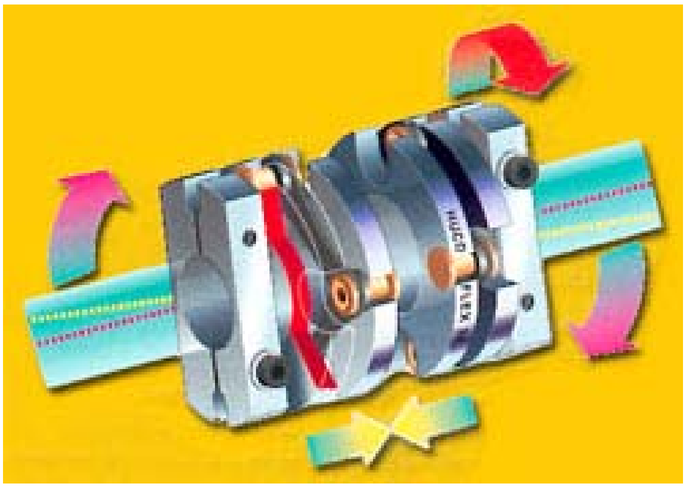


Figure 8: Torsion-resistant mode l/ No moving parts

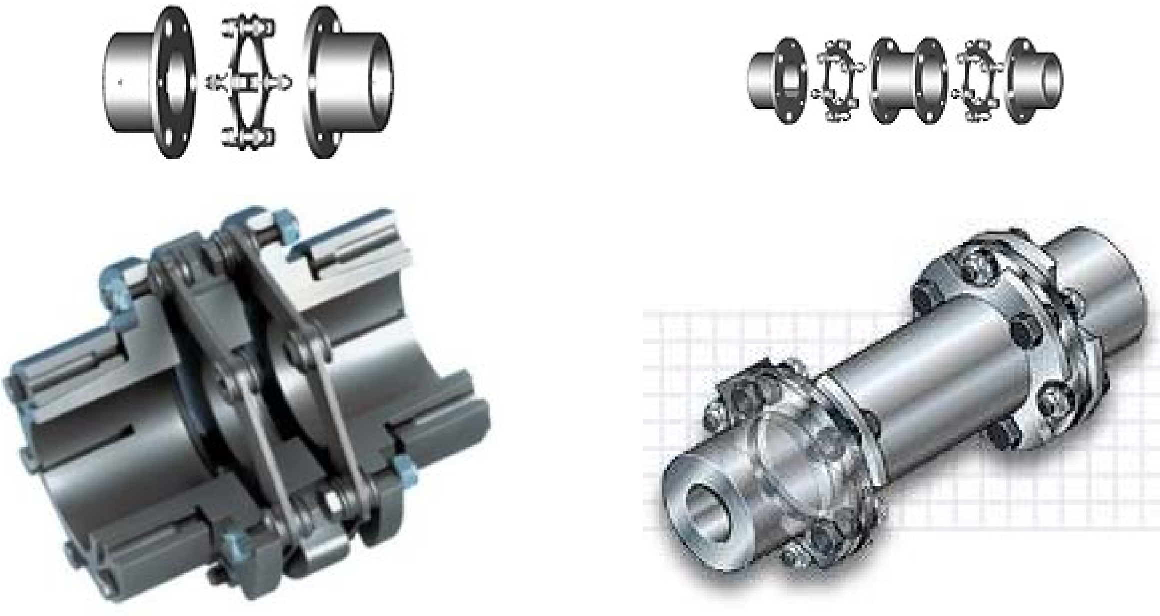


Figure 9: Some membrane coupling models

3.2.4. Chain couplings

The link between the two plates is transmitted by a double chain made of steel or nylon. Lubrication is essential in the case of a steel chain.

This coupling's plate's are in the form of toothed pinions.

Figure 10: Chain coupling

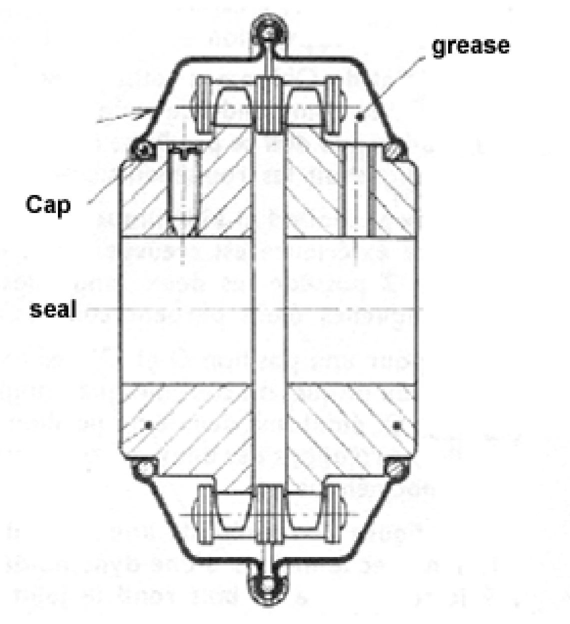
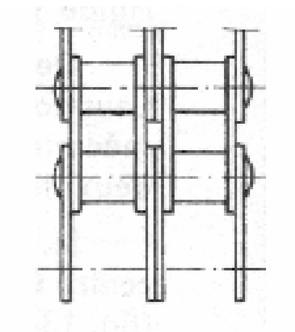


Figure 11: Detail of coupling and double chain



3.3. MAIN ELASTIC COUPLINGS

3.3.1. Function of elastic couplings

Like flexible couplings, elastic couplings ensure the transmission of rotation power but they also regularise the torque variations.

The elastic device is placed between two plates linked to the two shafts to be coupled.

This device takes up the alignment defects due to any assembly imperfections, regularises the motor torque (absorbs any instantaneous overloading), damps the vibrations and provides a great degree of start-up flexibility.

Generally, the following materials are used to make the elastic element:

- Elastomer or polyamide
- Rubber (synthetic or natural)
- Variable flexibility metallic spring

Natural rubber is often chosen because of its good dynamic qualities.

It can withstand relatively high temperatures (up to approximately 70° C), and is not damaged by accidental splashing with petroleum products (oil, petrol, diesel, etc.).

If permanent utilisation of the rubber elastic element at a temperature higher than 70° C is envisaged, this will lead to a gradual degradation in the qualities of the rubber, in which case products better suited to this situation should be preferred (special elastomers or polyamides).

The elastic device may consist of several blocks or may simply be made of a single piece.

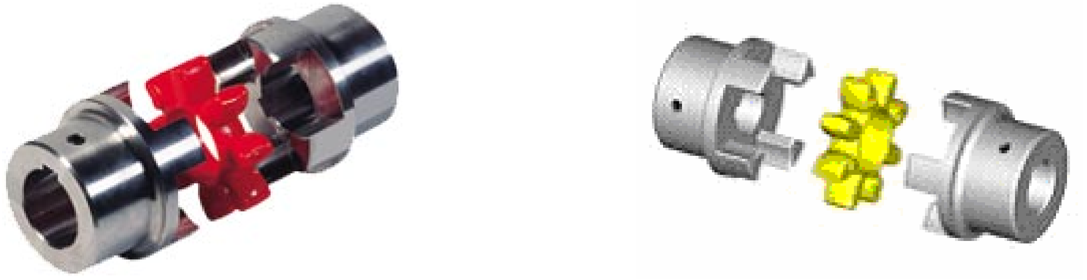


Figure 12: Single-piece elastic elements

Figure 13: Elastic element with pins

The resistance of an elastic coupling depends on the type of load exerted on the elastic device:

- compression force
- shear force
- traction force

Rubber and its derivatives can withstand greater pressure forces than shear or traction forces.

3.3.2. Types of elastic couplings

3.3.2.1. Elastic couplings submitted to pressure

These couplings are not designed to correct shaft alignment defects but only to compensate for axial shifts and damp shocks due to transmission.

Two poorly aligned shafts on this type of coupling will cause rapid wear of the elastic pads and additional forces on the shafts and their bearing blocks.

- **With "SEGOR SOUPLEX" sleeves**

  Each plate has four radial arms, with prismatic slots in which the elastic blocks are placed.

Figure 14: Example of a "SEGOR SOUPLEX" coupling

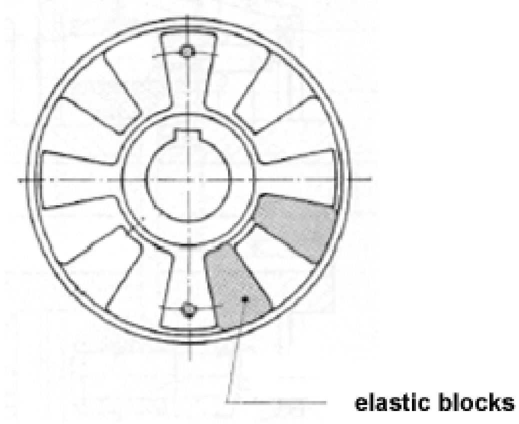


Figure 15: Detail of a plate with elastic blocks

Other similar coupling models exist, but they use elastic elements with a different shape.

Spherical studs, if they are housed between two flat surfaces, give a very good progressivity to the deformation.

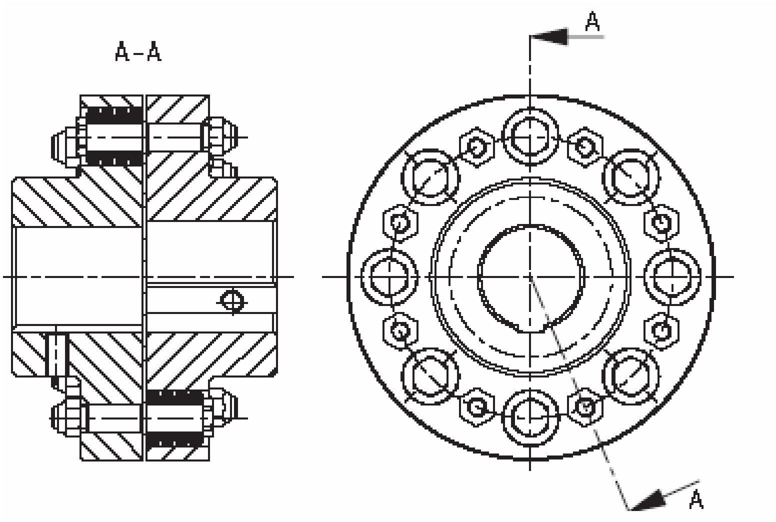


Figure 16: Detail of a spherical stud coupling

The "**Paulstra**" brand includes most of the coupling models that exist in the industry.

- **PAULSTRA MINIFLEX**

  This coupling's design gives it the following properties:

  - Socket mounting
  - Compact cylindrical shape
  - Elastic part that works in compression

Its main advantages are its small size and ease of use.

This coupling is not designed to receive axial traction forces, because that might cause the elastic element of the drive studs to slip out of the sleeves.

Figure 17: "PAULSTRA MINIFLEX" coupling

- **PAULSTRA JUBOFLEX**

This consists of two hubs with three radial arms, and a hexagonal-shaped rubber ring which provides the elastic link.

The elastic ring is submitted at assembly to compression pre-stressing so as to ensure that the rubber cannot be submitted to any traction constraint.

Thanks to this pre-stressing, this coupling has a very good resistance to deformation.

This type of coupling has very good torsion, axial and conical elasticity. But its radial elasticity is not as good.

Figure 18: "PAULSTRA JUBOFLEX" coupling

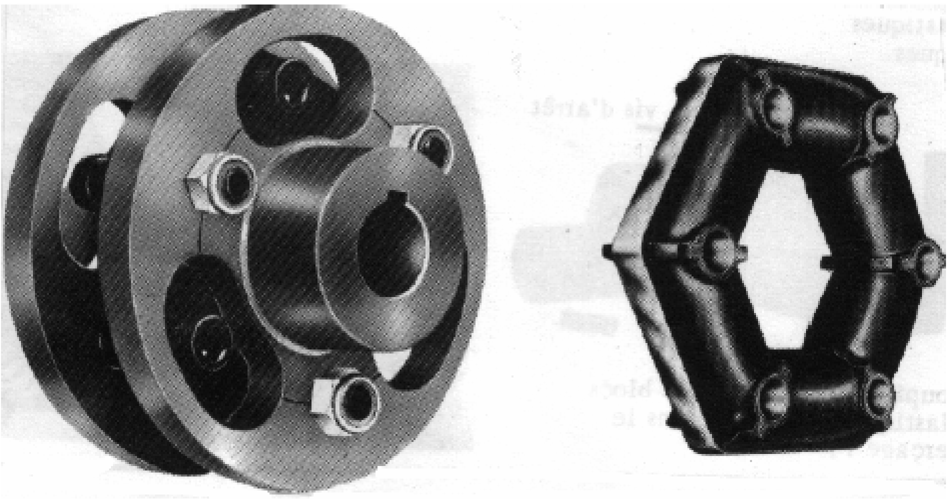


Figure 19: Example of a "PAULSTRA JUBOFLEX" coupling

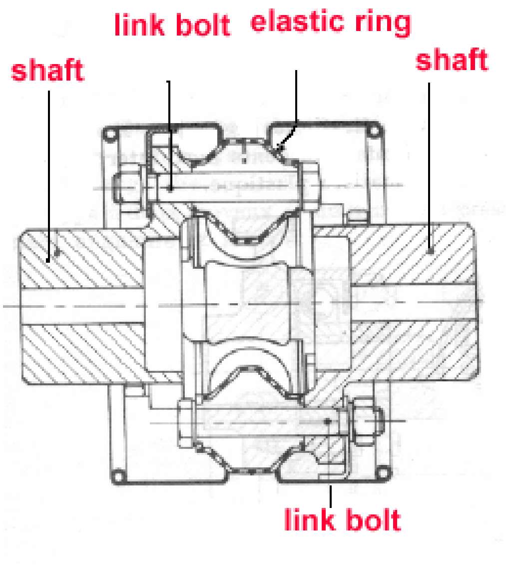
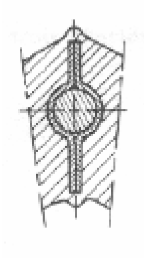


Figure 20: Setup detail

Figure 21: Section view of an elastic element



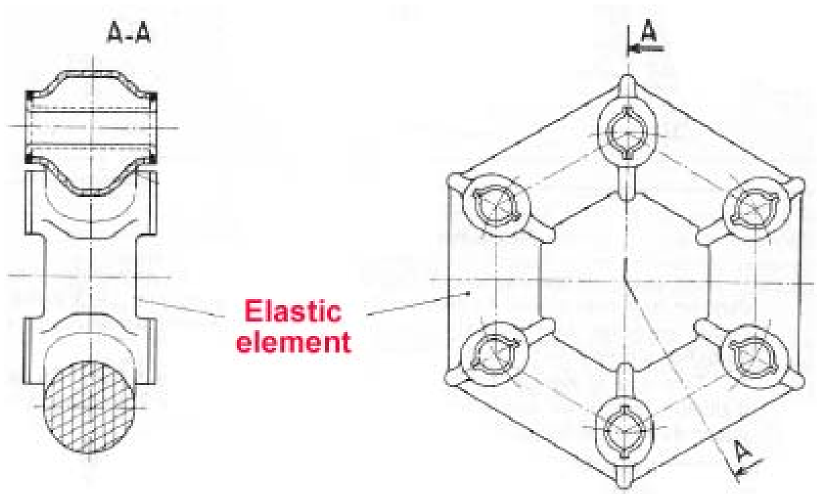


Figure 22: Detail of the elastic element

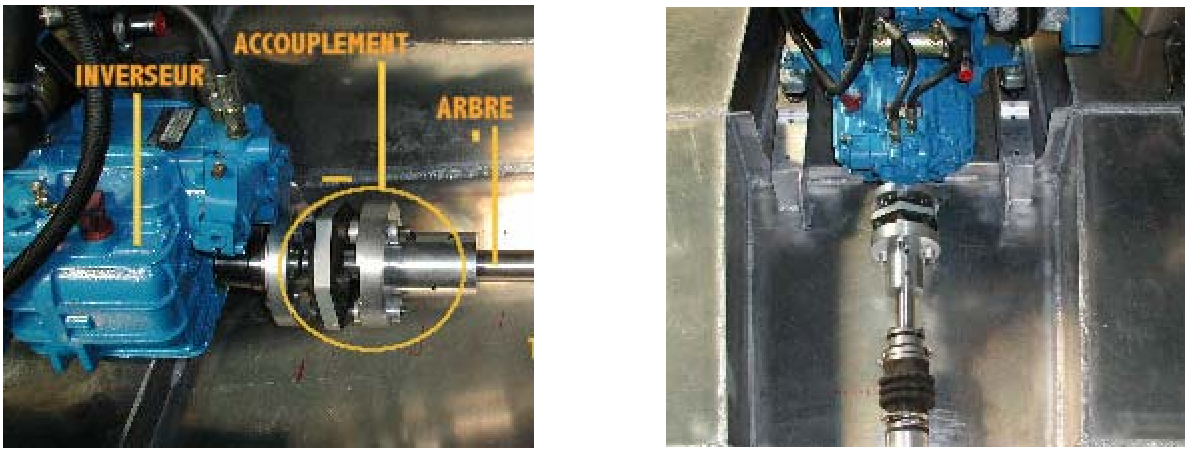


Figure 23: A POULSTRA coupling in position (boat engine)

3.3.2.2. Elastic couplings submitted to shear forces

This type of coupling is usually used for transmissions that have a pulsating rotation torque.

- **"COMELOR" sleeve**

The elastic elements consist of cylinders made of rubber. The twelve elements are housed for half in one of the twelve semi-cylindrical recesses in each plate.

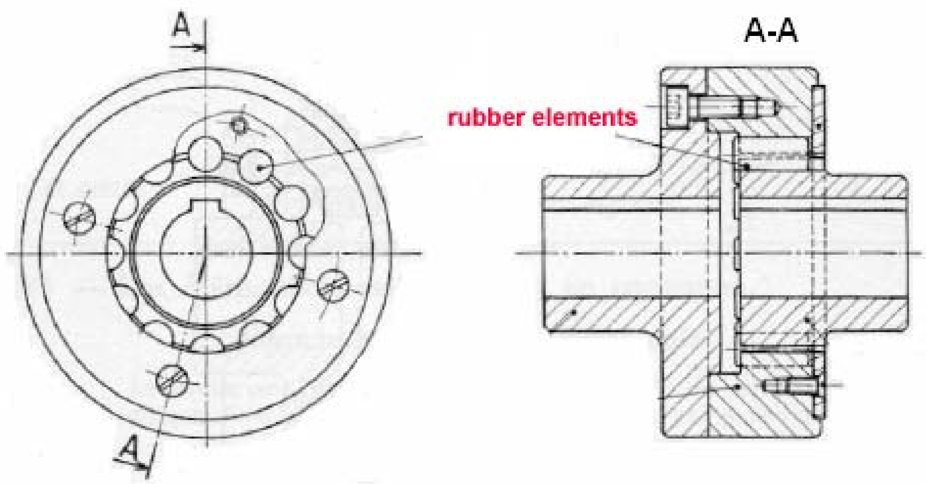


Figure 24: "COMELOR" coupling

- **"COLOMBES FLEXIMA" sleeve**

The blocks (4), made of fabric-covered rubber, are pressed against the rings (1 and 2) of one of the plates. Ring (3), which belongs to the second plate, is pressed against the middle of the block's length.

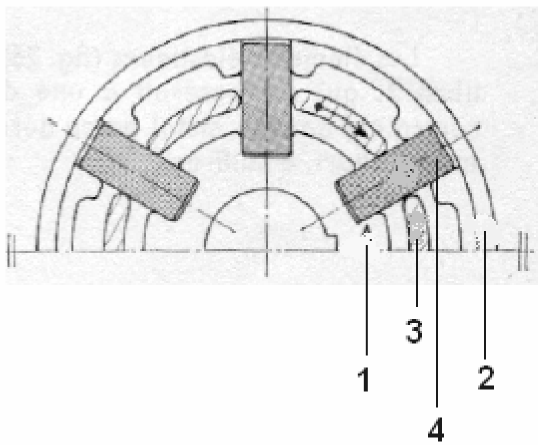


Figure 25: Detail of a "COLOMBES FLEXIMA" coupling

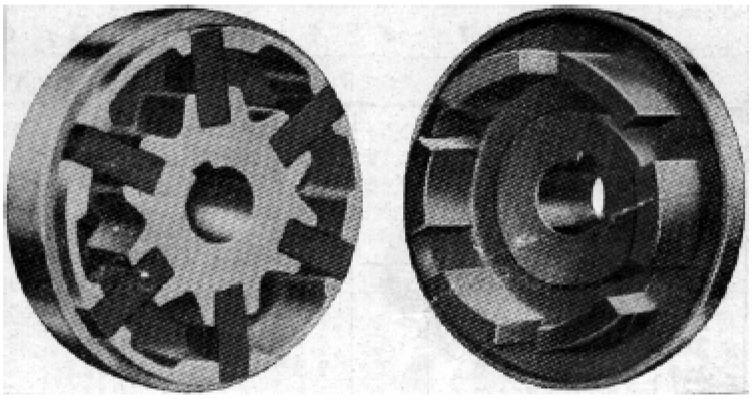


Figure 26: Example of a "FLEXIMA" sleeve

3.3.2.3. Elastic couplings submitted to traction

- **Rubber band sleeves**

The pin holes have very different radiuses, so that at rest the bands are in the radial position.

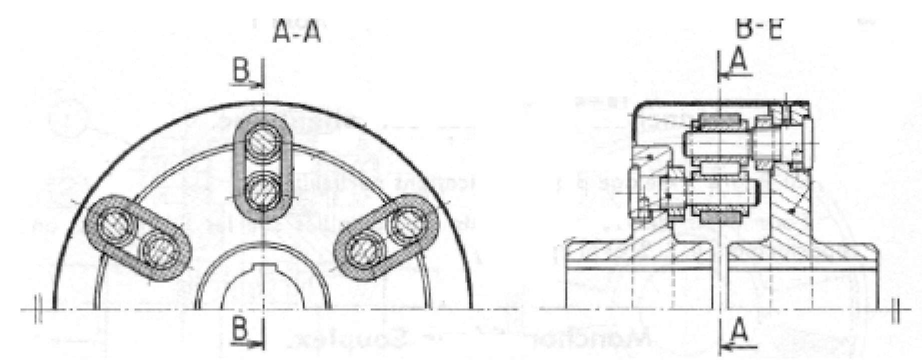


Figure 27: Rubber band sleeves

- **Endless belt sleeves**

An endless belt passes over pins fixed alternately to the two plates.

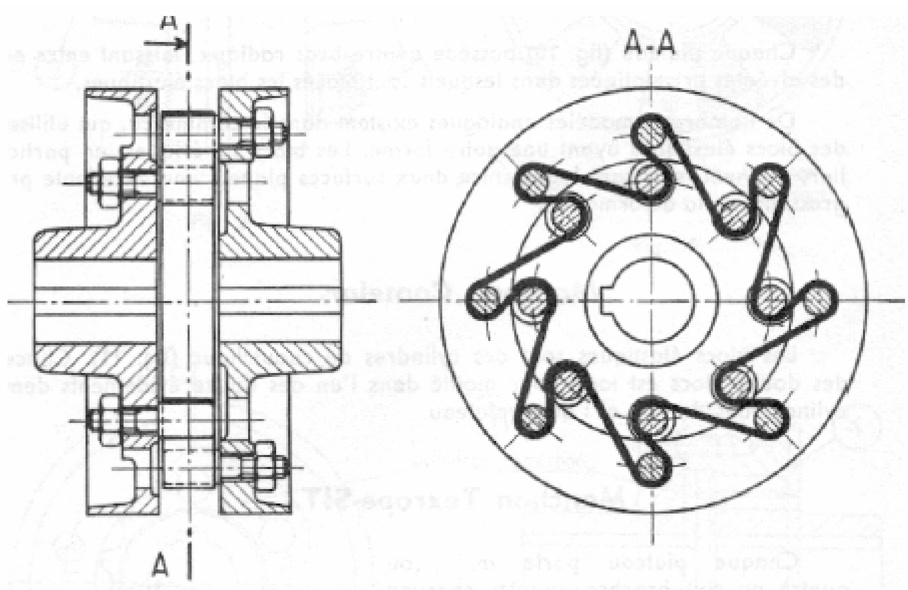


Figure 28: Endless belt sleeve

3.3.2.4. Other elastic couplings

- **"FLEXACIER" sleeve (CITROEN)**

Figure 29: Examples of "FLEXACIER" couplings

The lateral surface of each of the two plates (1 and 2) has lengthwise grooves made with a very precise degree of regularity.

These grooves flare out on the faces of the plates placed opposite them.

An endless blade (spring) made of special steel (3) passes through all the grooves.

A sheetmetal box (4) filled with grease protects the spring and groove. Sealing is ensured by seals made of synthetic rubber (5). (Figure 30)

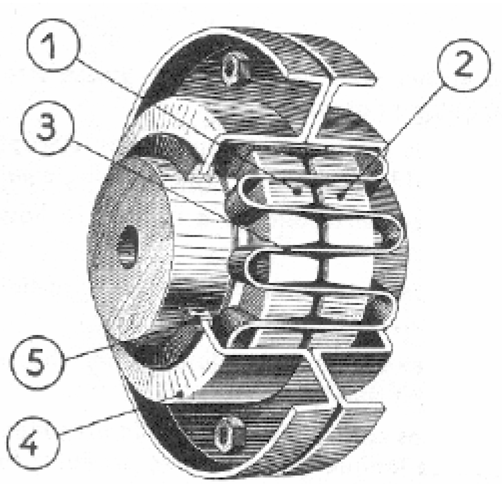


Figure 30: "FLEXACIER" coupling elements

The blade's elastic deformation makes it possible to balance the torque transmitted. The blade serves as a variable flexibility spring because the points at which it presses against the plates get closer to each other gradually as the deformation increases

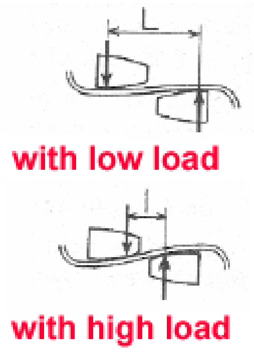


Figure 31: The loads on the spring

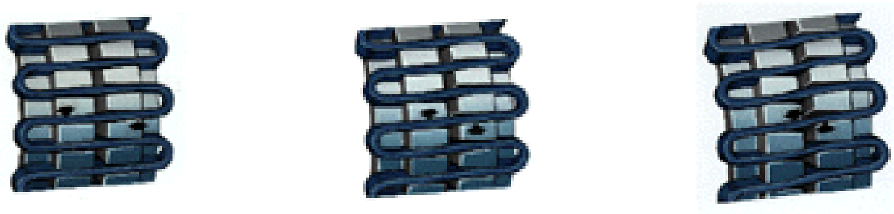


Figure 32: Detail of the loads on the spring

Figure 33: Detail of the possible misalignments

“PERIFLEX" coupling

The "PERIFLEX" coupling is also called rubber tyre coupling.

This is a coupling where the elastic element takes the form of a tyre fitted with an armature made up of layers of cotton or viscose fabric, inserted between the layers of rubber.

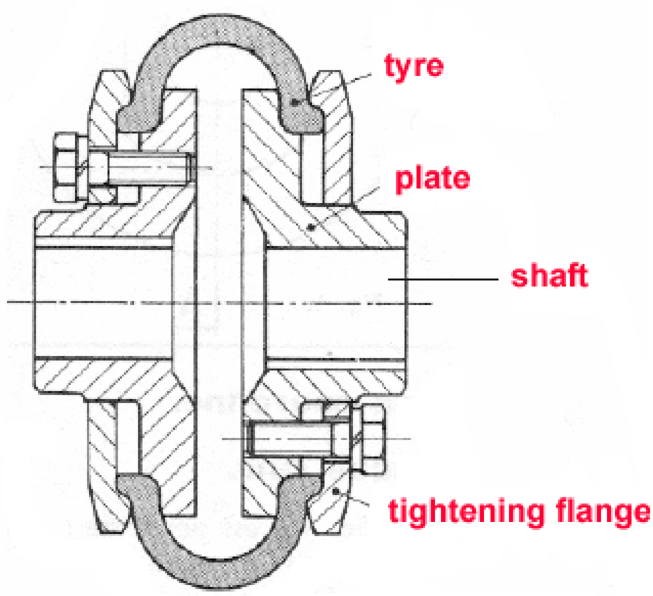


Figure 34: Setup detail

The tyre has an armature coated with vulcanized rubber that forms a whole. This tyre can contain between two and fourteen layers of fabric, depending on the torque to be transmitted.

The rubber tyre is placed between the plates which are fixed to the shafts and the tightening flanges. These tightening flanges must simply be tightened correctly to obtain a correct and regular drive.

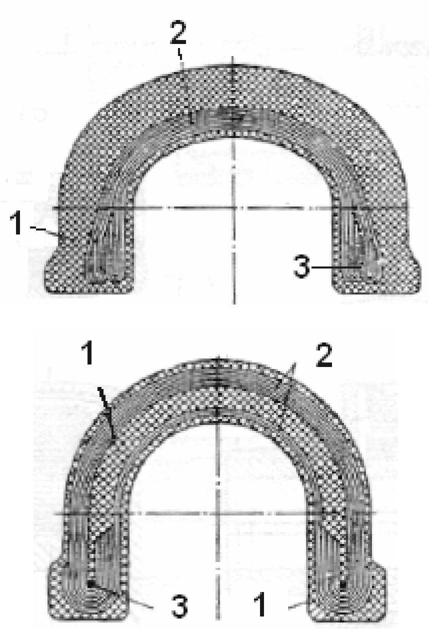


Figure 35: Tyre cross-section

1 *: rubber coating*
2 *: layers of fabric*
3 *: steel wire*

Figure 36: Example of a rubber tyre coupling

3.4. MAIN RIGID COUPLINGS

3.4.1. The function of rigid couplings

Rigid couplings are used to transmit rotation power in a permanent way between two shafts that are perfectly aligned (and will remain perfectly aligned in operation) as if they were welded together, without any change of the assembly's rotation frequency.

This makes it possible to extend the length of the shaft. The alignment errors are not in any way corrected, in fact they are even amplified. The transmissible torque is very high.

3.4.2. Sleeve coupling

The ends of the two shafts are fitted in the bore of a cast iron or steel sleeve. The shaft/sleeve link is completed by pinning for low power levels or by a keying system.

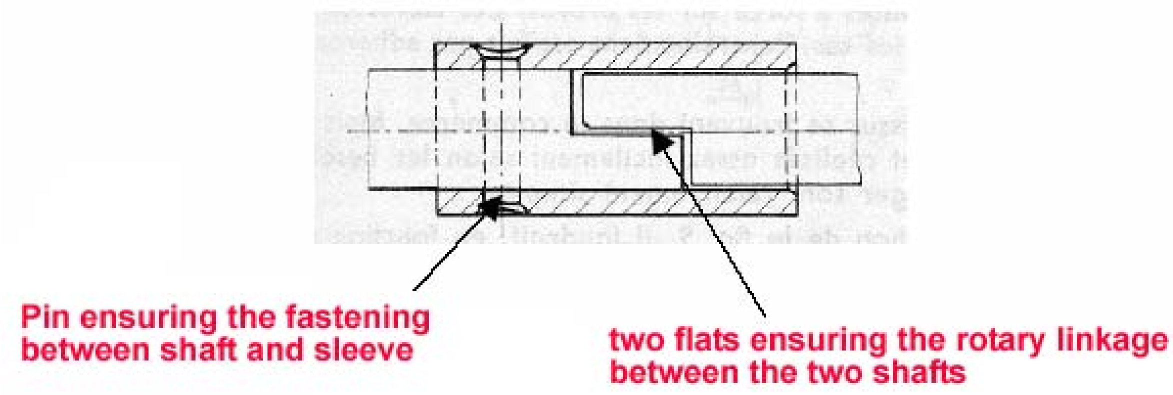


Figure 37: Detail of a rigid link with sleeve and flats

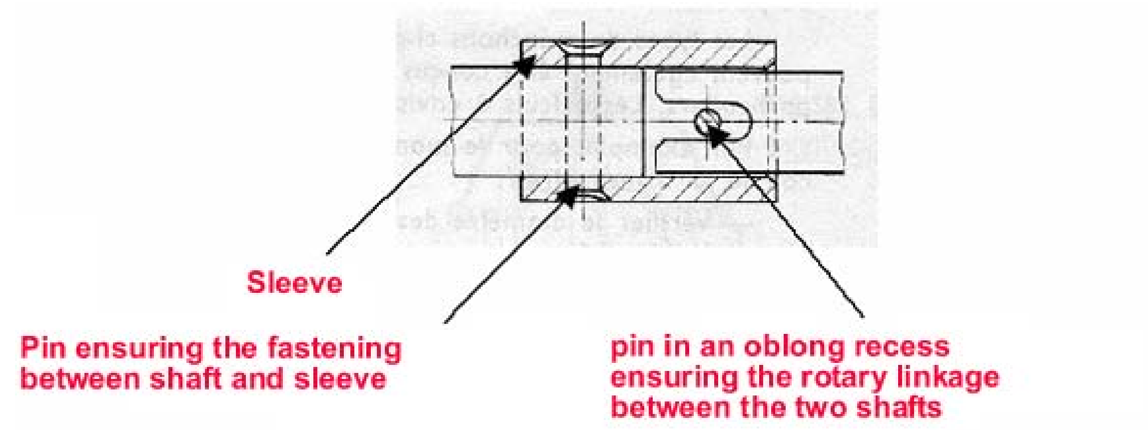


Figure 38: Detail of a rigid link with pin

With a rigid coupling with forced keying, the sleeve is simply made integral with each shaft by means of a gib-head key.

With these couplings, the relative centring of the two shafts is only ensured if they are strictly of the same diameter.

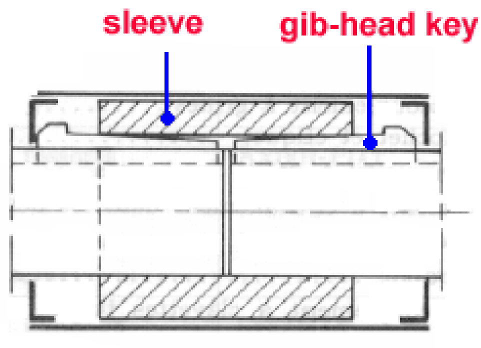


Figure 39: With gib-head key

It is only possible to uncouple and radially offset one of the shafts if the other one can receive the whole sleeve.

Assembly and disassembly are made difficult by the presence of gib-head keys.

This type of coupling is highly tolerant concerning the relative axial positioning of the two shafts and of the sleeve.

3.4.3. Split coupling

This is made of two shells pressed on to the ends of two shafts by means of bolts.

Rotational drive is ensured by adhesion. Safety can be improved by keying.

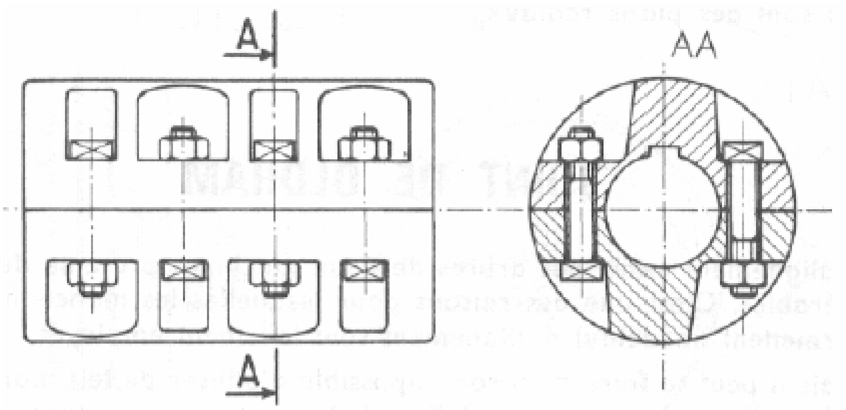


Figure 40: Sleeve coupling

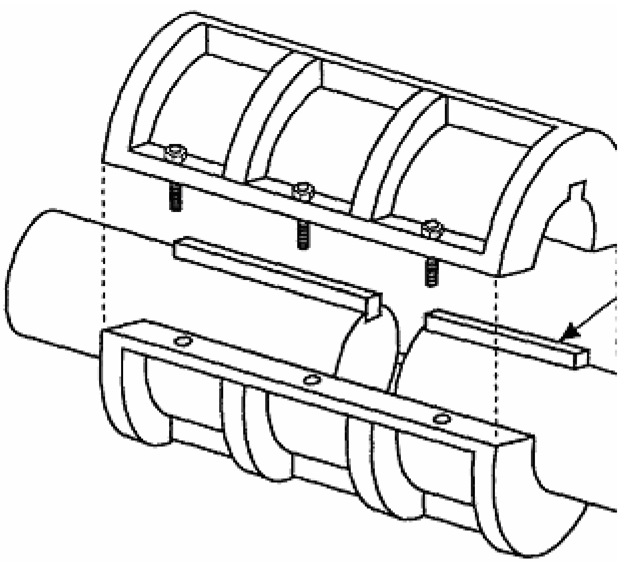


Figure 41: Detail of key

This is a highly tolerant coupling concerning the axial positioning of the two shafts.

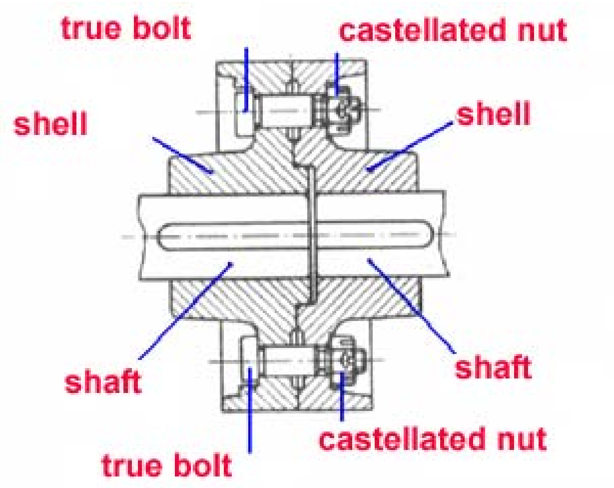
Assembly and disassembly are very easy.

The coupling will only be correct if the shafts are of exactly the same diameter.

Figure 42: Sleeve coupling

If the shells are made by casting, they may be poorly balanced because they are of different weights.

3.4.4. Plate coupling



The two plates are fitted on to their respective shaft end. The transmissible torque can be increased by keying. The two plates are held in position with respect to each other by a flat contact associated with a short centring device.

The torque is transmitted and the plates are held in their respective positions by means of true bolts that are blocked by means of castellated nuts and split pins.

Figure 43: Detail of a plate coupling

Disassembly is very difficult with this type of coupling.

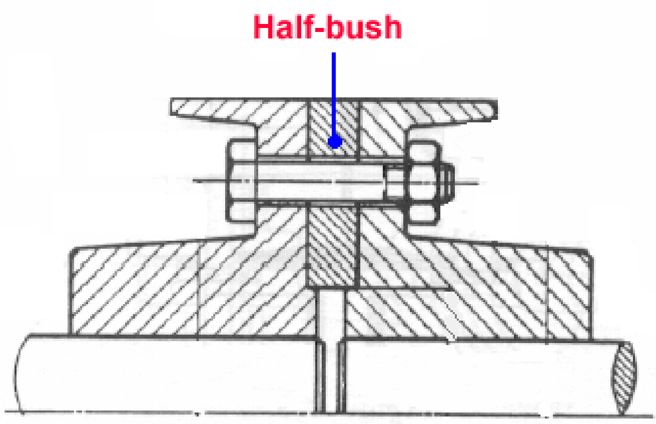
Uncoupling or removal of one of the plates requires an axial movement.

The key feature of this coupling is that it is very robust.

This type of coupling also exists with centring ensured by two half-bushes.

With this principle, disassembly is easier. The plates are centred by the two half-bushes.

Figure 44: With half-bushes



3.4.5. Flange coupling

Like the other rigid couplings, this coupling requires a perfect alignment of the two shafts to be linked.

The slightest alignment defect will cause vibrations and alterations (twisting and bending) of the shaft, which might damage the installation.

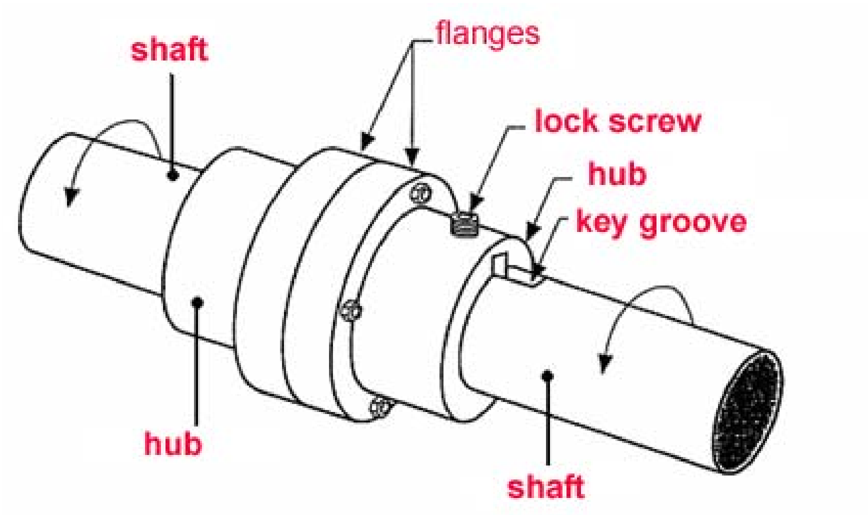


Figure 45: Flange coupling

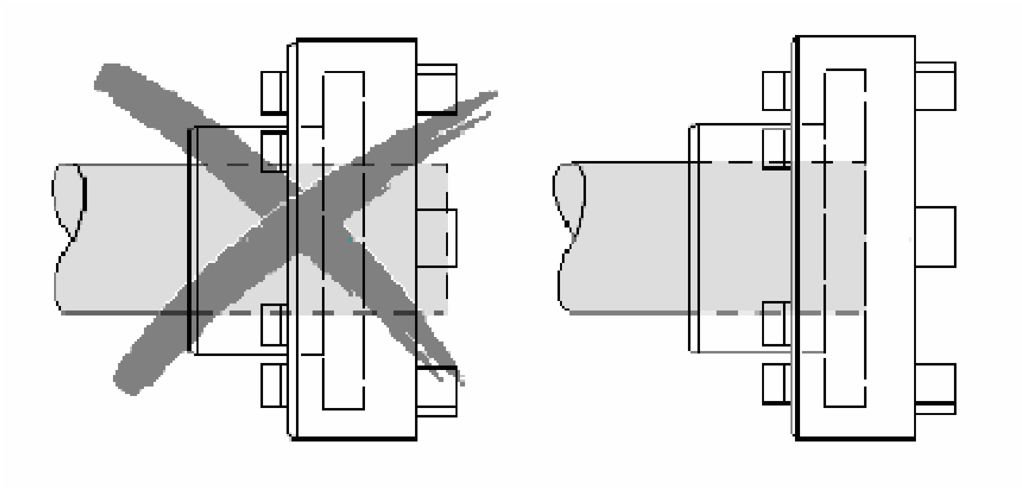


Figure 46: Assembly method

3.5. UNIVERSAL JOINT

The universal joint is a mechanical device that ensures an angular rotation transmission between two shafts whose geometrical axes converge on the same point.

It is used to couple two rotating shafts whose angular positions with respect to each other can vary: for example, to drive a receiver which will obligatorily be misaligned with the motor.

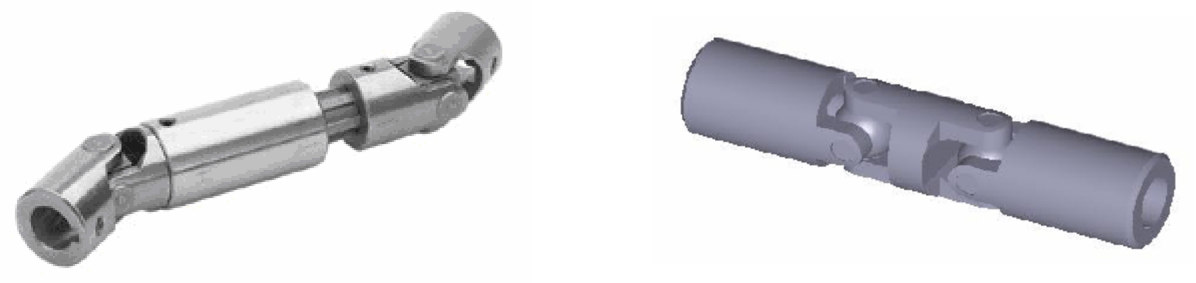


Figure 47: Examples of universal joints

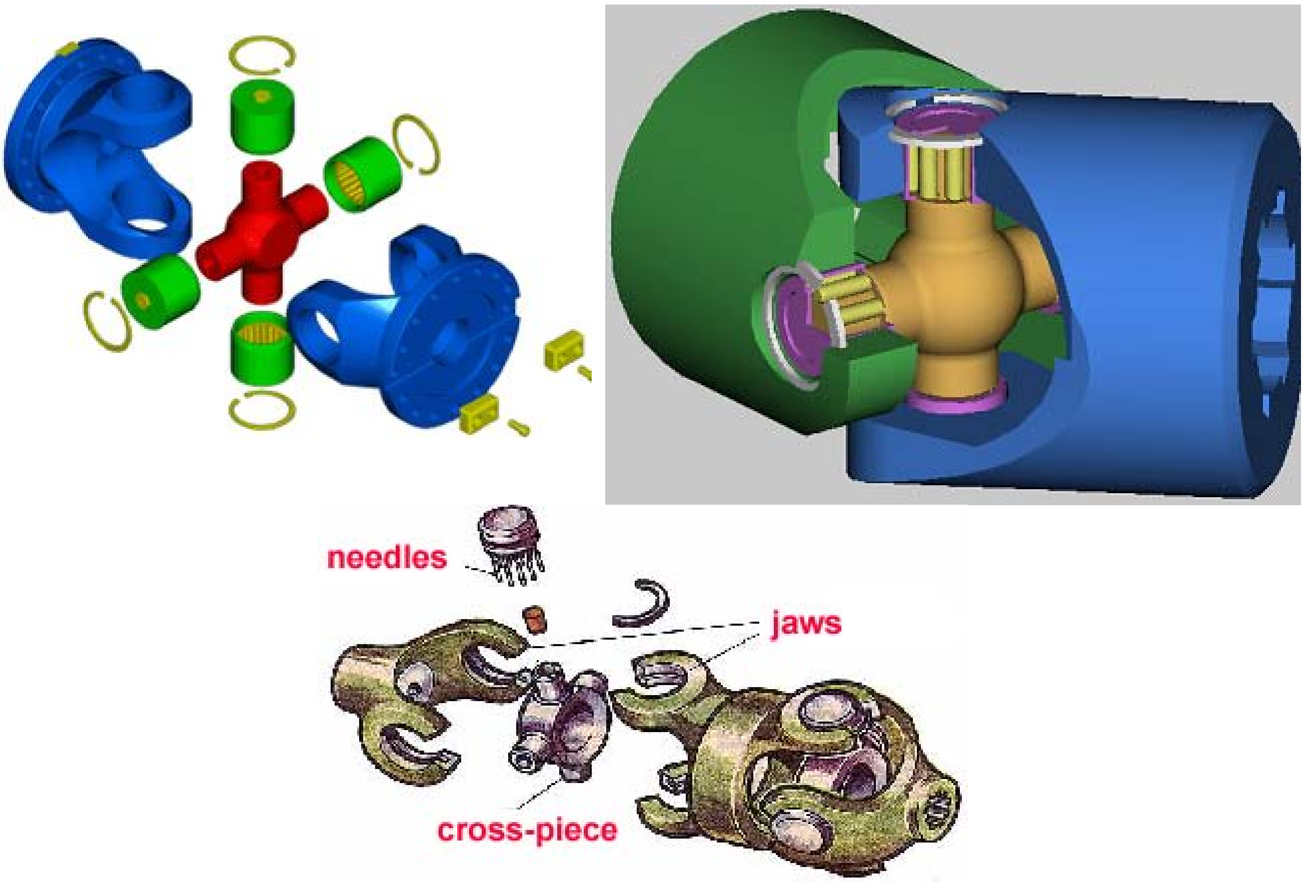


Figure 48: Composition of a universal joint

Universal joints are made up of two hubs linked to the input and output shafts and a cross-piece.

The central part (cross-piece) authorises a large angle between the two shafts.

Universal joints are particularly well-suited for the transmission of forces at high speed. The maximum speed depends on the working angle.

The maximum working angle is 45°, all types of universal joint taken into account (double articulation = 90°).

Figure 49: Universal joints in an installation

For angles exceeding 20°, adopt low rotation speeds.

Conventional universal joints can support speeds of up to 2,000 rpm[1] whereas joints fitted with needle bearings can take speeds of up to 4,000 rpm[1].

Joints fitted with needle bearings are generally only used for speeds of more than 1,000 rpm[1].

In order to obtain a uniform movement, two single universal joints should be used, that is to say a double universal joint. In applications accepting slight rotation variations or only offering slight tilt angles, a single universal joint will do.

In order to obtain a uniform movement, you must ensure that the tilt angles are the same at each end of the intermediate shaft.

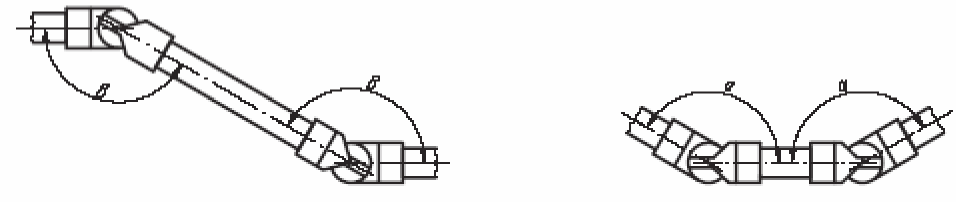


Figure 50: Identical tilt angles

3.6. MAINTENANCE OF COUPLINGS

3.6.1. Maintenance

When carrying out maintenance operations on couplings, very great care must be taken concerning safety. You must make sure that the drive system is cut out (fuse removed, electrical power switched off, warning panel in place, installation shutdown procedure done according to the rules, etc.)

Rotating parts can cause **serious injuries**.

A bit more care must be taken for the maintenance of universal joints than for other couplings. Universal joints that operate at a continuous speed must be lubricated at least once a day. If they are used in a dirty atmosphere, it is recommended to protect them with a rubber protection sheath.

A universal joint can operate without protection, but will require regular lubrication.

Daily lubrication is recommended for many applications. The fact of protecting the articulation with a bellows filled with grease will significantly improve operation, and extend its service life by as much as five times.

In general, universal joints are ground to size. Correct operation of the articulations will only be ensured if, after disassembly, all the components are re-assembled in the original configuration.

The method for disassembling a universal joint is simple. You just have to seize rod **1** firmly with your left hand and rod **2** with your right hand (Fig a).

You must then fold rod **2** backwards to the stop, then turn this rod sideways to the right, to obtain the position shown in Fig B.

Then continue the sideways rotation movement to the right, you will then be able to remove rod **2** very easily.

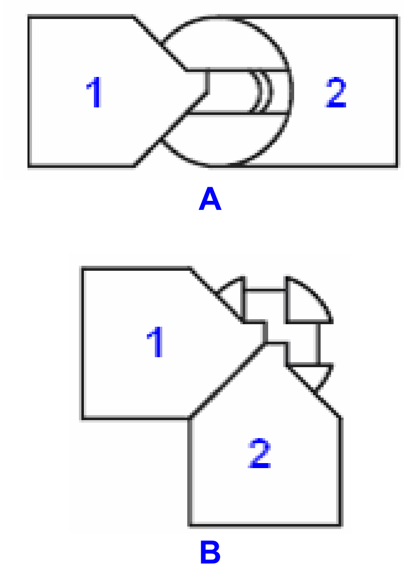


Figure 51: Disassembly method

Proceed in the reverse order to re-install the rod,.

Certain couplings have been specially designed to facilitate maintenance.

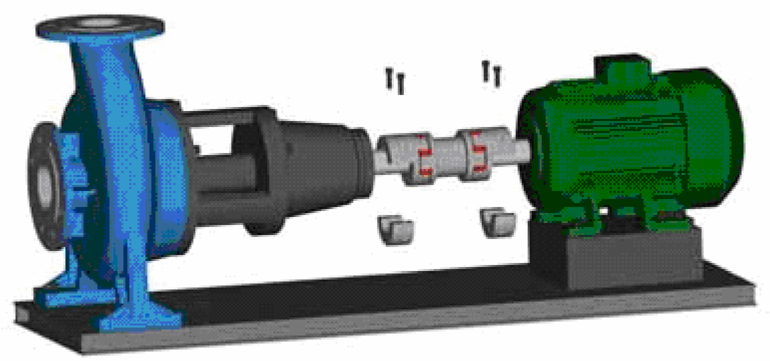
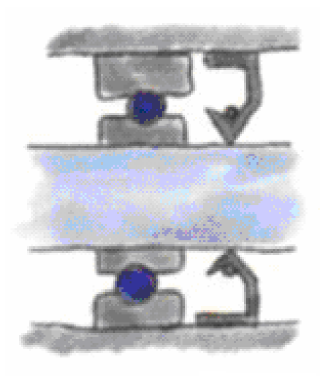


Figure 52: Split coupling

In fact, split couplings are held by four screws, which means it is easy to disassemble the assembly quickly without having to move the two pieces of equipment linked by the coupling.

Figure 53: Example of a split coupling

3.6.2. Alignment problems



Problems on rotary machines usually lead to production shutdowns. Nearly one failure in two is due to defective alignment. Furthermore, a misalignment will increase power consumption.

It must be possible to control production, which means that a precise alignment of all the rotary machines is required.

In the oil industry, rotary machines work 24 hours a day, and untimely shutdowns are never welcome, for a reason. This is why alignment is a very important mission in everyday maintenance.

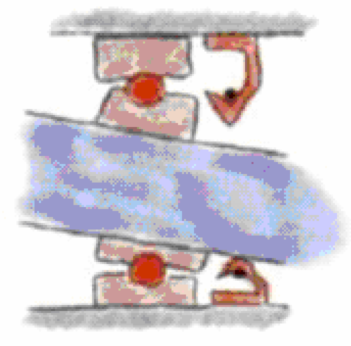


Figure 54: Example of alignment and misalignment (with ball bearings in this case)

A flexible (or elastic) coupling can withstand a misalignment over a given period of time. As for rigid couplings, no misalignment is permitted. Any excessive misalignment will, over time, damage the coupling as well as the installation's bearings and bearing blocks. The coupling's elastic reactions which knock on to the shafts, bearings and bearing blocks are proportional to the amplitudes of the misalignments imposed.

The more a coupling is flexible, the better it will accept alignment defects, so with this type of coupling, the alignment operations are less difficult than with rigid couplings.

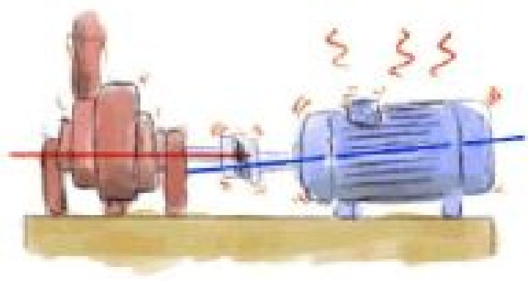


Figure 55: Excessive misalignment

The correct alignment of machines reduces the risks of problems and breakages. Poor alignment can have the following consequences:

- Lost production
- Leaks on seals
- Vibrations
- Bearing rupture
- Shaft rupture
- Serious play on the couplings and noise

3.6.3. Alignment method

Alignment of the machines must be carried out with care to ensure that any concentricity and parallelism deviations between the two half-couplings are compatible with the coupling manufacturer's recommendations.

The two half-couplings are assembled temporarily to make it easier to move them.

Adjusting the parallelism of the two shafts using a gauge:

- At a point on the circumference, measure the gap between the two faces of the coupling.

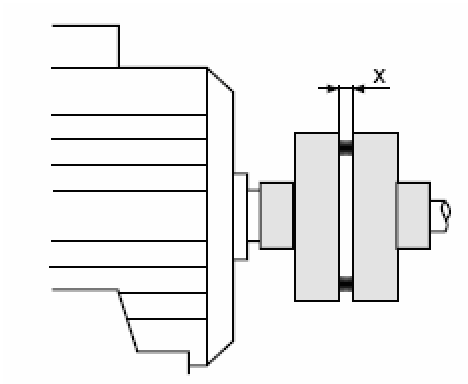


Figure 56: Adjusting the parallelism

- Then rotate the shafts through 90°, 180° and 270° and measure at each angle.
- The difference between the two extreme values (dimension **X**) must not exceed 0.05 mm for ordinary couplings.

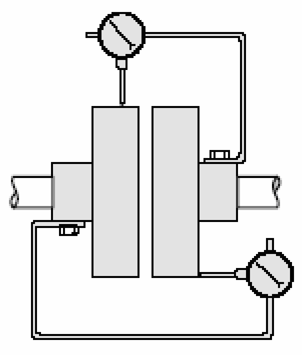


Figure 57: Axial and radial adjustment

To obtain correct alignment, you must also check the coaxiality of the two shafts.

To do this, install two dial gauges and slowly rotate the two shafts; the measured deviations will indicate that it is necessary to carry out an axial or radial adjustment if the deviation exceeds 0.05 mm.

Once you have completed this operation, you just have to lock the couplings together and check rotation by attaching the dial gauge to the mounting frame.

The oil industry imposes extremely strict requirements for its installations.

Infrared devices are often used to monitor installations in operation, to check the various critical points (coupling, bearing blocks, etc.).

An alignment defect on an item of equipment always results in a rise of temperature. This rise, although it cannot be seen in the visible spectrum, appears instantaneously in the infrared.

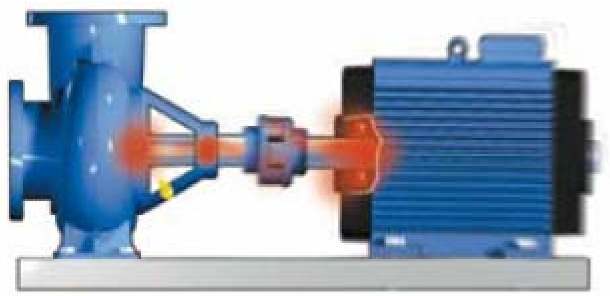


Figure 58: Heat generated by an alignment defect

Infrared thermography is a well-known technique used for maintenance purposes in the oil sector.

A thermogram is an image that gives the temperature of the various bodies making up the equipment.

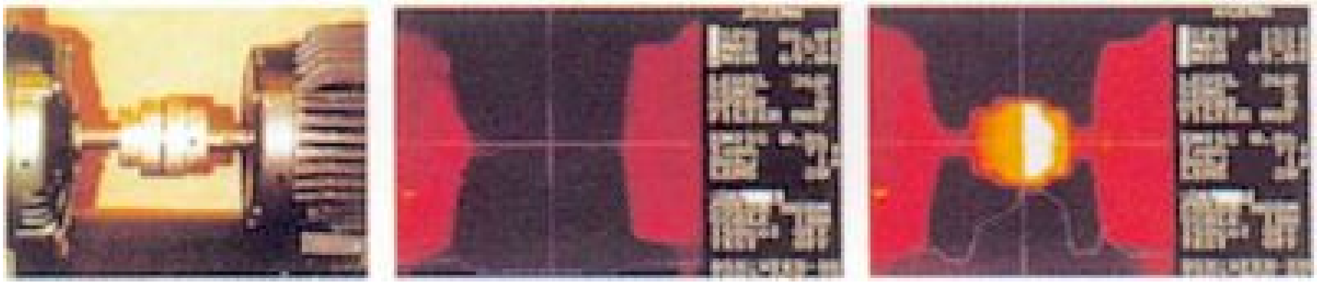


Figure 59: Thermography

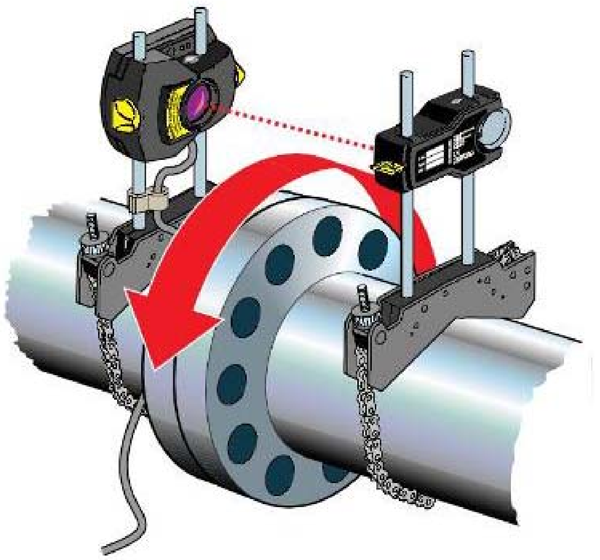


Figure 60: Laser alignment method

3.6.4. Aid to diagnosis and solution

Problem	Cause	Risk indication	Repair
Irregular bearing noises. Vibrations	Rubber element (or membrane) worn	Snapping sound on the safety protection. Sparks.	Isolate the installation (electrically and mechanically) Visually check the coupling elements, replace them if there is any damage Replace the rubber element (or the membrane)
	Out-of-balance	High loads on the connected parts	Isolate the installation (electrically and mechanically) Check the balancing of the installation's components, correct if necessary
	Loose bolts	Detachment of parts which could cause serious damage	Isolate the installation (electrically and mechanically) Check the coupling elements and replace them if they are damaged Block the screws to prevent any loosening
Premature wear of the rubber element (or membrane)	Operation in a high ambient temperature	Modification of the elastic element's properties	Isolate the installation (electrically and mechanically) Replace the elastic element Check the temperature in the place where the installation is housed is correct

Problem	Cause	Risk indication	Repair
	Contact with aggressive elements	Modification of the elastic element's properties	Isolate the installation (electrically and mechanically) Inspect the damage to the coupling elements and to the elastic element, if necessary replace the damaged parts Use a suitable elastic element or prevent any contact with aggressive elements
	Overloading due to excessive torque	Coupling destroyed Overloading repercussions on the connected parts	Isolate the installation (electrically and mechanically) Inspect the coupling then replace it Use a suitable coupling Operate the installation in accordance with the rules
	Elastic element destroyed	Coupling damaged	Isolate the installation (electrically and mechanically) Inspect the coupling Replace it and the elastic element Adjust the alignment

Table 1: Diagnosis of coupling problems

4. BELTS AND PULLEYS

4.1. BELTS

Belts, like chains, are used to transmit power.

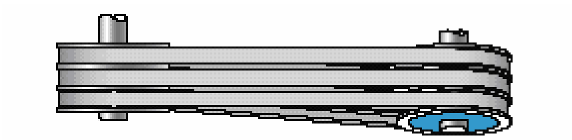
Belts are made of a flexible material (usually polyurethane, but rubber or leather are also sometimes used in large installations), often in the form of a loop. This is the flexible element that transmits the power from the motor shaft to the receiver shaft.

Thanks to belts, the requirements (transmission that may be submitted to great forces, elasticity, damping of oscillations and shocks, high rotation speeds) are met.

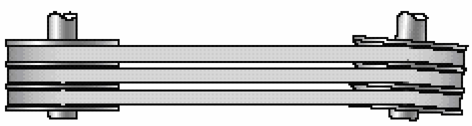
Depending on the type of belt, several shafts may be driven simultaneously (also see the pulley configuration).

Figure 61: Belts and pulleys

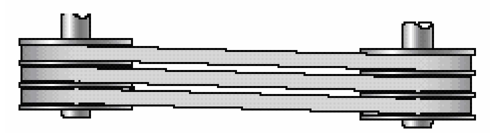
Like flexible and elastic couplings, belts accept a slight misalignment between the motor and receiver shafts.



Angular and parallel misalignment



Angular misalignment



Parallel misalignment

Figure 62: Possible misalignments

4.1.1. V-belts

V-belts are also sometimes called trapezoidal belts

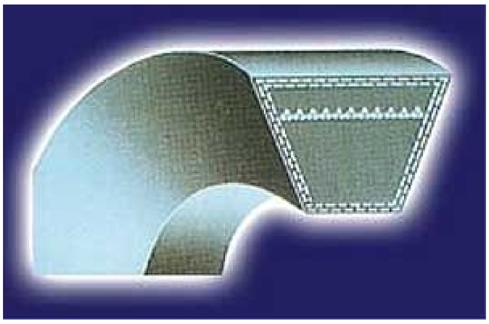
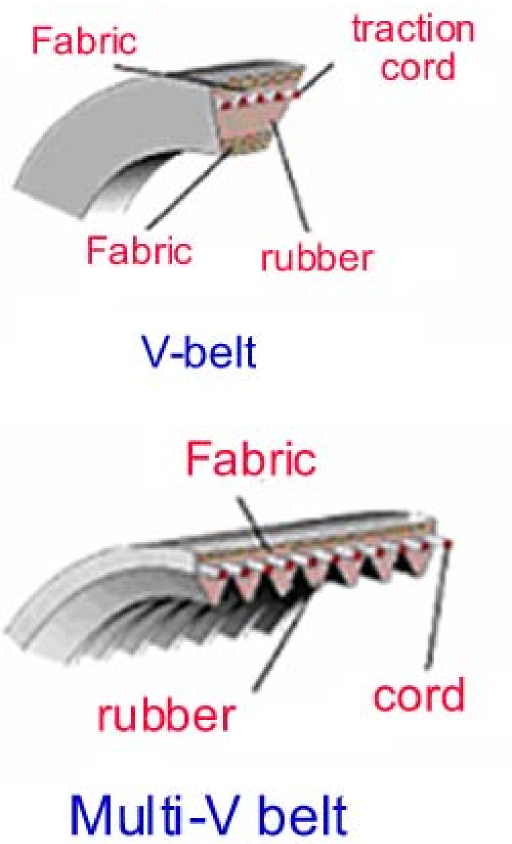


Figure 63: V-belt

4.1.1.1. Envelope V-belts



Adhesion drive

For multi-V belts, the cords distribute the load proportionally in several grooves instead of forcing the whole load into a single groove.

Figure 64: V- and multi-V belts

Figure 65: Detail of a multi-V belt

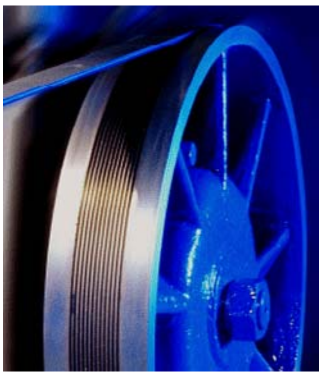


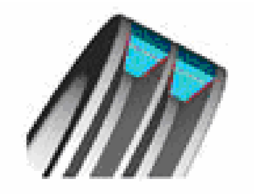
Figure 66: Multi-V belt and pulley

It transmits its power via the friction that exists between its walls and the walls of the pulley.

This transmission mode limits slipping between the elements to 3%.

This force transmission mechanism has the advantage of letting the belt slip when it is submitted to shocks, to deform itself when the pulleys are no longer aligned; and without these characteristics the belt would have broken.

Figure 67: Pulleys for V-belts



Transmission efficiency depends on the belt's tension and its contact with pulleys.

Figure 68: Pulley / belt contact

If the tension is too low or contact is not made correctly with the pulley, the transmission efficiency will drop significantly. Transmission can very quickly lose 10 to 15 % of its efficiency.

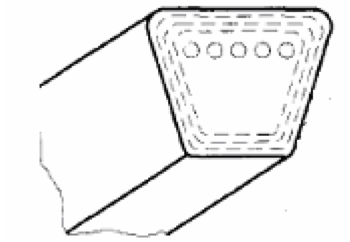


Figure 69: V-belt profile

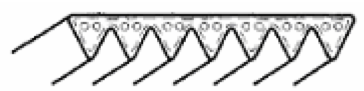


Figure 70: Multi-V-belt profile

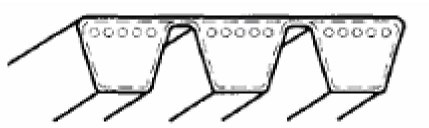


Figure 71: Multi-rib belt profile

Furthermore, pulleys and belts will deteriorate faster if the transmission slips. It is not sufficient to simply increase the tension because, if you do that, it is the bearings that may have to be replaced more frequently as the load will be greater.

Figure 72: Application of envelope V-belts

The main cause of problems with an installation due to the belt is an incorrect installation, in particular poor pulley alignment between the pulleys.

V-belts are particularly tolerant: they can take a misalignment of up to 6° before any instability appears. The manufacturers, however, recommend that any misalignment should be limited to 0.5°.

4.1.1.2. Synchronous V-belts (cogged)

Drive by obstacle

This is a flexible cogged link connecting the motor to the machine to transmit high levels of power. Here the function is to transmit power without any slipping.

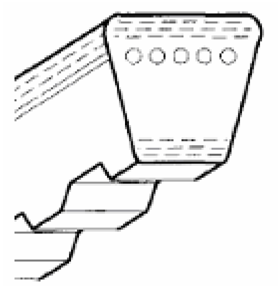
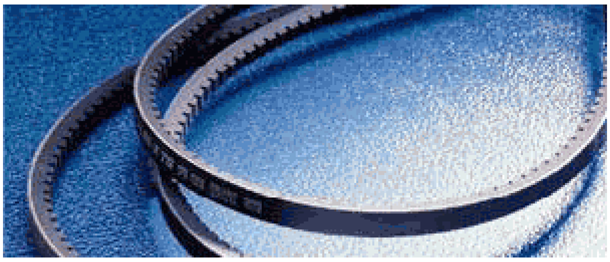


Figure 73: Profile of cogged V-belts



This type of belt avoids the problem of phase-shifts between the input and output. Even when correctly tautened, without slipping, a non-cogged belt will shift over time because of its elasticity.

Figure 74: Examples of cogged belts

Its elongation will not be the same between a tight belt and a loose belt, and it is this difference that will cause the shift.

Figure 75: Cogged V-belt with its pulley

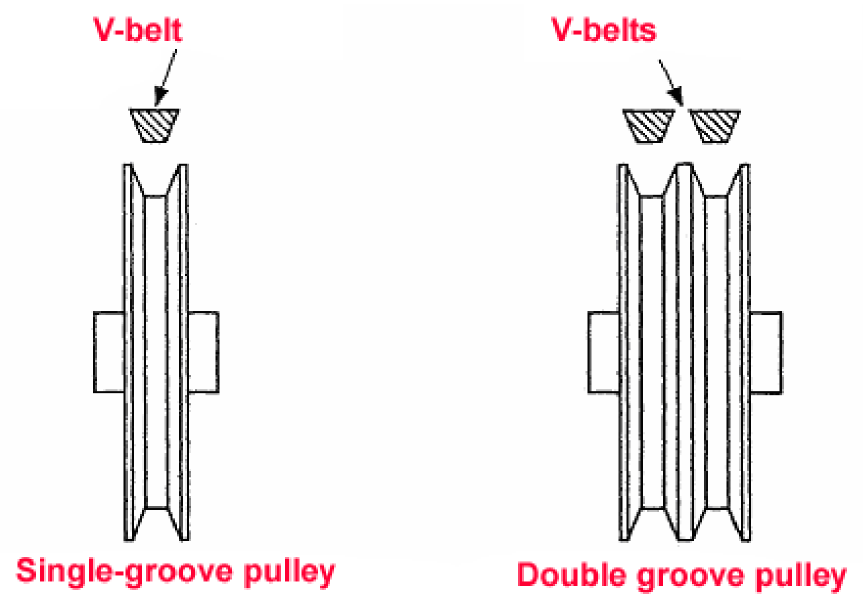


Figure 76: Detail of belts and pulleys

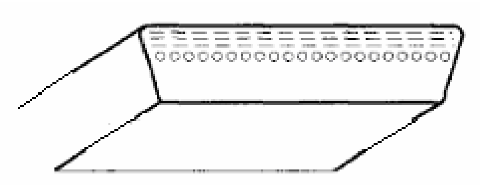
4.1.2. Flat belts

4.1.2.1. Smooth belts

Drive by adhesion

Flat belts transmit a mechanical force from one pulley to another, thus making it possible to change the rotation speed by changing the modulus (drive wheel diameter divided by the driven wheel diameter).

Figure 77: Smooth flat belt



Flat belts transmit a sufficient amount of force; and their slippage often makes it possible to avoid mechanical breakages.

Figure 78: Smooth flat belt

The pulleys used have a camber making it possible to ensure self-centring of the belt once it has been aligned on the two pulleys.

Flat belts provide a better efficiency than the other transmission elements, regular and precise operation, simple handling, and a long service life.

With flat belts, it is possible to obtain simple, orthogonal, tapered or multi-pulley transmissions.

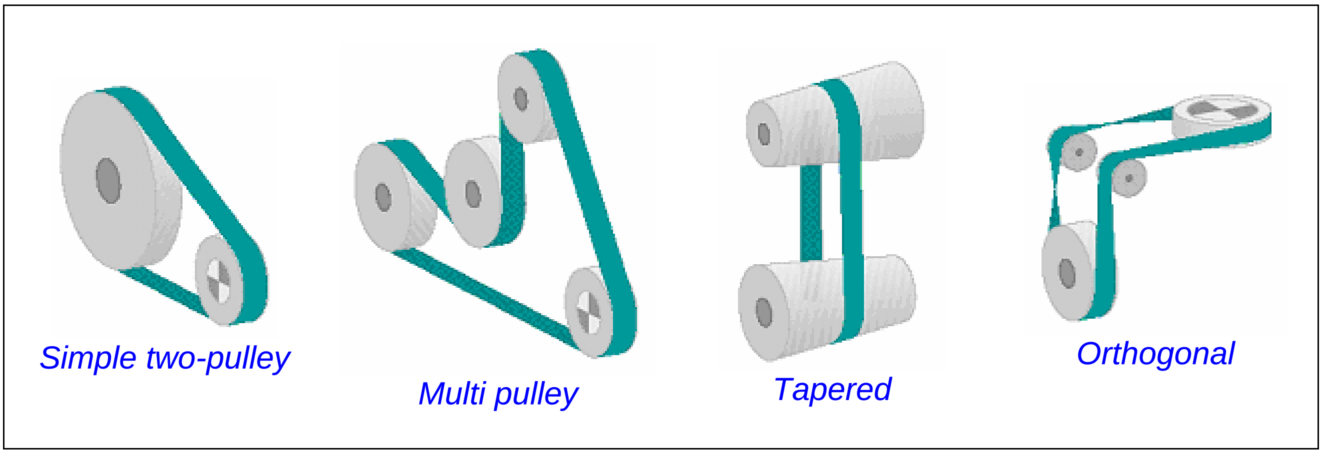


Figure 79: Possible types of transmission

Flat belts have low power consumption, slight slippage, easy and quick handling which means reduced production shutdown times, good damping properties and therefore a good preservation of the bearings.

Flat belts stand out clearly from V-belts concerning their efficiency.



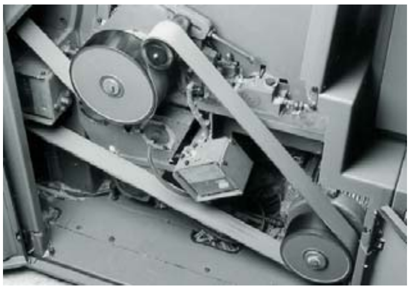
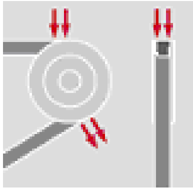


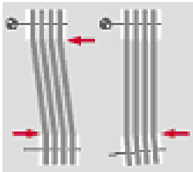
Figure 80: Examples of flat-belt applications

They are however subject to energy losses due to:

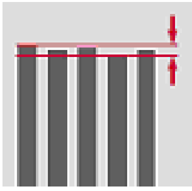
- Friction of the belt edges at the pulley entrance and exit.



- Losses due to high friction in case of non-aligned pulleys.



- Variations of lengths and rotation speeds in the case of irregular loads



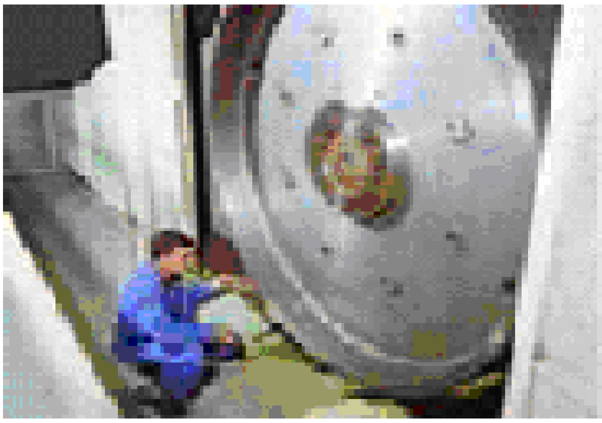
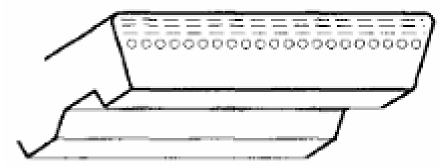



Figure 81: Possible dimensions for pulleys and smooth flat belts

4.1.2.2. Cogged flat belts

Drive by obstacle



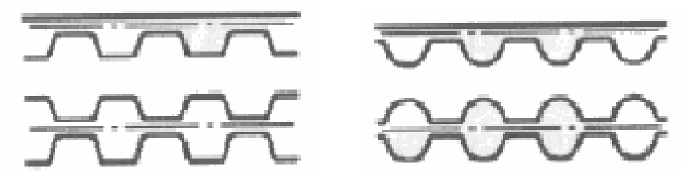
This is a flat belt with cogs. It functions by meshing without any slippage.

Figure 82: Cogged flat belt (1)

It withstands low speeds well and requires a lower initial tension.

Figure 83: Detail of belt and pulley

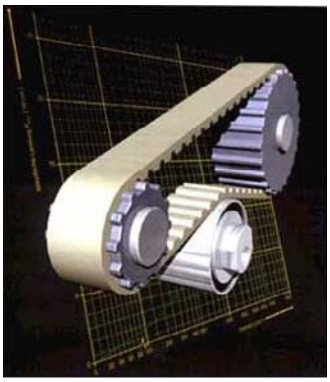
Figure 84: Cogged flat belt (2)

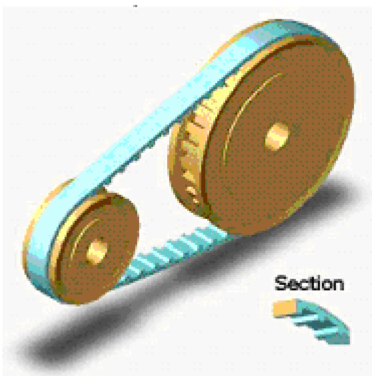


Straight-line

Curved

Figure 85: Cogged flat belt profiles





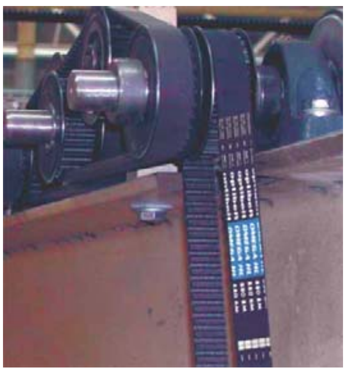
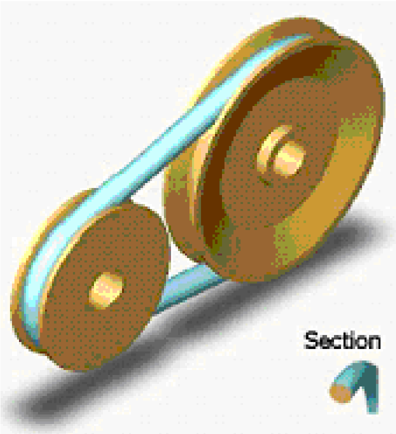


Figure 86: Applications with cogged flat belts

4.1.3. Round belts

Drive by adhesion

These belts are used as efficient drive components in precision mechanical applications, the construction of machines and apparatuses and on conveyor belts with driven rollers.



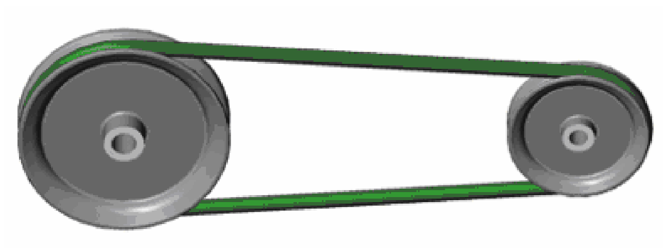


Figure 87: Round belt and pulleys

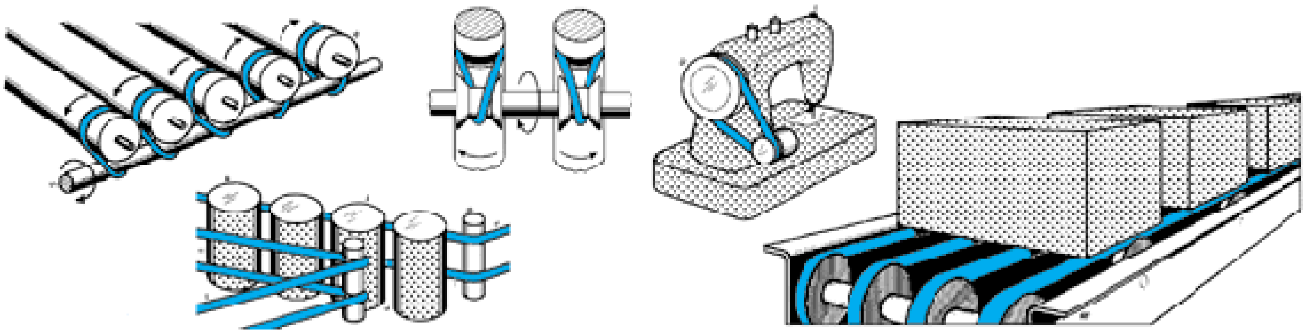


Figure 88: Applications with round belts

Thanks to their high degree of flexibility, elasticity and small diameter, round belts are capable of ensuring angular transmissions in every possible direction.

4.1.4. Detachable belts

These belts are above all used for conveying goods (very long conveyor belts, transporter belts), but they can also be used as a temporary replacement solution further to a failure when there are no spare parts available.

Figure 89: Detachable belt

They are designed to:

- replace any type of belt
- resist in applications where conventional belts are unsatisfactory.

They offer many advantages:

- easy adaptation
- no need for junction tools
- long service life
- low maintenance
- low noise levels
- low vibration levels
- length as required

Made of elastomer and polyester fabric, these belts are not only extremely robust but also highly flexible, while offering improved performance with respect to conventional belts.

Figure 90: Applications with a detachable belt (conveyor here)

They can be made to the required dimension (length) and joined on site. There is no need to disassemble the equipment to install the belt, nor for any welding (bonding) tool for making the coupling.

Possibility of being used in extreme conditions. They can resist high temperatures (100° C), abrasion, hydrocarbons, water, vapour, industrial solvents and chemical products. They also exist with a Teflon coating capable of withstanding temperatures as high as 240° C.

These belts require very little maintenance, no lubrication, no belt tensioner in operation and ensure a noise reduction of the order of 50%.

Packed in the form of reels, they can be cut to length as required which makes it possible to reduce the amount held in stock.

4.1.5. Advantages and drawbacks of belts

The advantages:

- Transmission flexibility
- Possibility of varying the centre-to-centre distance
- No lubrication
- Silent
- Low purchase and installation costs

The drawbacks:

- Irregular transmission ratio (slippage for smooth belts)
- Need for a belt tensioner (in most cases)

4.2. PULLEYS

Pulleys are indissociable from belts.

Pulleys have the same profile as the belts, that is to say that the belt fits perfectly into the pulley (Male/female for V-belts or round belts).

Smooth pulleys are used for smooth belts and, likewise, cogged pulleys are used for cogged belts.

Each belt is used with the corresponding pulleys, otherwise there is a risk that the installation will very quickly break down.

Figure 91: Examples of pulleys for cogged belts

Figure 92: Examples of pulleys for smooth belts and of grooved pulleys

4.3. TENSIONERS

The wear and aging of the belt cause a gradual decrease in its installation tension.

To avoid having to adjust the installation, it is possible to include a device making it possible to ensure a constant and regular belt tension.

This device is called a belt tensioner.

Figure 93: Automatic belt tensioner

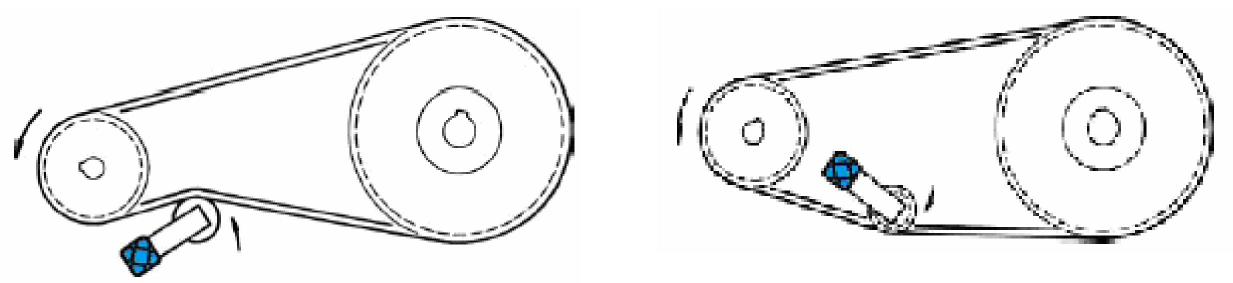


Figure 94: Tensioner operating principles

4.3.1. Automatic tensioner

4.3.1.1. General

Automatic tensioners are designed and manufactured for a specific purpose, so as to maintain the belt at a virtually constant tension whatever the operating level.

This type of tensioner does not, in theory, require any maintenance and adapts to the normal lengthening of the belt.

Each tensioner is designed to ensure exactly the tension, damping and pick-up of play required for the intended utilisation.

Figure 95: Automatic tensioners

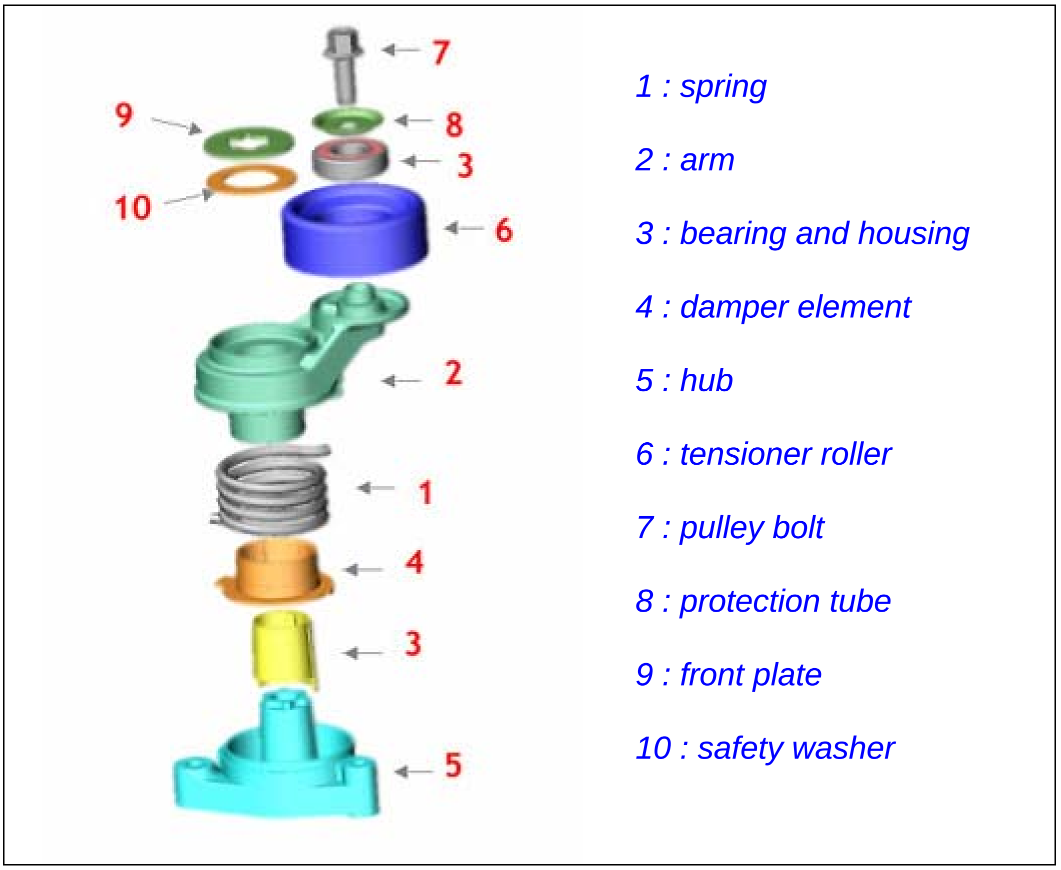


Figure 96 : Exploded view of an automatic tensioner

4.3.1.2. Automatic tensioner operation

The spring maintains a constant belt tension.

The arm links the spring to the tensioner while maintaining the alignment.

The bearing ensures the angular alignment required for belt centring.

The damper element (spring base) increases the damping of the tensioner and the uniformity of the load on the belt.

The spring's hub takes different shapes depending on the type of belt: groove, flat or cambered.

The pulley bolt makes it possible to maintain and/or replace the tensioner roller. It is also used to manoeuvre the arm.

The protection tube protects the bearing against foreign objects, external contamination (dust, sand, etc.) and also against the tools used for maintenance or installation.

The front plate holds all the tensioner components in place.

The safety washer provides a friction surface.

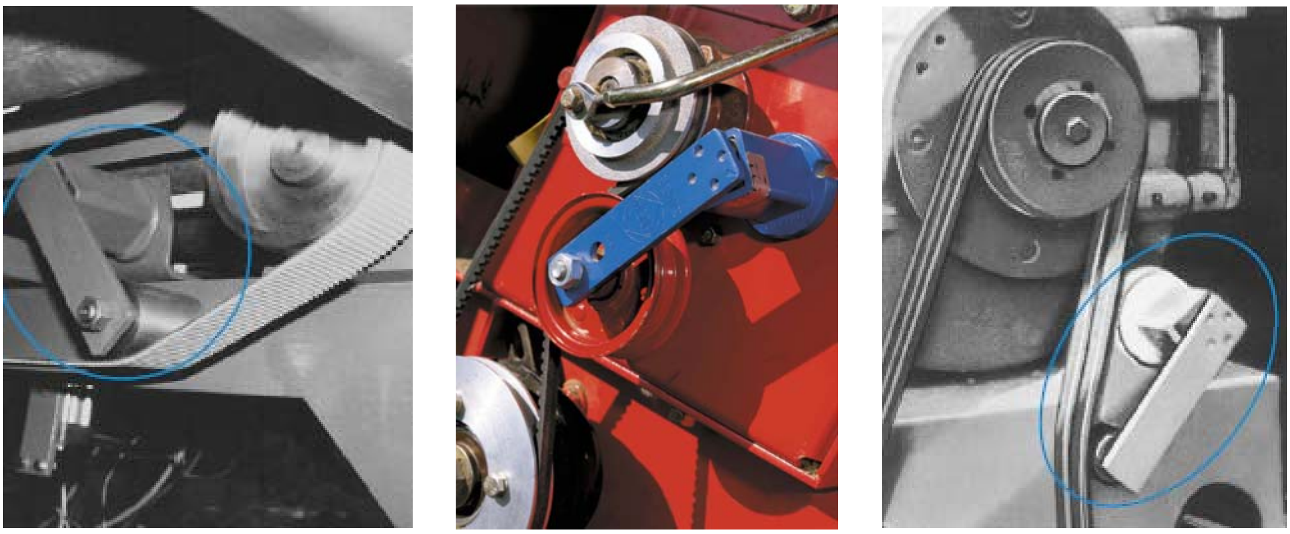


Figure 97: Automatic tensioners in operation

4.3.2. Manual tensioner

Unlike automatic tensioners, manual tensioners do not automatically maintain the belt's tension. Human intervention is required.

The installation must be monitored regularly and it will be necessary to intervene on demand, which means that the installation will have to be shut down.

This process is less commonly used than the automatic system but it does nevertheless exist. It can be found on installations that were not designed to be fitted with an automatic tensioner.

Figure 98: Manual tensioner

Adjustment with the installation shutdown:

When the belt is loose, loosen the tensioner lock screw, press the roller against the belt until you obtain the required tension and tighten the tensioner lock screw again.

4.4. BELT APPLICATIONS

The most common applications are shown in the figures below.

There are a multitude of possible setups for belts, but the transmission principle will always be the same, by obstacle or by adhesion.

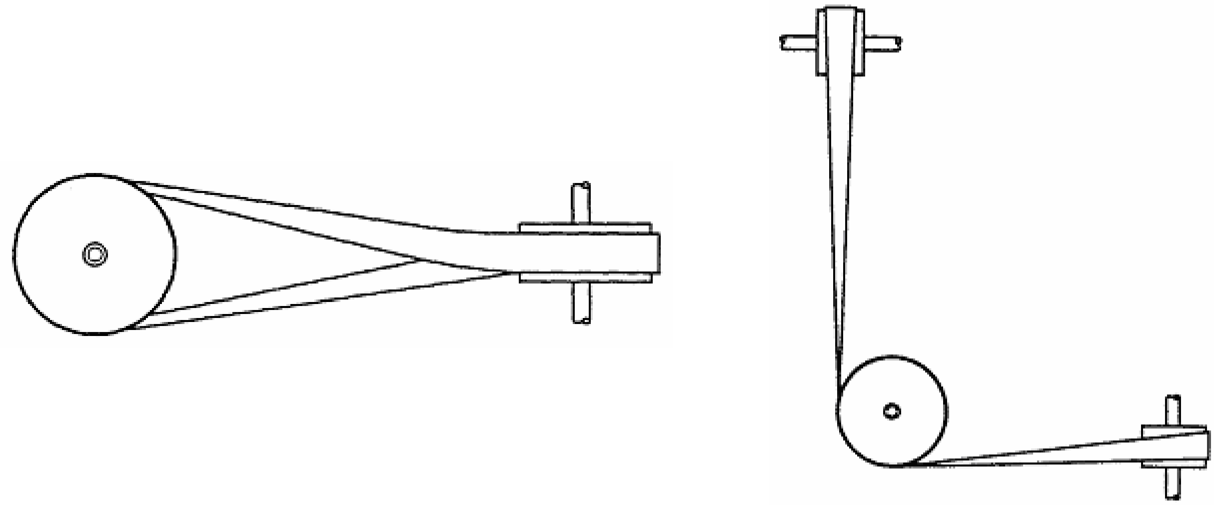


Figure 99: Examples of applications with flat belts

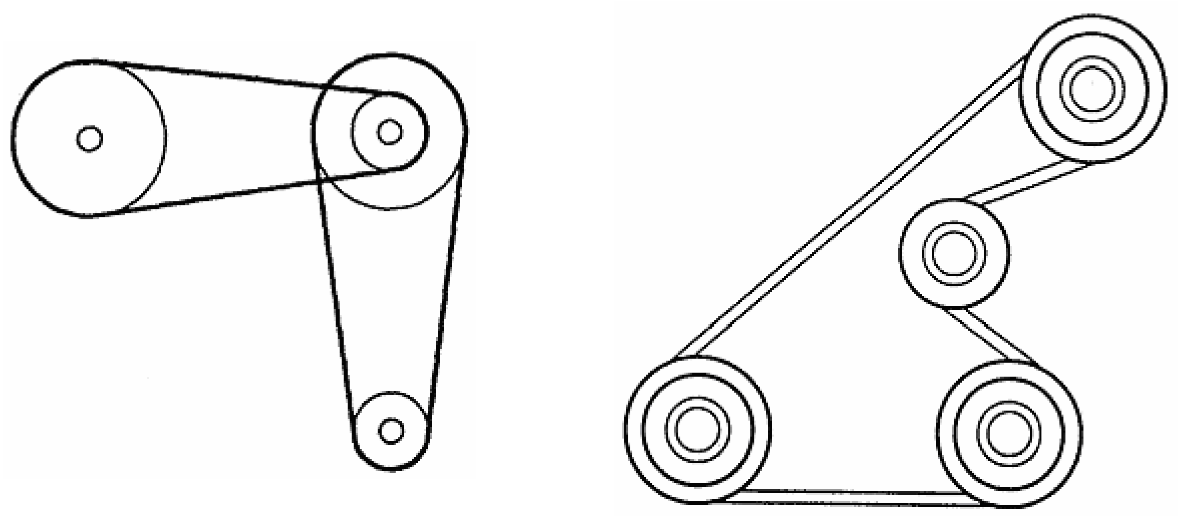


Figure 100: Examples of applications with cogged, flat or round belts

4.5. BELT MAINTENANCE

Belts or transmission devices, in the same respect as gear or roller chains.

The operating principle is based on two main elements: a contact surface whose size depends on its friction coefficient, and an armature capable of transforming the tangential force taken from the pulley into a longitudinal traction force between the pulleys. The combination of these two elements characterises the transmissible force, this being linked to the absence of slippage on the first one and the resistance to traction of the second one.

This is why these elements are usually made of an elastomer and synthetic fibres.

Thanks to its flexibility, the belt allows a certain degree of manufacturing imprecision. This is the cheapest solution for a transmission system (no lubrication).

Belts dampen vibrations, absorb juddering and authorise slippage in the case of overloading. They also serve as "fuse" in the case of blockage of a transmission component. If the fuse blows, that no doubt means that the belt had a manufacturing defect, but early destruction may also mean there is a problem with the transmission's design. Like with electricity, there is no point installing a "fuse" with a higher resistance to overcome the operating problem.

In its first hours in operation, the belt settles in gently and will require further adjustment. The great majority of V-belts undergo an elongation which, over a normal operating life, can reach 3%. For example, for a belt 100 inches long, this corresponds to an elongation of 3 inches.

Without regular maintenance, the length of a belt's life will naturally be significantly shortened.

Another thing that must be taken into account is the wear on the pulleys. Even if the pulleys are made of steel and the belts of elastomer, the pulleys will not escape becoming worn. An inspection tool designed for this purpose tells whether the pulley should be replaced.

Figure 101: Groove pulley inspection gauge

The utilisation of an unsuitable pulley will shorten the lives of the belts and pulley support bearings.

Using pulleys that are too small, have too short a centre-to-centre distance or an insufficient number of belts are among the reasons why an installation that functions with belts will not perform to the best.

The tension of the belts and the alignment of the pulleys are all the same the factors that are most often responsible for problems.

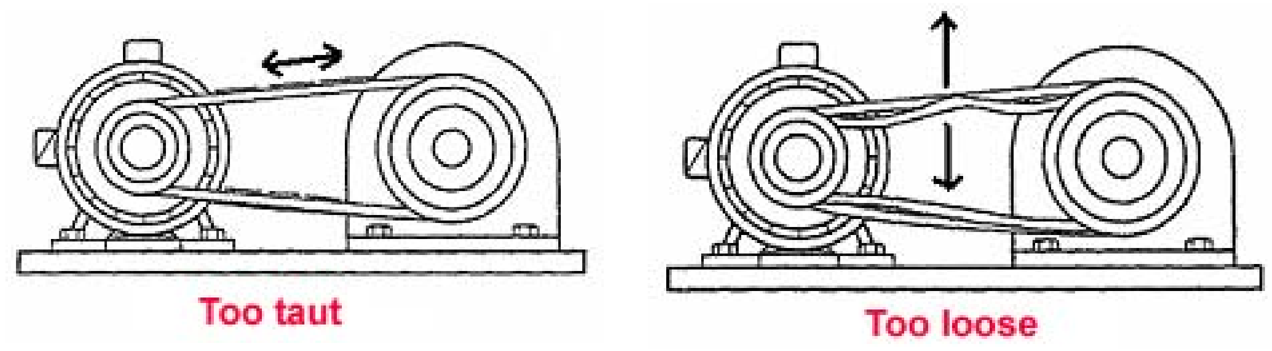


Figure 102: Belt tension

At the time of belt replacement, it is essential to check the correct alignment of the pulleys and their degree of wear.

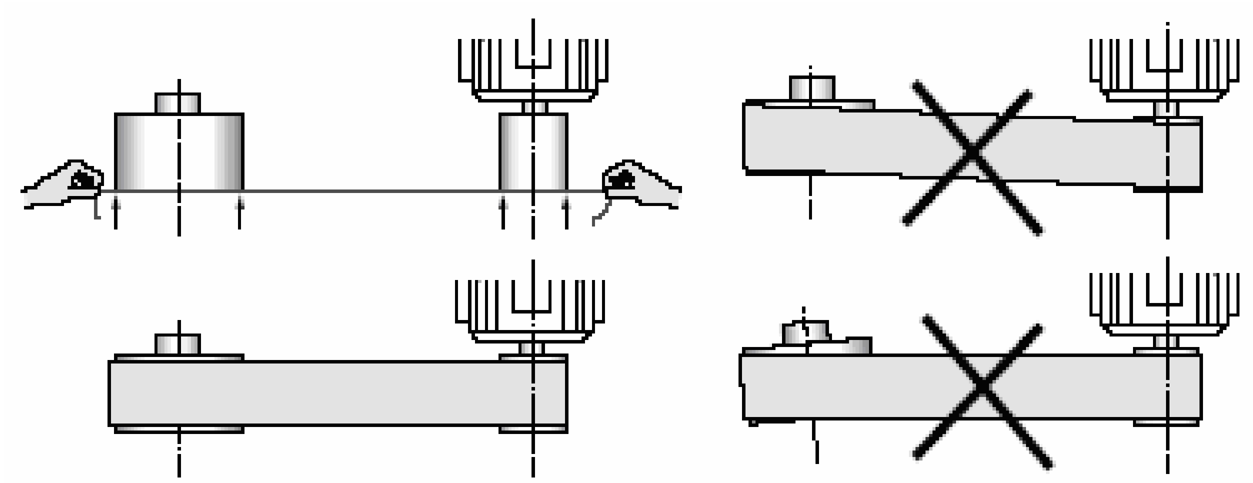


Figure 103: Pulley alignment

When aligning the pulleys, check that the motor shaft is effectively parallel with the receiver pulley's shaft.

Belts do not require much maintenance, however you must regularly monitor their condition, check for visible traces of wear, the tension, so as to avoid any problems.

Belt wear and aging will gradually cause the installation tension to decrease. To avoid having to re-adjust the tension, it is possible to fit the installation with an automatic tensioner, which will ensure a constant and regular belt tension.

The belt tension, pulley alignment and wear are the most important parameters. These are the parameters that will affect the life of a belt transmission.

4.5.1. Causes of belt deterioration

4.5.1.1. Scattered cracking on the ribs

Small visible cracks over the whole length of one or more ribs:

- The operating temperature and the fatigue caused by the winding of the belt around the pulleys can cause this problem.
- The cracks start at the top of the ribs and propagate inwards to the traction cords.
- Cracks one or two centimetres apart, 80% of the belt's life has been exhausted.

The belt must be replaced with a belt that can withstand high temperatures and you must ensure that the material the belt is made of is crack-resistant.

Figure 104: Cracking

4.5.1.2. Rib shearing

Bits of the ribs separate from the belt. When the ribs shear off, the belt may break at any moment.

- Shearing is imminent when several adjacent cracks propagate in parallel with the traction cord.
- A high utilisation temperature, belt tension and age are responsible for this.

Replace the belt with a belt that can withstand heat better. You must not leave a belt to run in a place where the temperature is very high because it will age much faster than would normally be the case.

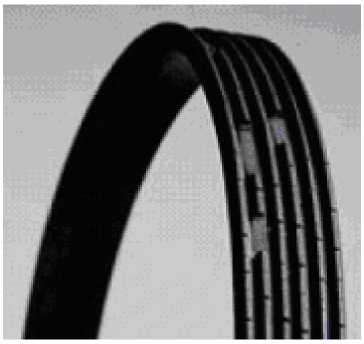


Figure 105: Shearing off

4.5.1.3. Fraying

The belt's material is torn off from the ribs and accumulates in the belt's grooves.

There are several possible causes:

- Insufficient tension
- Poor pulley alignment
- Worn pulleys

When fraying starts to cause a noise or creates vibrations, it is time to replace the belt. This replacement will have to be carried out more or less quickly depending on the degree of fraying.

Figure 106: Fraying

4.5.1.4. Abrasion

The back of the belt is shiny or polished. At an earlier stage, the traction cords would have been visible.

- Contact with foreign matter over the whole pulley/belt: loose screw, etc.
- Incorrect tension

Check the installation's surroundings and correct the situation >> tighten the screw, etc. Replacement of the belt, check of the tension and of the correct operation of the tensioner roller if there is one.

Figure 107: Abrasion

4.5.1.5. Damaged edges

The edges of the belt have a polished, shiny appearance. The cords are getting frayed, the ribs may have been destroyed. A squeaking noise can be heard.

In the worst case, the belt may come out of the pulley.

- Poor alignment is often at the origin of a premature rupture of the belt.

- The misalignment forces the belt to twist in operation and causes rapid wear.

Align the installation correctly. Check the condition of the pulleys, tensioners and axles to see that they are not broken or twisted. Systematically replace the belt.

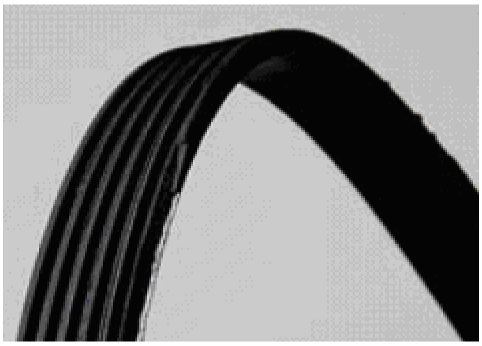


Figure 108: Damaged edges

4.5.1.6. Uneven wear

Damage visible on the edge of the belt. The cords may be broken or the ribs may be jagged. A squeaking noise may be heard.

- Presence of foreign matter (piece of metal, small stone, etc.) in the pulley.
- Pulley in poor condition.

Check the pulleys and replace if necessary. Clean the installation. Replace the belt.

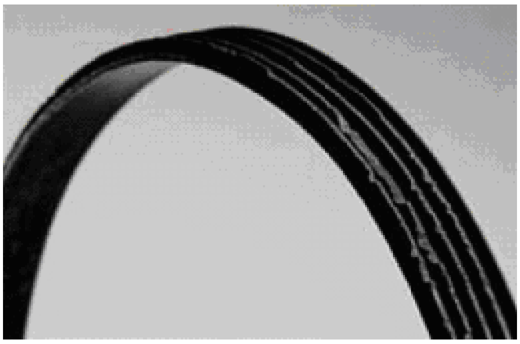


Figure 109: Uneven wear

4.5.1.7. Contamination

The surface of the belt is chipped, swollen or sticky.

- Presence of oil, grease or chemical products weakening the components, making the belt spongy and causing it to slip and heat up.

Avoid the sources of pollution and contamination. Clean the installation. Replace the belt. Use a compatible belt.

Figure 110: Contamination

4.5.1.8. Broken belt

Destruction of the belt, it is broken in two as if it had been torn off.

- Presence of a large foreign object in a pulley >> it may cut the traction cords.

- Rupture of the traction cords >> the belt was forced when being installed and one or more cords were broken, but this was not noticed at the time.

- Pulley or tensioner broken, excessive juddering.

Check the installation to determine which part is responsible for destruction and replace it. Do not force the new belt when installing it.

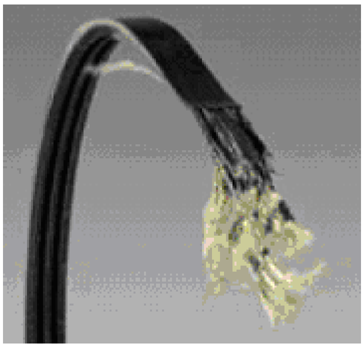


Figure 111: Broken belt

4.5.2. Noise

Noise may be due to poor alignment or incorrect belt tension.

There is a method – where the belt is lightly sprayed with water in operation – that makes it possible to know the cause of the noise.

- The noise appears just after the belt has been dampened: problem with the tension or incorrect positioning

- the noise decreases for some seconds and then reappears again: misalignment problem.

- The noise increases immediately after the belt has been dampened, but no longer increases after that: tension problem

Check the installation: alignment, tension, lengthening of the belt.

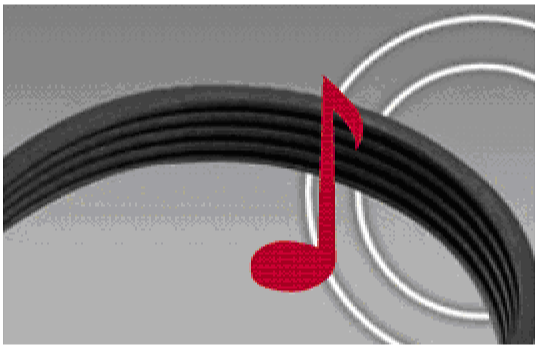


Figure 112: Noise

4.6. INSTALLING BELTS

4.6.1. Installation

To make it possible to install belts correctly, there must be a system enabling an adjustment of more than 3% of the measured centre-to-centre distance "E".

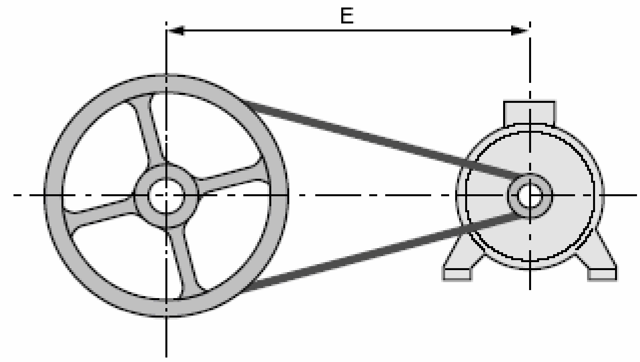
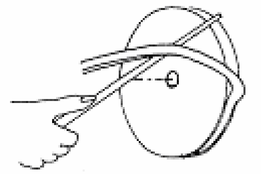


Figure 113: Centre-to-centre distance detail

Belts must never be installed by force. Loosen the tensioner, if the installation has one, or loosen the motor. Do not "pull" too much on the belt, otherwise you might break the traction cords.



Also take care when using a metallic tool (such as a screwdriver) on pulleys > risk of damage.

Figure 114: Installation

For cogged belts, position the cogs correctly in the pulley grooves.

When the belt installation operation has been completed, or after each intervention, do not forget to put the belt protection cover back in place to avoid any accidents.

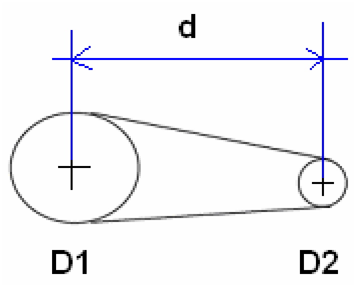
Most installations are fitted with a protection grid for the belts, but you may still come across installations that do not have one. In that case, you must be extremely careful when passing close to the machine and, if possible, try to find a solution to avoid potentially dangerous situations with belts.

Figure 115: Examples of protection grids on installations

There is a **method that allows you to calculate the length of a belt (flat)**.

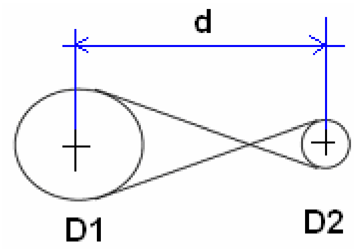
Two pulleys with dia. **D1** and **D2** and centre-to-centre distance **d** are linked by a flat belt.

- **For a straight belt**



$$L = \pi \frac{D1 + D2}{2} + 2d + \frac{(D1 - D2)^2}{4d}$$

- **For a crossed belt**



$$L = \pi \frac{D1 + D2}{2} + 2d + \frac{(D1 + D2)^2}{4d}$$

4.6.2. Ideal belt tension at installation

The tensioning procedure is a very important operation because the length of the service life of the belt, bearings and transmission system in general depends on it.

4.6.2.1. Steel armature belt

The ideal tension for a steel armature belt is the tension that avoids any tooth skipping.

A good installation tension optimises the quality of meshing, the positioning of the belt, decreases the sound level and thus contributes to the length of the installation's service life.

By regularly checking the tension on the steel armature belt, it is possible to detect any problems because a correctly adjusted tension will not change over time.

4.6.2.2. Belt with an aramide or glass fibre armature

Aramide: this is an abbreviation of the term "aromatic polyamide" and designates a category of synthetic fibres including Kevlar.

The tension of these belts decreases in use. This tension can be reduced by as much as 80%

It is essential to carry out adjustments on a regular basis. The belt must be replaced depending on its condition or its sound level.

4.7. EXERCISES

1. Why are belts used?

2. Give the possible types of misalignment:

3. List the possible types of drive that use belts:

4. What criterion does transmission efficiency depend on?

5. What is the maximum permissible misalignment for a V-belt?

6. List the drawbacks of belts:

7. What type of pulley is used for a smooth belt?

8. What causes belt wear and aging?

9. What is the name of the device that is used to avoid having to adjust the tension of an installation?

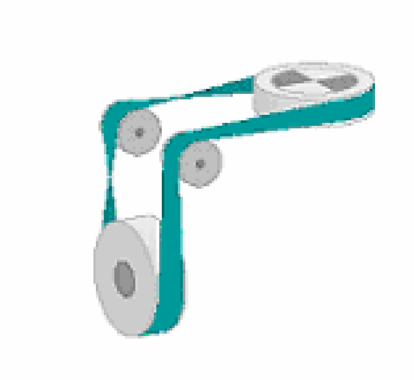
10. What are the main factors responsible for problems?

11. What causes uneven wear on a belt?

12. What materials are used to make belts?

13. Composition of an envelope V-belt:

14. What is this type of transmission called?



5. TRANSMISSION CHAINS AND PINIONS

5.1. TRANSMISSION CHAINS

5.1.1. Functions of transmission chains

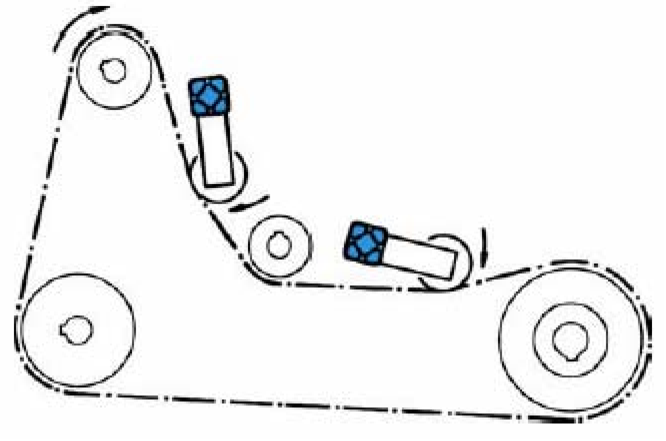
Like belts, chains are used to transmit power in an installation.

Usually, chains are made of steel for a question of strength (heavy loads), but other materials may also be used (nylon or plastic)

Figure 116: Chain and pinion

In mechanical terms, a chain is a set of identical *links* that is used to transmit a movement.

Do not get confused with nautical language, where a chain is a unit of length equal to 15 feet. The basic element of this chain is called a link.



This is a system of transmission by obstacle. The size of the transmission essentially depends on the chain's ability to withstand the traction force.

Like with belts, a device ensuring a constant chain tension may be used.

Figure 117: Tensioner device

In order to increase the tension course, it is also possible to install several tensioners on long transmission systems.

Usually, chains are made of steel for a question of strength, but chains made of synthetic material may also be used in installations that transmit lower levels of power, or for completely different types of utilisation.

There are several sorts of chain: roller chains that are used to transmit power, handling chains that are used for conveying and lifting.

Figure 118: Roller chain and leaf mechanical chain

In use for more than a century in their present form, mechanical chains are derived from primitive chains that can be traced back as far as two hundred years BC, and more recently to the sixteenth century in sketches made by Leonardo da Vinci (1452-1519).

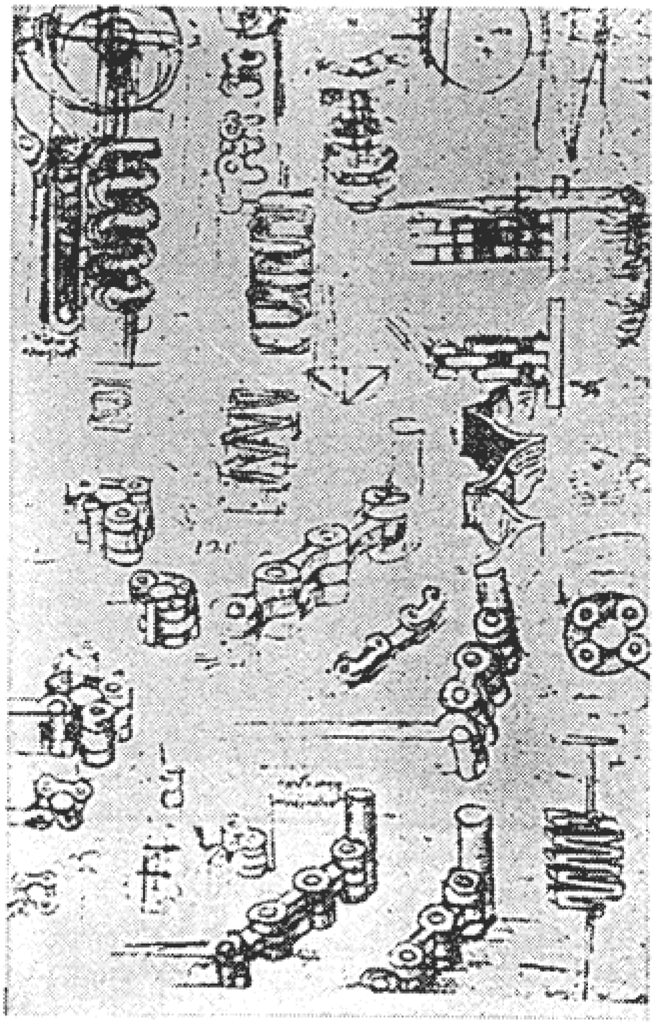


Figure 119: Sketch of chains made by Leonardo da Vinci

If chains, particularly the roller chain invented in 1880 by Hans RENOLD, have applications in every branch of industry, it is because they bring together a rich palette of qualities:

- great utilisation flexibility, especially concerning the distance between the shafts to be linked
- for the same level of power, smaller dimensions than any other means of transmission
- precise and invariable transmission ratio
- excellent efficiency (of the order of 98% for transmission chains)
- load on the bearing blocks equal only to the useful force
- reliability ensured even in a difficult environment
- low installation cost

Although there are advantages, there are also some drawbacks:

- need for lubrication
- high sound level
- longitudinal vibrations
- limitation on the transmission ratio

Mechanical chains are used to fulfil two main functions:

- transmission of a movement, torque or power
- moving or lifting loads

They are also present, in their various forms and for one or other of the above functions, in every sector of industrial activity.

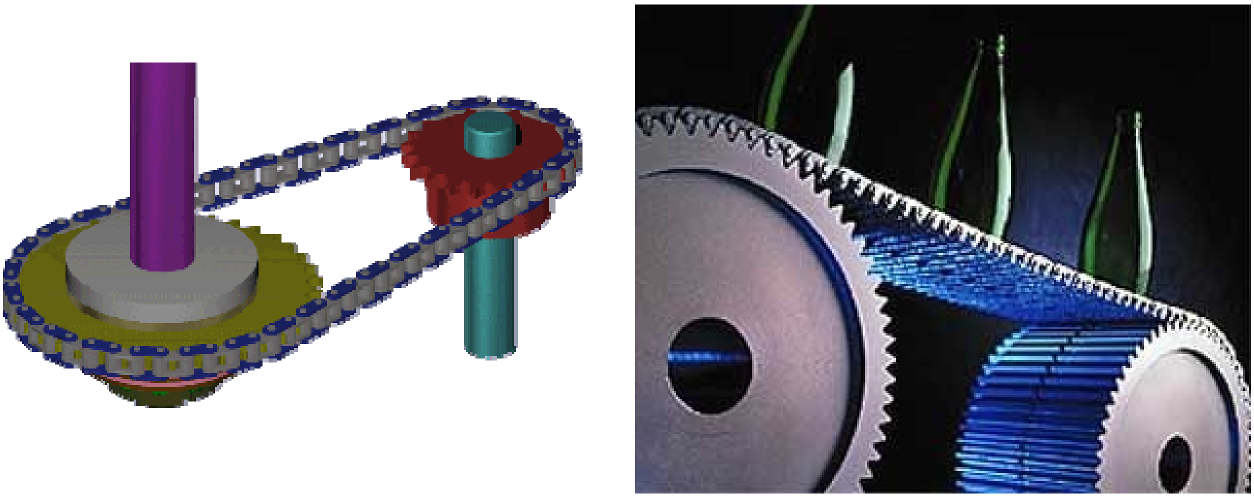


Figure 120: Transmission of power / conveying

The chain has the advantage of being very easy to implement due to its modular link structure.

5.1.2. Roller chain components

A chain is made up of a series of links which placed one after the other form a length of chain.

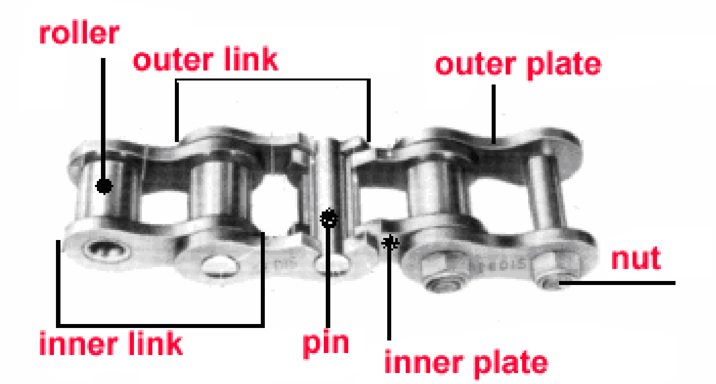
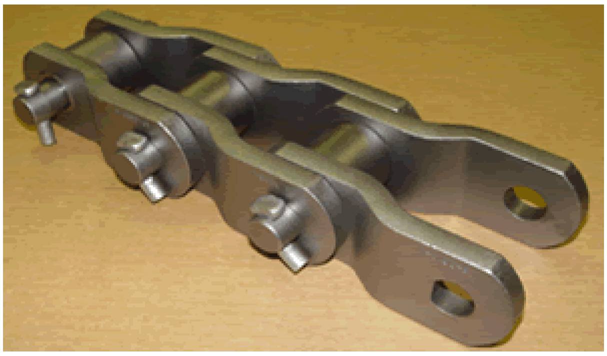


Figure 121: Roller chain components

The links are attached to each other by means of pins, which are either riveted or bolted.



The pins can also be pinned or held by a wire (in which case it will be a steel wire).

Figure 122: Pinned pins (offset links in this case)

Figure 123: Pins held with a wire

You can obtain any length of chain simply by adding links as required.

Figure 124: Adding links

Two lengths of chain can also be joined together by means of a quick release link. You will find chain link pliers quite useful for this purpose.

Figure 125: Quick release link (a spring in this case) and chain link pliers

There are three types of quick release link:

- Spring quick release link
- Pin quick release fastener
- Wire quick release fastener

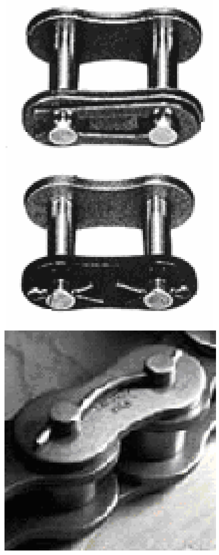


Figure 126: Spring, pin and wire quick release fastener

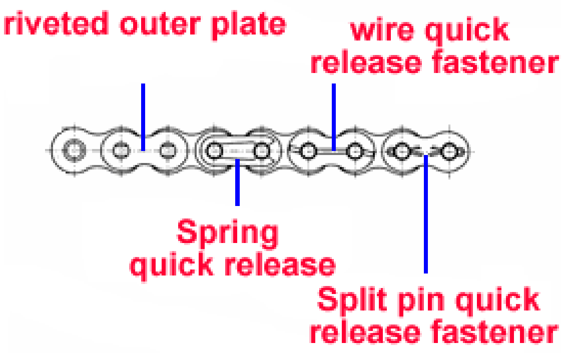


Figure 127 : Different types of link fastener

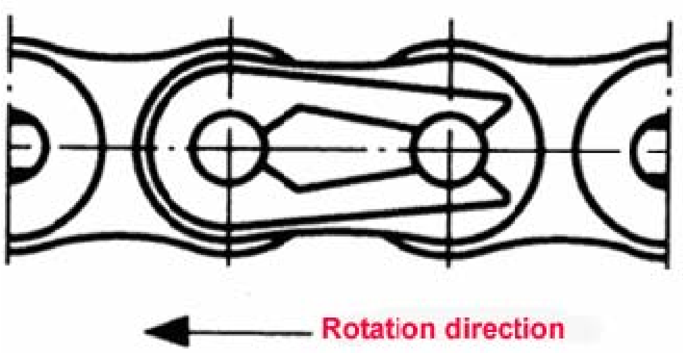


Figure 128 : Utilisation direction for a spring quick release fastener

5.1.3. Production method

In order to optimise the quality of chains, the manufacturers have had to adopt a manufacturing method. These days, chains are manufactured with the greatest thoroughness and extreme professionalism because there is no room for error.

Ball calibration:

- eliminates stamping grooves and sharp edges
- improved fitting and fatigue resistance

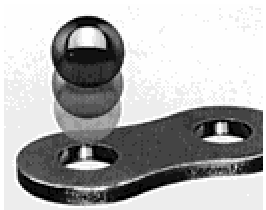


Figure 129: Ball calibration

Improved surface treatment:

- very deep case hardening of the pins and bushes
- longer chain service life

Figure 130: Heat treatment

Cold shot peening:

- improved fatigue resistance of the pins, plates, bushes and rollers
- consolidation of the hinge surfaces
- improved load absorption properties

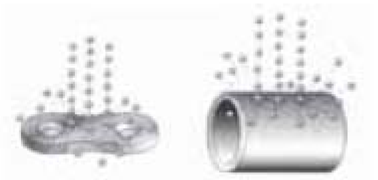


Figure 131: Shot peening

Shock-resistant rollers:

- precise manufacturing process
- uniform metal thickness
- total absence of tapering

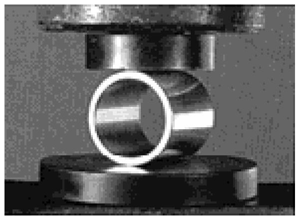


Figure 132: Shock-resistance

Pre-loading:

- high-stress pre-loading
- minimised initial lengthening in service
- improved load-resistance properties

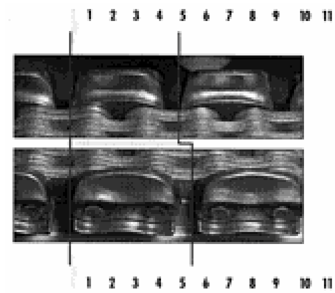
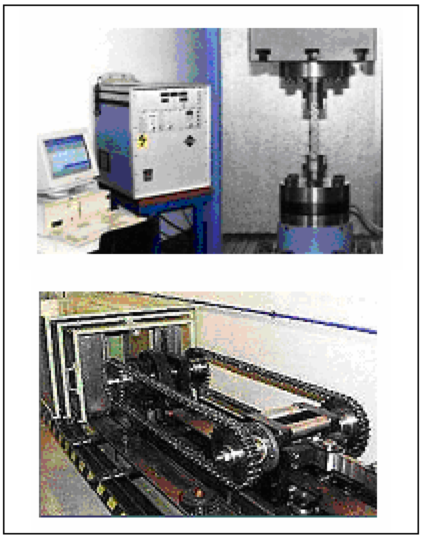


Figure 133: High-stress pre-loading



The constant quality of chains is not only due to the regular inspections performed but also to the tests each element is subjected to throughout manufacturing.

However, great care must be taken depending on where the product comes from: the manufacturing standards are not all the same and the quality of the finished product may differ greatly according to its place of origin.

Figure 134: Apparatus for checking the fatigue and wear resistance

Consequently, despite their interchangeability, the roller chains on the market are not all of the same quality.

Certain manufacturers have developed manufacturing processes that ensure an ideal combination of resistance to wear, resistance to fatigue and breaking load.

5.1.4. Pitch selection

The roller chain is defined by its pitch. Like with bolts, the pitch of chains (and of pinions) may be measured in mm or in inches (B.S >> British standard)

The pitch is the distance between two pins.

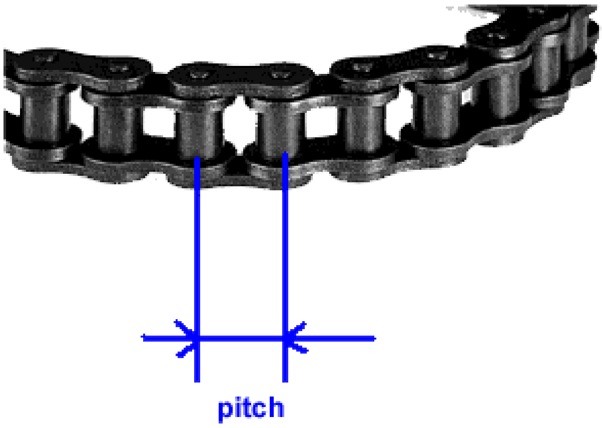


Figure 135: Chain pitch

Each pitch has:

- a normal speed range
- a ceiling speed range
- a power transmission range

It is recommended to choose the pitch in such a way that it is situated in the normal speed range.

If, for technical reasons, you have to choose a pitch in the ceiling speed range, you are advised to pay particular attention to the following parameters:

- Beating and vibrations
- Slapping

- Fatigue resistance
- Lubrication

5.1.5. Different types of roller chain

There are several different types of roller chain available on the market, each corresponding to a particular utilisation area.

With respect to high-efficiency roller chains, the roller chains used in the oil sector have an optimised operation and power rating.

They are fitted with high strength and high precision rollers.

They show their superiority in the tough conditions encountered when drilling, with a maximum power transmission and very high chain speeds.

At rotation speeds that are, in part, very high the chains operate in the ceiling ranges and in this case chains with high-strength rollers must be used.

5.1.5.1. Single roller chains

Figure 136: Single roller chains (steel and stainless steel)

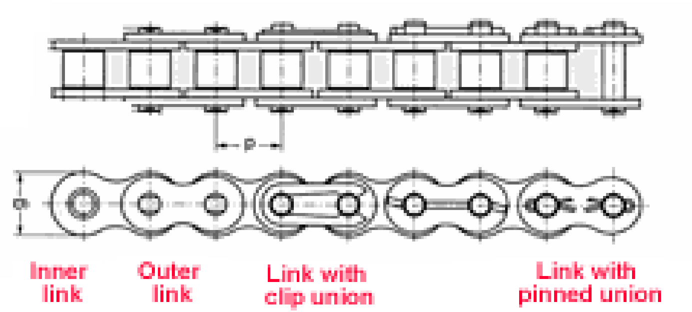


Figure 137: Detail of single rollers

5.1.5.2. Double roller chains

Figure 138: Double roller chain

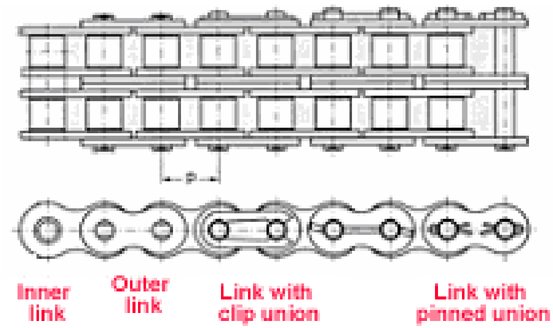


Figure 139: Detail of double rollers

5.1.5.3. Triple roller chains

Figure 140: Triple roller chain

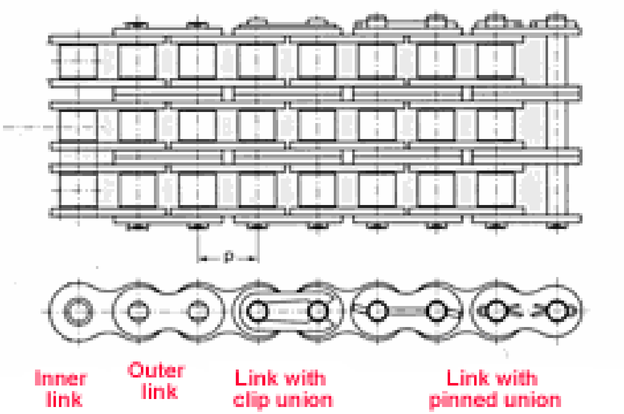


Figure 141: Detail of triple rollers

5.1.5.4. Chain with bushes for drilling machines

These chains do not have rollers, meshing is accomplished directly on the bushes.

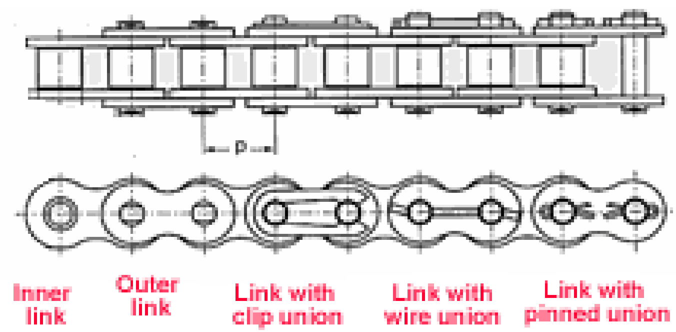


Figure 142: Detail of a bush chain

5.1.5.5. Hollow-pin chain

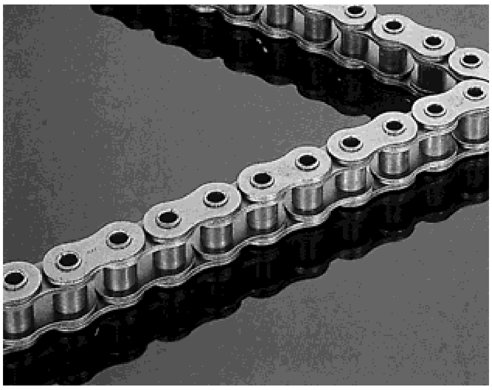
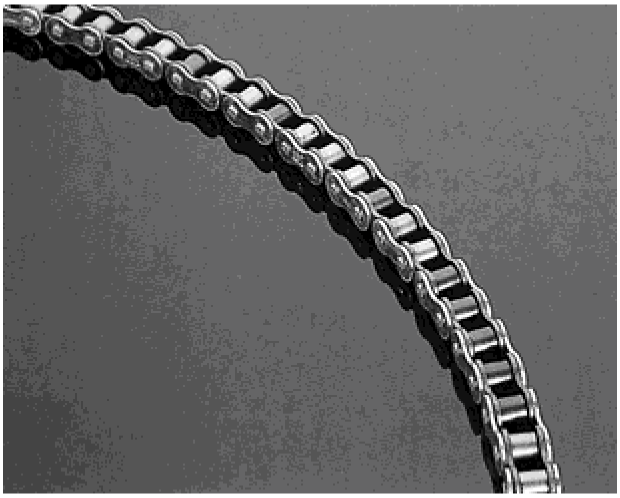


Figure 143: Hollow-pin chain (and handling chain)

5.1.5.6. Lateral bending roller chain



Chain specially designed to work with bending. It is usually used for power transmissions where it is impossible to achieve perfect alignment.

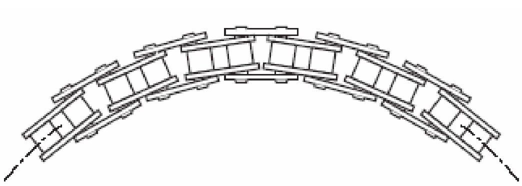
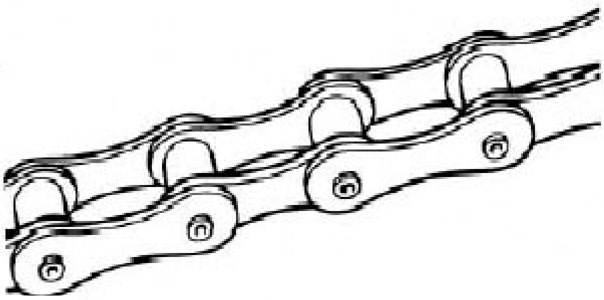


Figure 144: Lateral bending chain

5.1.5.7. Long-pitch roller chain

Long-pitch pins are used for applications that require a speed and transmitted power lower than that provided by equivalent short-pitch chains.



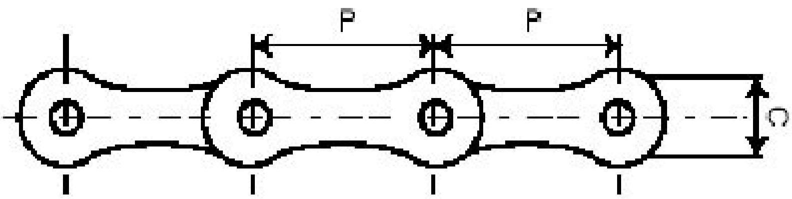


Figure 145: Long-pitch chain

Particularly recommended for low speed applications with long centre-to-centre distances.

Offset-link chains are used for highly loaded low-speed transmissions.

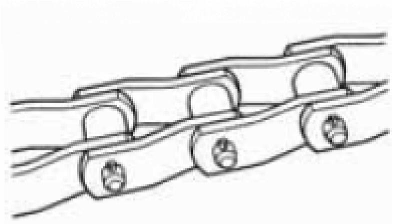


Figure 146: Offset link chains

5.1.5.8. Plastic chains

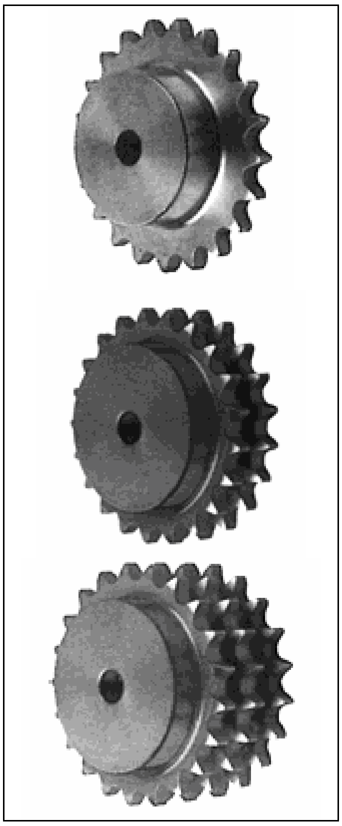
This type of chain is used in the medical world for a very particular purpose (sterilization).

This type of chain does not require any lubrication, there is therefore no risk of lubricant splashing.

The outer plates are made of stainless steel and the rest is made of plastic.

Figure 147: Chain for medical use

5.2. PINIONS



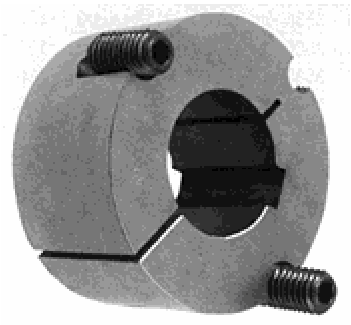
Just as belts are indissociable from pulleys in order to work, chains must be associated with pinions of a different shape, size, material and pitch depending on the area in which they are used.

The pinion (or wheel for handling chains) is like a polygon that has a number of sides equal to the number of teeth.

During pinion rotation, the chain at its meshing and unmeshing points, rises or falls with respect to the pinion axle.

This phenomenon is called the **polygonal effect**. The polygonal effect is inversely proportional to the number of teeth: the greatest number of teeth will be used whenever possible.

Figure 148: Single, double and triple pinion



For design reasons, there are also pinions with a removable hub.

Figure 149: Removable hub

Figure 150: Pinions with a removable hub

5.3. CHAIN MAINTENANCE

Transmission chains do not in fact require much maintenance.

A visual check of lengthening due to wear, satisfactory lubrication, and of the good condition of the pinions (wear, soiling, etc.) is all that is required.

Naturally, you must also monitor the condition of all the parts added to the chains (attachments, quick release fasteners, guides, etc.).

It is not necessary to systematically change the pinions when you replace the chain. You must nevertheless visually check that the teeth are intact (wear of the faces, deformation of the teeth dedenda), check the perfect meshing (no play) of the new chain and check their alignment.

But you should be aware that the chain's life will be shorter and shorter if it is mounted on the same pinions.

You must never add a new length of chain to a worn chain. Likewise, you must not join two chains with different pitches together. A worn chain no longer has the same pitch as the new chain and does not mesh in the same way on the pinions.

The immediate effect would be a significant acceleration in the whole transmission system's wear process.

5.3.1. Lubrication

The length of a chain's possible life depends on the maintenance personnel and more particularly on the lubrication that the personnel apply to the chain(s).

A large number of mistakes can be made when lubricating chains that you must absolutely try to avoid in order finally to achieve correct and perfect lubrication of these chains.

A chain's resistance to wear depends essentially on its good lubrication.

The use of an unsuitable lubricant and of incorrect lubrication methods will cause anti-lubrication, a cause of premature chain wear and failure. The statistics show that nearly 60% of problems on chains are due to unsuitable lubrication.

Aerosol spray lubricants are very widely used for the lubrication of chains. Unfortunately, these sprays very often contain a solvent that evaporates after application and leave a thick film of lubricant without fluidity.

In practice, these lubricants which do not stay fluid and thicken, only form a lubricant film inside the chain's articulations at the time of their first application, because it is only at the time of this first application that the path taken by the lubricant to reach the articulations (through the gaps between side plates) is still free.

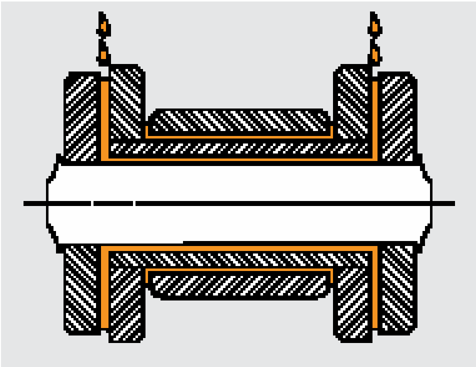


Figure 151: Path taken by the lubricant

At the time of the subsequent applications, the product accumulates on the outer parts of the links and rollers in ever-thicker layers of grease, which generally get still thicker and harden due to the incrustation of dust from the surroundings.

This means the lubricant cannot penetrate into the articulations. The chain's external appearance leads you to believe that it is correctly lubricated, but that is totally untrue.

To obtain effective lubrication, a sufficient quantity of lubricant must enter into the articulations at the time of each application. In fact, the lubricant must enter through the very small gaps to reach the articulation, made up of the pin and of the bush.

The chain roller's needs in oil are relatively low. The oil must therefore always be applied on the upper edges of the lateral links.

The essential condition for the good lubrication of the chain is that its articulations should permanently be supplied with a sufficient reserve of lubricant.

Only oils that are sufficiently fluid can meet this condition.

Lubricants that thicken after application are prohibited.

Always use products specially suited to the lubrication of chains, and that remain fluid after application and that have specific properties.

These products offer an optimum solution for the problems posed in the case of manual lubrication.

5.3.1.1. Manual lubrication

For chain transmissions that function at low speeds (up to about 0.5 m/s), you can use a manual type lubrication.

The oil must be applied with a paintbrush, an oilcan or an aerosol spray, which must contain a fluid lubricant product.

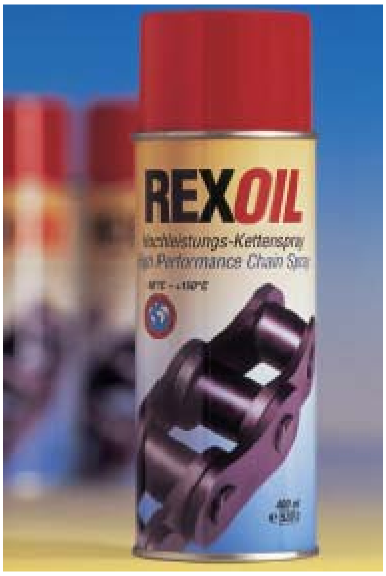
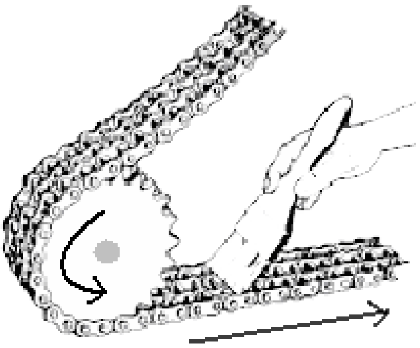


Figure 152: Aerosol spray for lubricating chains



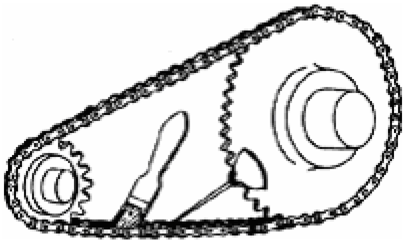


Figure 153: Lubrication with a paintbrush or an oilcan

In the case of lubrication with a paintbrush, you must pay great attention to ensure that the paintbrush's bristles (and then the paintbrush itself) do not get caught up between the pinion and the chain, as this could result in an installation failure.

Insofar as possible, always apply the paintbrush at the output from the pinion to avoid the paintbrush (or even your hand >> DANGER) being "sucked into" the pinion.

5.3.1.2. Lubrication by oilsplash

For chain speeds of up to 4 m/s, the chain can itself be immersed in the oil.

The chain should not be immersed too deeply, because foam might then form and compromise the lubricant's effectiveness.

For higher speeds, an oil projection disc is positioned beside the pinion. It is then only the disc that plunges into the oil.

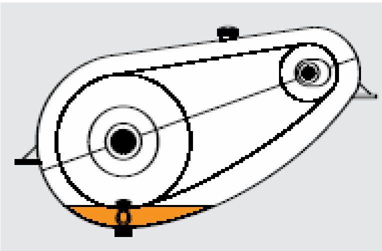


Figure 154: Oilsplash lubrication

5.3.1.3. Drip lubrication

This is an open-circuit, and therefore a lost-oil type of lubrication.

There is a closed oil tank (placed above the installation), from which a carefully positioned pipe comes out. There are pipes with a smaller diameter coming out of this pipe through which the oil flows under the effect of gravity and drips onto the chains to be lubricated.

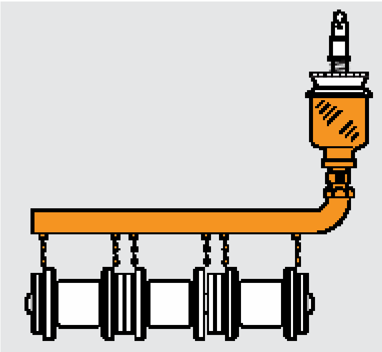
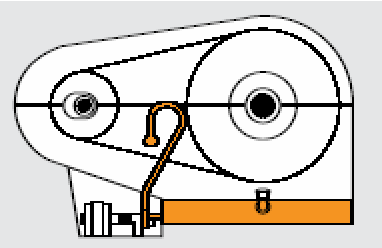


Figure 155: Drip lubrication

5.3.1.4. Oil pump lubrication

This is a closed-circuit, pressurised type of lubrication.

The oil is sprayed out by means of sprayers (often called nozzles or jets) on the upper edges of the links but not on the chain's rollers.



With this process, the oil temperature must not exceed 100 to 150° C, to ensure that the oil does not lose its properties.

Figure 156: Oil pump lubrication

5.3.2. Lengthening due to wear

Roller chains are usually subject to a maximum permissible lengthening of 3%, that is to say a lengthening of 30 mm per metre of chain.

Further to lengthening, the chain rises gradually up the pinion's teeth. If a chain with a known degree of wear remains on the pinions during prolonged use, a gradual wear of the teeth flanks appears which causes pitting and scratches on the teeth.

It is obvious that the wear between the pin and the bush causes the chain to lengthen.

A strange thing is that the wear on the articulation surfaces does not increase the distance between each roller two pitches apart. This is why it is preferable and prudent to use only pinions with an odd number of teeth.

The rollers then alternate in the teeth with each chain cycle, without any increase of the pitch, which reduces the wear on the pinions.

It is certain that a lengthening of a chain plays on the length of its service life and on that of the pinions.

Figure 157: Installing a chain

5.3.3. Problems and solutions

Despite its appearance, this chain has been in operation for several years, but there are no signs of wear, no marks on the rollers. The fact is that this chain has always benefited from regular maintenance and sufficient lubrication.

All that can be seen in the chain's links is simply the dirt that has accumulated between two inspections.

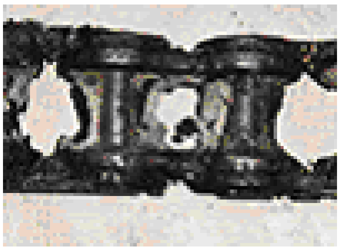
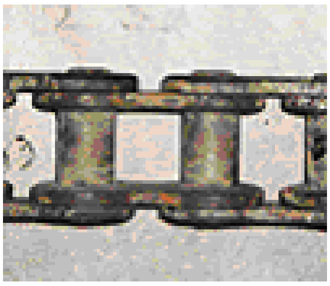


Figure 158: Correct maintenance



As for this chain, its maintenance and lubrication leave a lot to be desired. You can clearly see the corrosion on the plates and on the rollers and, at this stage, it is high time to do something about it!!!!!

Figure 159: Doubtful maintenance

In this chapter, we are going to try and provide an overview of what happens most frequently to chains and their components.

5.3.3.1. Abrasion

The chain has rubbed against a fixed point on the installation.

In this case, you will have to check the assembly's alignment before the damage to the chain and the pinions is so great that they have to be replaced.

Figure 160: Abrasion

5.3.3.2. Corrosion

This chain has been used in a humid environment. Furthermore, it is clear that there has been insufficient lubrication and a heavy load has been exerted on the rollers.

Insofar as possible, you must try to protect the chain against water infiltrations or, otherwise, use a stainless steel chain. You must also adopt a regular and serious lubrication scheme, and also avoid overloading the installation.

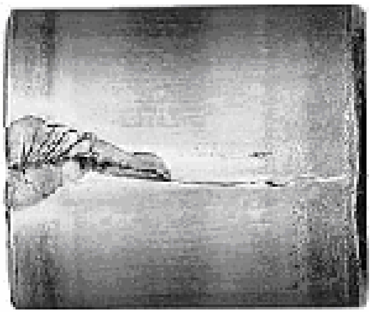
Figure 161: Corrosion

5.3.3.3. Cracking

The outer plates are cracked. The cracks are visible to the naked eye.

Figure 162: Cracking of the outer plate

This is due to high levels of juddering.



A crack has initiated on the edge of the hole in the plate and propagated, this is a classic case of fatigue failure.

You must find the cause of this juddering or use a chain with a larger pitch.

Figure 163: Cracking

5.3.3.4. Erosion

The chain has been contaminated by chemical products.

In this case, you must try to protect the installation against chemical aggressions or use a chain designed for that purpose.

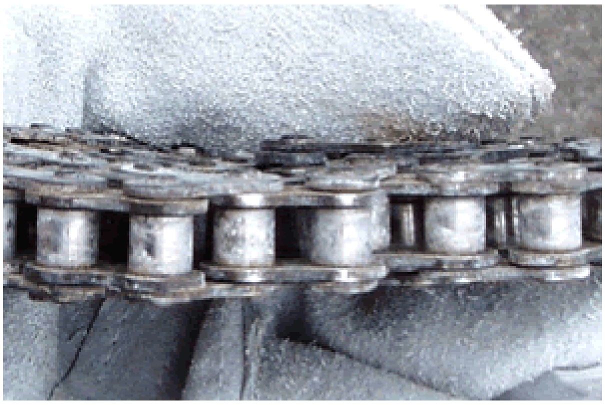


Figure 164: Erosion

5.3.3.5. Fatigue

The pin is extremely dry and does not show any signs of lubrication. Furthermore, signs of chipping can be seen as well as the presence of corrosion.

You must adopt an appropriate and regular rate of lubrication. Furthermore, if the chain is used regularly in a humid atmosphere, it would be a good idea to use a chain made of stainless steel.

Figure 165: Fatigue

5.3.3.6. Friction corrosion

This type of corrosion is caused by an inappropriate type of lubrication and an obvious lack of lubricant. You can see that the lubricant, because there is not enough of it, has not been able to arrive at the chain's internal components.

The chain must be treated against rust, and when the rust has been completely eliminated, you will have to adopt an effective lubrication scheme.

Figure 166: Friction corrosion

5.3.3.7. Chipping

The face of the pin shows serious signs of chipping, to such an extent that the surfaces have fused together.

The great pressure that this type of chain is submitted to means that the lubricant is driven out between the parts thus allowing the surfaces to come into direct contact when the chain passes through the pinions.

You must use a high-quality lubricant that can withstand high pressures, and also check that the means of lubrication ensures that there is always a film of lubricant between the surfaces in contact.

Figure 167: Chipping

5.3.3.8. Lubrication and alignment

In this case, no lubrication has been applied since the installation was put into service. Furthermore, it is possible that there is a misalignment of the pinions and the distance between the pinions is greater than recommended.

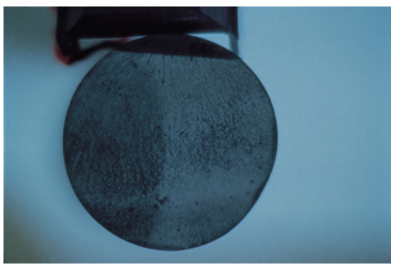
A satisfactory and effective means of lubrication must be put in place. You must also ensure correct alignment of the pinions and install an automatic chain tensioner.

Figure 168: Poor lubrication and misalignment

5.3.3.9. Overloading

The pin has broken due to overloading or to juddering. The break initiated in the corner of the pin's flat part.

Figure 169: Overloading



You must determine the cause of the overloading and absolutely prevent this phenomenon from occurring again, or use a stronger chain.

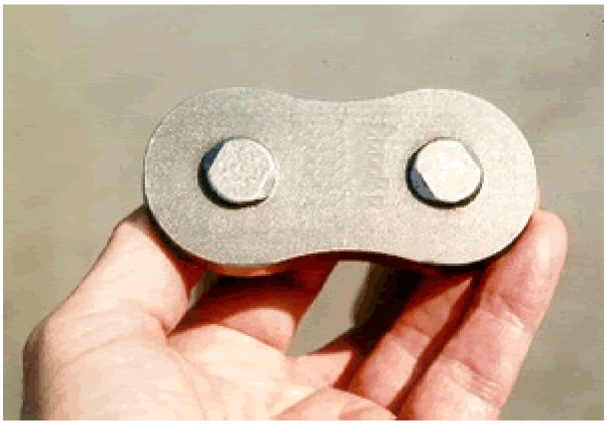
5.3.3.10. Pitting corrosion

Pitting corrosion can clearly be seen here. The chain is used in a humid environment and the coat of protective grease has been eliminated as a result of high pressure cleaning.

You must not forget to re-apply grease to the chain after having cleaned it.

Figure 170: Pitting

5.3.3.11. Pin deformation



The chain rises in operation. It is submitted to serious overloading.

You should use a chain with a larger pitch and review the lubrication system.

Figure 171: Deformed pins

5.3.3.12. Wear

The cross-section of the pins is worn, the position of the intermediate plates can clearly be seen.

Normal wear. Over a long period of time, the pins have gradually become worn until they have reached the maximum authorised lengthening.

You must regularly monitor chain lengthening.

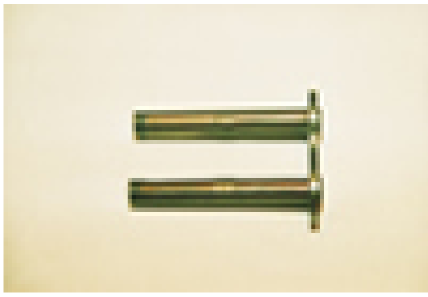


Figure 172: Wear

5.3.3.13. Wheal wear

The original chain had suffered from pitch elongation. A new chain was put in place on the already worn cog wheels which were incompatible with the pitch of the new chain. This led to severe wear of the teeth and, in all likelihood, to a rapid elongation of the chain.

You must check the condition of cog wheels when installing a new chain in an installation as well as the compatibility of the pitch. If obvious wear of the teeth is observed, you must change the wheel(s).

Figure 173: Wheel wear

5.4. CHOICE OF CHAIN

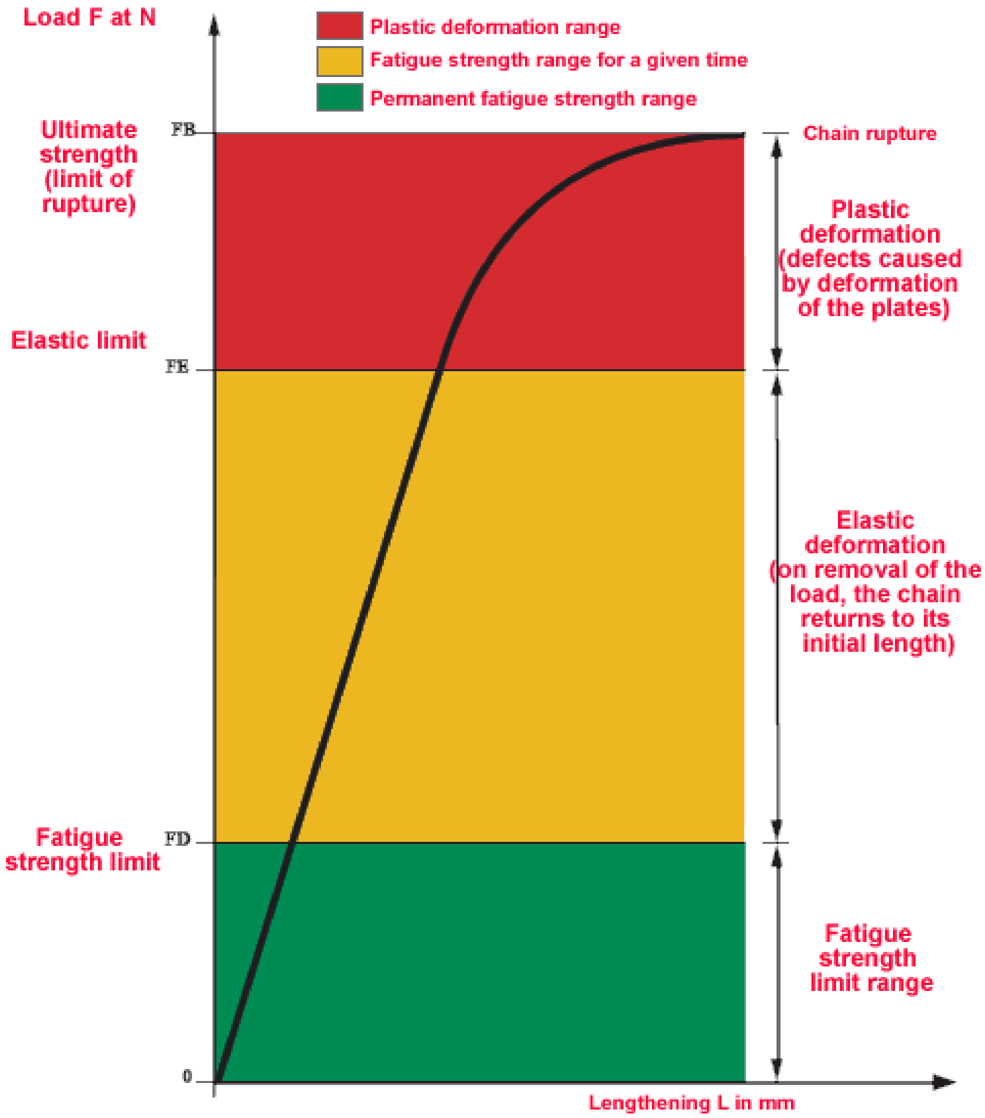


Figure 174: Quality criteria.

5.4.1. Fatigue strength

This indicates up to what limit the chain can withstand the juddering due to operation, the loads generated by the polygonal effect of the pinions and alternating forces, without breaking.

Besides the effects of the manufacturing techniques and the quality of the materials on the fatigue strength, it is also important to reach a balanced trade-off when determining the ultimate strength.

Too high ultimate strength values are not an advantage, because they cause a reduction in the elasticity and in the fatigue strength.

When a chain's ultimate strength exceeds a certain value, the fatigue strength – the decisive value – decreases significantly.

5.4.2. Elastic limit

This represents the load range below the permanent deformation range.

The operating loads and juddering that do not exceed the elasticity limit only cause an elastic deformation that only lasts for the time the overloading is effectively applied.

The elastic limit is therefore of considerable importance because all the loads above that limit, fixed by the permanent deformation, cannot be used for the chain.

5.4.3. Rupture load

The level of the rupture load is of secondary importance because a lasting deformation occurs before the rupture load limit is reached, that is to say from the elastic limit, when the chain has already become unusable.

5.5. EXERCISES

15. What type of transmission is obtained with a chain?

16. What method is used to increase the tension course on long transmissions?

17. List the drawbacks of chains.

18. Can you join together two chains with different pitches? Explain.

19. Definition of the chain pitch.

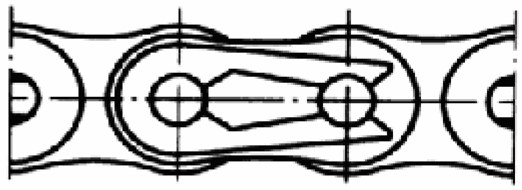
20. What parameters must be monitored closely when using the ceiling speed range?

21. What is the maximum permissible lengthening of roller chains?

22. List the various chain lubrication methods.

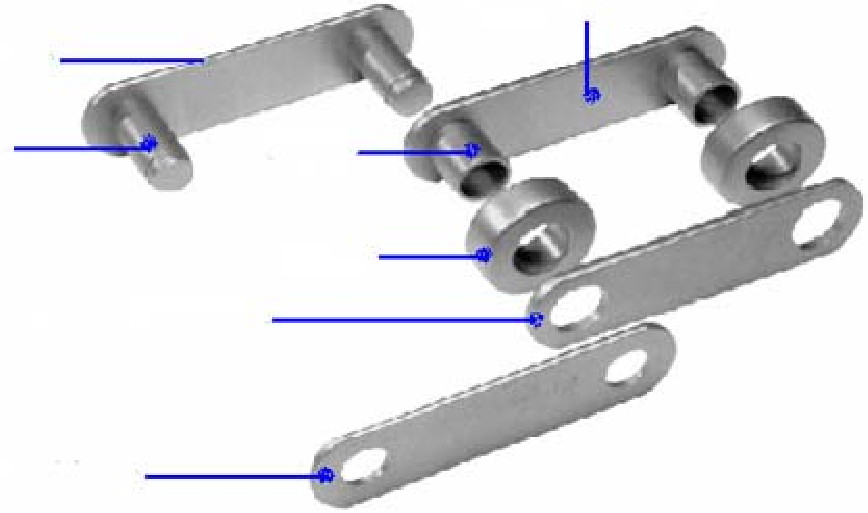
23. What is the name of tool used to join chains together?

24. Indicate the chain rotation direction.



25. What type of pinion must you use to avoid having a polygonal force?

26. Complete the diagram.



27. What role is played by the fasteners?

28. Why isn't it an advantage to have too high a rupture value?

6. HANDLING CHAINS AND WHEELS

6.1. HANDLING CHAINS

6.1.1. The functions of handling chains

Handling chains, like transmission chains, are made up of a series of articulations coupled together by side plates, and each articulation is made up of a pin and bush around which the roller swivels.

The pin and bush are made of case hardened steel, which means that high pressures can be applied to the articulations. These pressures are due to the loads being transported and to the meshing effects.

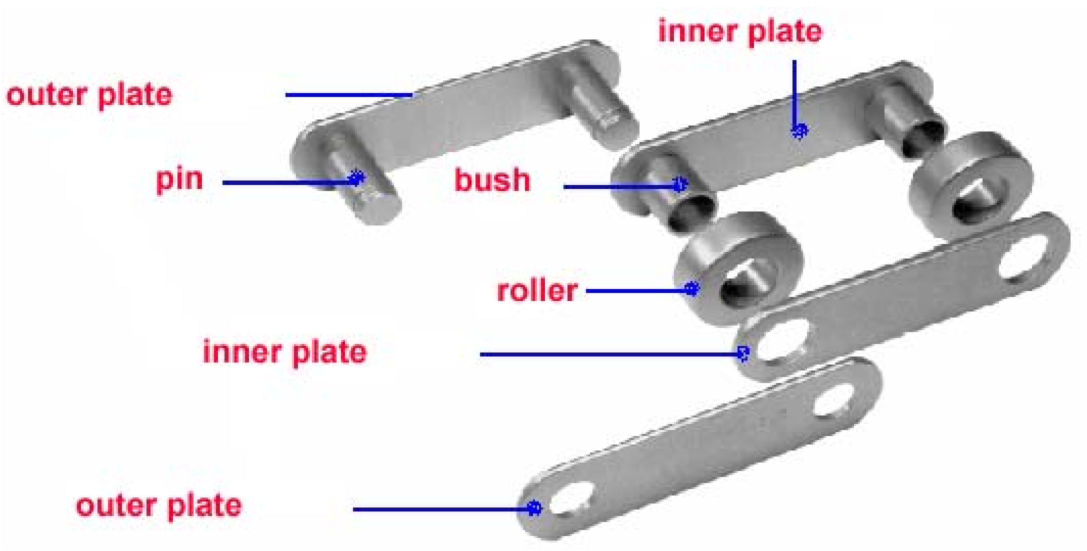


Figure 175: Detail of handling chain composition

The characteristic shared by all chains lies in the relative movement between the link's plate and the pin. Forces, that are often considerable, are transmitted by the articulation, which generates very high levels of stress.

Insufficient lubrication at this spot will cause premature wear and the failure of the chain, which will lead to a production shutdown.

Precise and appropriate lubrication is essential for optimum operation and a long service life for conveyor chains. The manual lubrication method, for conveyor chains, is obsolete. Only an automatic lubrication system is capable of dosing the lubricant precisely and of directing it to the strategic points of the chain.

6.1.2. The different types of chain

An extensive range of pitches exists for each series of chains. The minimum pitch often depends on the strength of the teeth, as for the maximum pitch it is limited by the cross-section of the plates and the stiffness of the chain.

There are several different types of chain for conveying, lifting and handling:

- Bush chain: this is used for low-speed conveying, and in the case where the load is not supported by the chain.

- Roller chain: the diameter of the rollers is smaller than the height of the plates. The roller reduces the force at the time of rolling over the wheel and protects the bush against shocks and wear.

- Runner chains: the diameter of the rollers is greater than the height of the plates. The load to be carried rolls on the runners. They may be flat or shouldered to ensure lateral guidance.

Likewise, there are also several different versions of chains:

- **Hollow-pin chain**

  Hollow-pin chains are suited to all applications when used under normal conditions.

  It allows a fast attachment of the fasteners on the outer links by bolting them through the hollow pins.

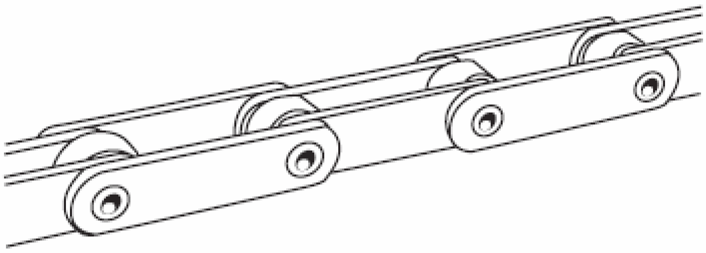


Figure 176: Hollow-pin chain

- **Solid-pin chain**

  Solid-pin chains are stronger than hollow-pin chains, but they have the same characteristics (pitch, width between inner plates, runner diameter).

  They are used for more difficult applications.

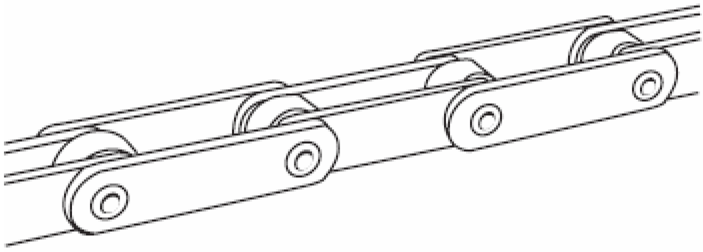


Figure 177: Solid-pin chain

- **Eccentric plate chain**

Eccentric plate chains make it possible to deposit loads directly on chains, which can thus run without the rollers coming into contact with the objects being transported.

The special shape of the plates avoids snagging of the deposited loads when the wheels mesh.

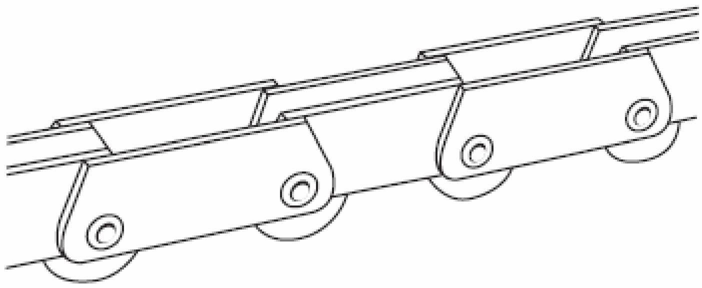


Figure 178: Eccentric plate chain

- **Leaf chain**

Leaf chains are above all used in the following applications:

  - Drawing benches
  - Furnace door movements
  - Machine tool counterweights
  - Operating dam sluice gates
  - Forklift truck lift

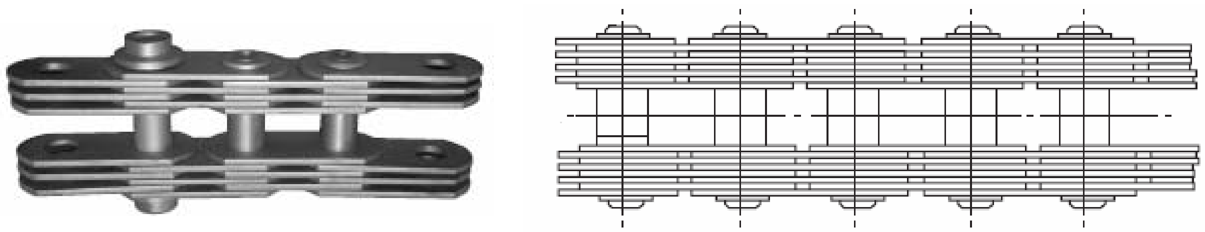


Figure 179: Leaf chains

The leaf chains shown in the figure correspond to the most common types of utilisation.

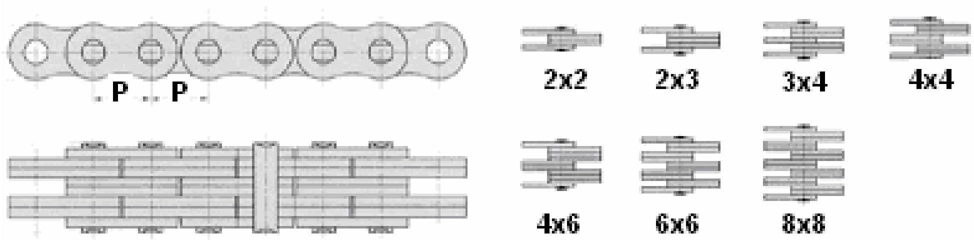


Figure 180: Details of leaf chains

Conveyor chains

This type of chain is driven by a pinion (more like a gear than a pinion).

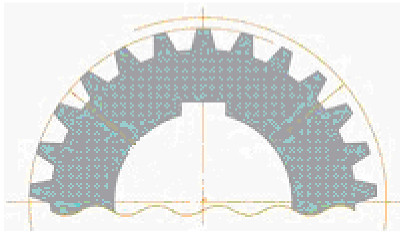


Figure 181: Pinion profile

Given these chains' great width, they must be guided to prevent them leaving the pinions.

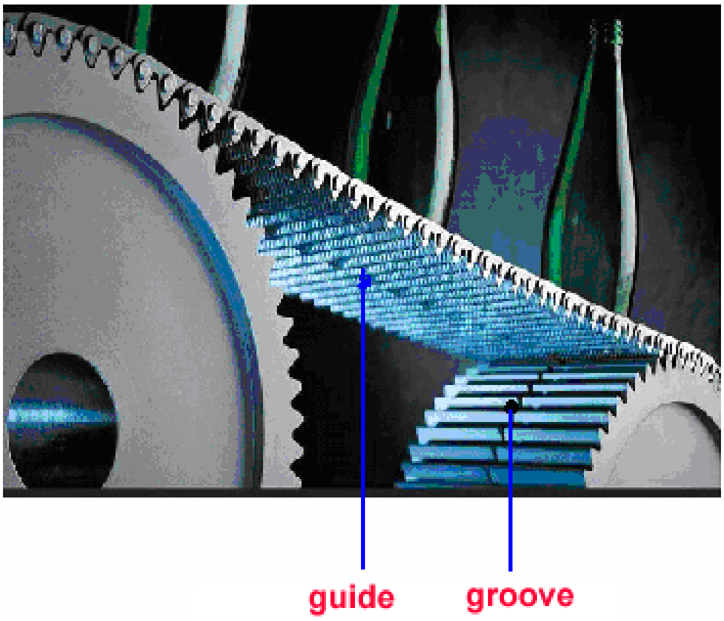


Figure 182: Details of chain (guide) and pinion (groove)

The pinions are machined with a groove that will guide the chain.

The chain has studs that fit into the groove in the pinions, which prevents the chain from slipping off in any direction.

There are three different methods of guidance:

- **Central guide**: the guide links, in the centre of the chain, align with a groove in the centre of the pinion

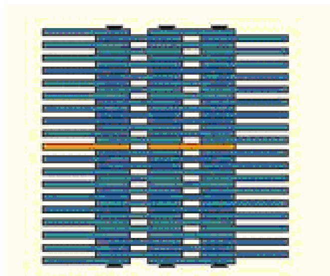


Figure 183: Central guide

- **Lateral guide:** the guide links are situated on the outer edges of the chain and the pinions position themselves inside guide links.

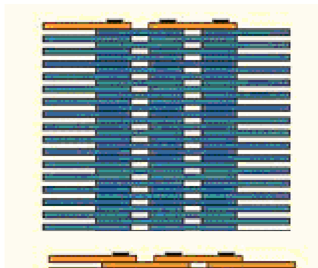


Figure 184: Lateral guide

- **Multiguides**: multiple guide links are situated on the outer edges of the chain.

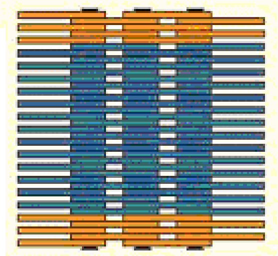


Figure 185: Multiguide

6.1.3. Fasteners

Fasteners make it possible to adapt the basic chain to all the special types of handling applications.

The fastener may be an integral part of the side plate or be added to it by riveting or welding to one or both sides of the link.

There are many different types of fastener, of all shapes and sizes. We will only see a small sample in this paragraph.

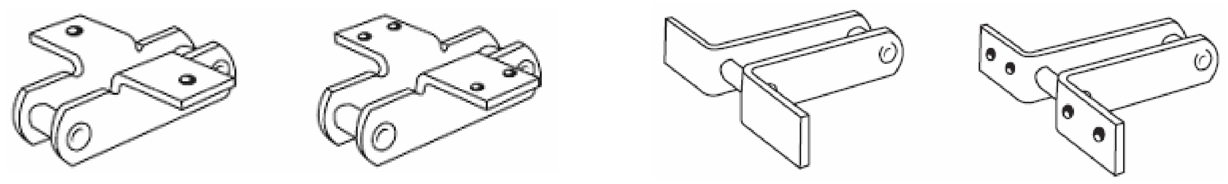


Figure 186: Integral fasteners

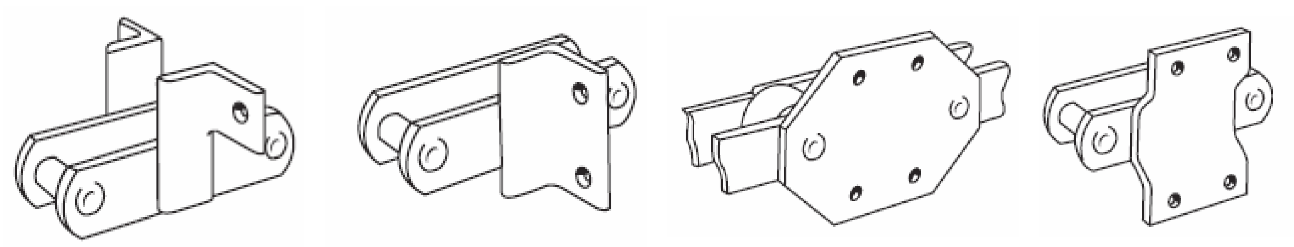


Figure 187: Welded fasteners

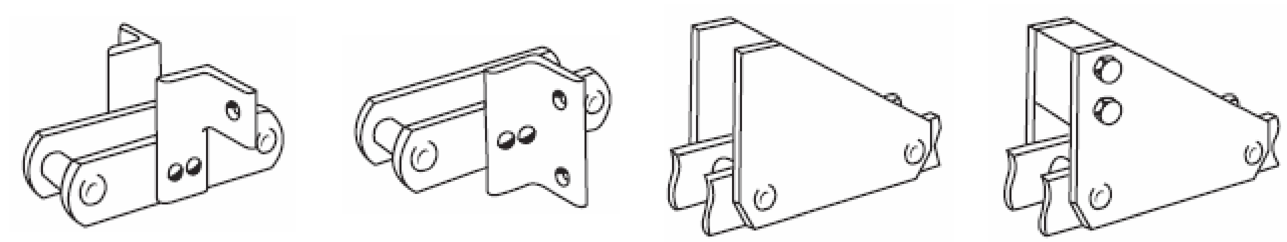


Figure 188: Riveted fasteners

6.1.4. Coupling links

It is quite simple to join (couple) chains thanks to one of the following types of link.

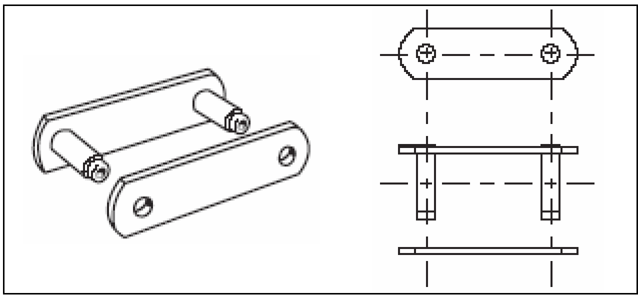


Figure 189: Rivet link

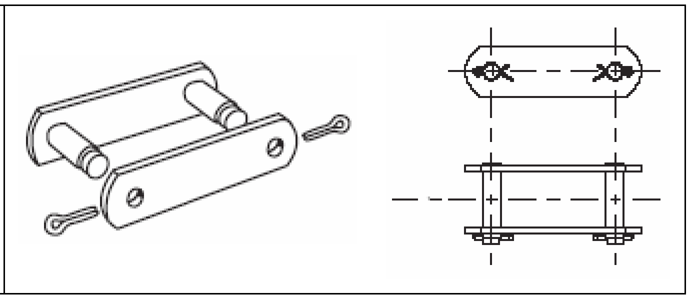


Figure 190: Pinned link

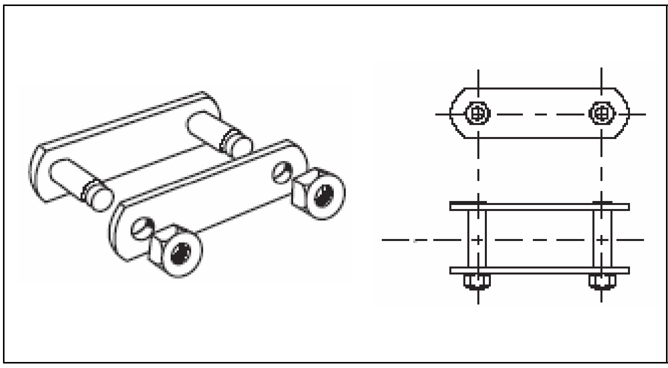


Figure 191: Bolted link (self-locking nuts)

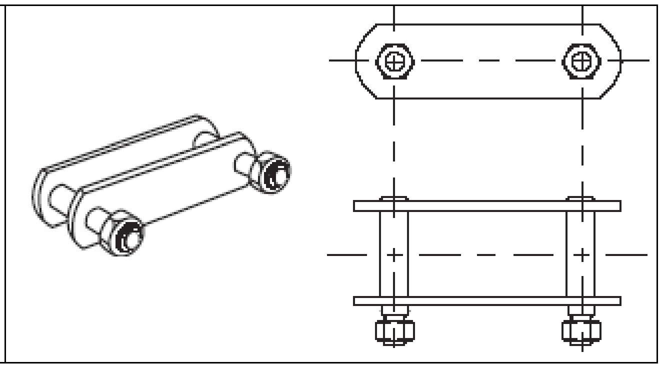


Figure 192: Extended pin link

The extended pins used in extended pin links make it possible to insert a special fastener between the bolts and the plates, with the nuts being used to tighten the assembly.

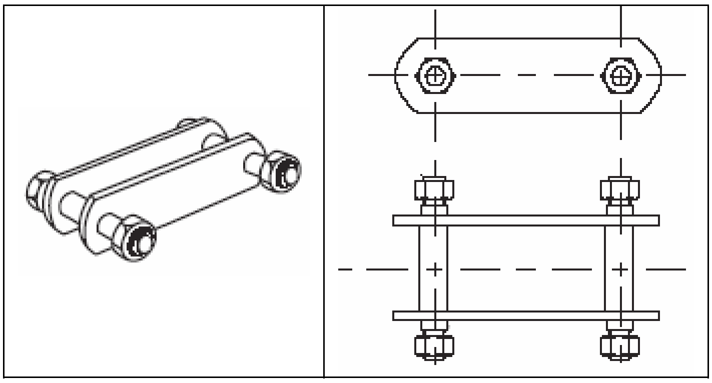


Figure 193: Pin link threaded on both ends

With the following link (fig.114) added parts can be attached on both sides of the link, because both ends of the pins are threaded.

6.2. WHEELS

Drive wheels are made of cast iron or welded steel with a symmetrical or offset hub.

Steel wheels with added toothed segments are also used.

Usually the teeth are as cast or flame cut. For specific applications (high speed), they are cut and sometimes induction-hardened to obtain a high degree of surface hardness.

Figure 194: Drive wheels

In specific installations (feed elevator, bulk conveyor), the wheels' teeth must be clear to avoid any accumulation of material at the root of the teeth which might cause the chain to rise (>>excessive tension!!!), and therefore poor meshing, and then cause the chain to break.

Like transmission chains, handling chains have a pitch.

This pitch depends on the size of the intervals between the fasteners, the working speed and the available distance between the wheels.

The polygonal effect is great when the number of teeth is small and operating smoothness will be affected. Wheels with a large number of teeth must therefore be used, compatible with the other requirements (spacing of the fasteners and utilisation conditions).

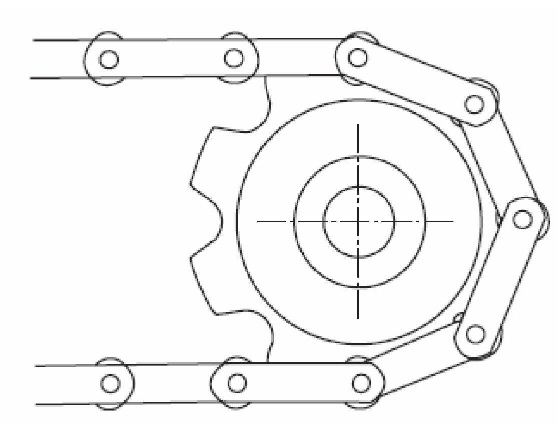
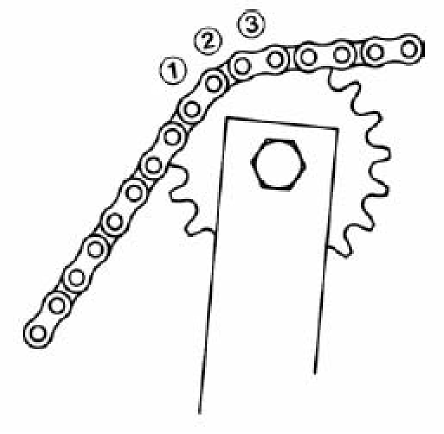


Figure 195: Chain drive (1)

Handling chains are usually driven by means of a cogwheel.

Insofar as possible, the chains should be wound around the wheels in a 180° arc.



Sometimes this condition cannot be met, in particular for complex circuits however, insofar as possible, the goal is to never have less than three teeth meshed on each driven wheel.

Figure 196: Chain drive (2)

It is possible that, in some rare cases, it will not be possible to have any shaft that can be driven or any wheel installed in a circuit.

Driving is then ensured by an intermediate chain fitted with studs.

These studs are integral with the links and may be articulated inside these links.

This setup will be preferred for a large installation, but it will only be possible to ensure driving in one direction.

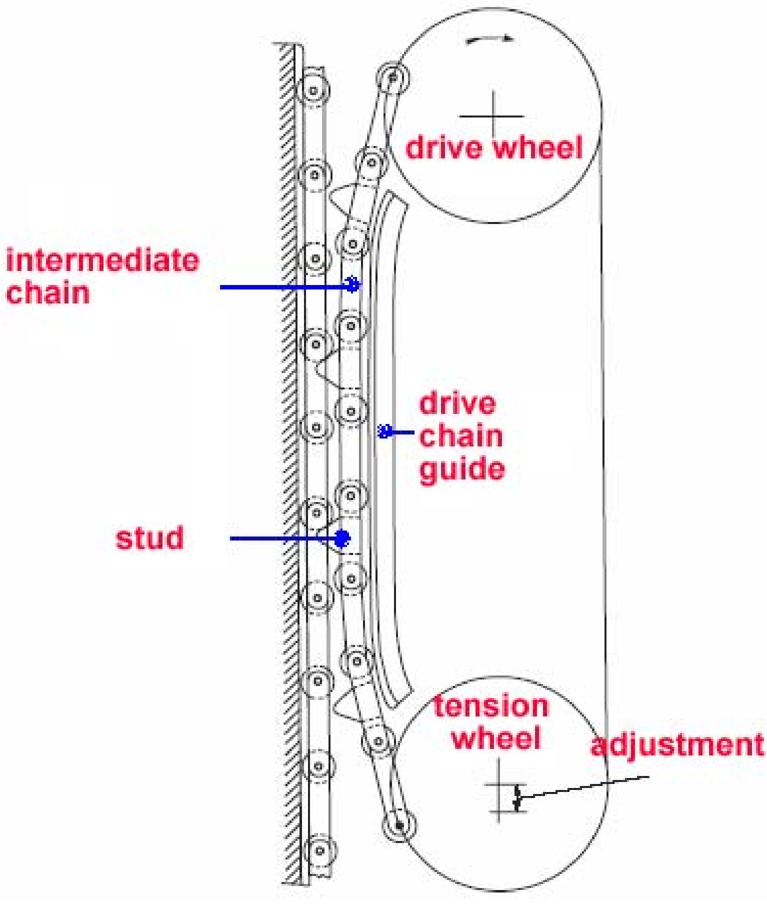


Figure 197: Intermediate chain

6.3. MAINTENANCE OF HANDLING CHAINS

Transmission chains do not in fact require much maintenance.

A visual check of lengthening due to wear, satisfactory lubrication, and of the good condition of the pinions (wear, soiling, etc.) is all that is required.

Naturally, you must also monitor the condition of all the parts added to the chains (attachments, quick release fasteners, guides, etc.).

It is not necessary to change the wheel(s) systematically when you replace the chain. You must nevertheless visually check that the teeth are intact (wear of the faces, deformation of the teeth dedenda), check the perfect meshing (no play) of the new chain and check their alignment.

But you should be aware that the chain's life will be shorter and shorter if it is mounted on the same wheels.

You must never add a new length of chain to a worn chain. Likewise, you must not join two chains with different pitches together. A worn chain no longer has the same pitch as the new chain and does not mesh in the same way on the pinions. The immediate effect would be a significant acceleration in the whole transmission system's wear process.

6.3.1. Tension adjustment

Like for power transmission chains, it is essential to have an adjustment system to take up the lengthening due to wear.

The adjustment range must make it possible to install the chain and take up the lengthening due to wear.

In an installation that includes several counter-gears, the tension wheel will always be the wheel placed immediately after a drive shaft, because the force required for adjustment must be at its lowest at this place on the chain.

The tension must be checked periodically so as to maintain installation performance.

For large installations (such as conveyors for example), it is preferable to use a turnbuckle system.

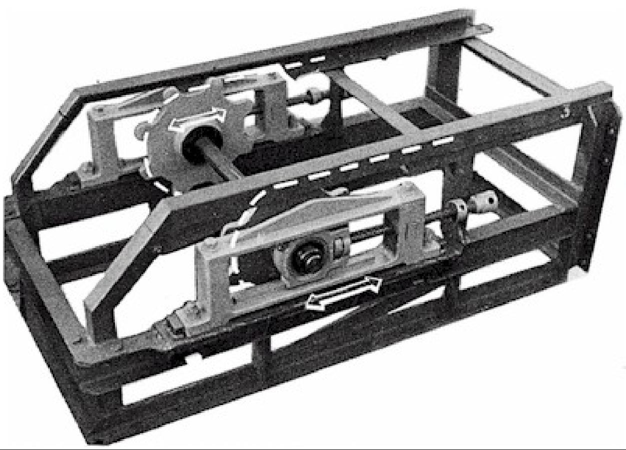
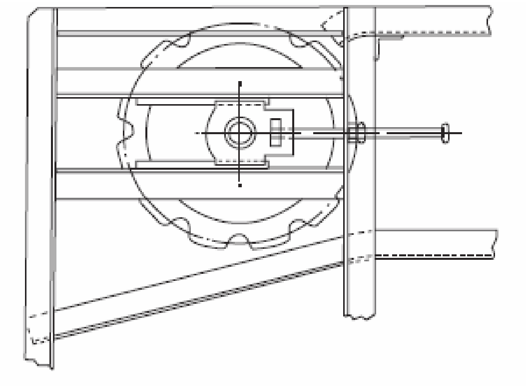


Figure 198: Turnbuckle tensioner

The countershaft bearing blocks are mounted inside slides: when the optimum tension is reached, you just have to lock the screw to maintain the bearing blocks rigidly in position.



There are cases where the installations must have an automatic adjustment, particularly in the case of dilation.

This automatic adjustment is obtained by means of counterweights, springs and pneumatic or hydraulic devices. In some cases it is even the machine's own weight that is used for this purpose.

Figure 199: Detail of a turnbuckle

6.3.2. Lubrication

The lubrication process for handling chains is more or less the same as for power transmission chains.

The lubrication must reach the places where there is friction, and penetrate between the bush and pin. The lubricant can be distributed automatically drop by drop or manually with a brush.

In difficult conditions, the chains' articulations are sometimes fitted with an axial greasing circuit.

The choice of lubricant will be determined according to the place and nature of the work:

- For normal applications, a good quality mineral oil will be sufficient.
- In humid conditions, the choice will rather be for insoluble grease, but there is a risk that the inside of the articulations will not be lubricated: so lubrication with oil will be preferable.
- In an abrasive atmosphere, the chains may be greased with a dry lubricant (colloidal graphite)
- In a very severely abrasive atmosphere, the chains' articulations may have a greasing circuit through the centre of the pins so that the wear parts receive grease under pressure.
- When working at high temperature (between 100° and 300° C), a dry lubricant is recommended.
- Depending on the type of work (feed, bottle conveying, etc.) special lubricants, usually soluble, are used to avoid dirtying the products.

6.4. CHOICE OF CHAIN

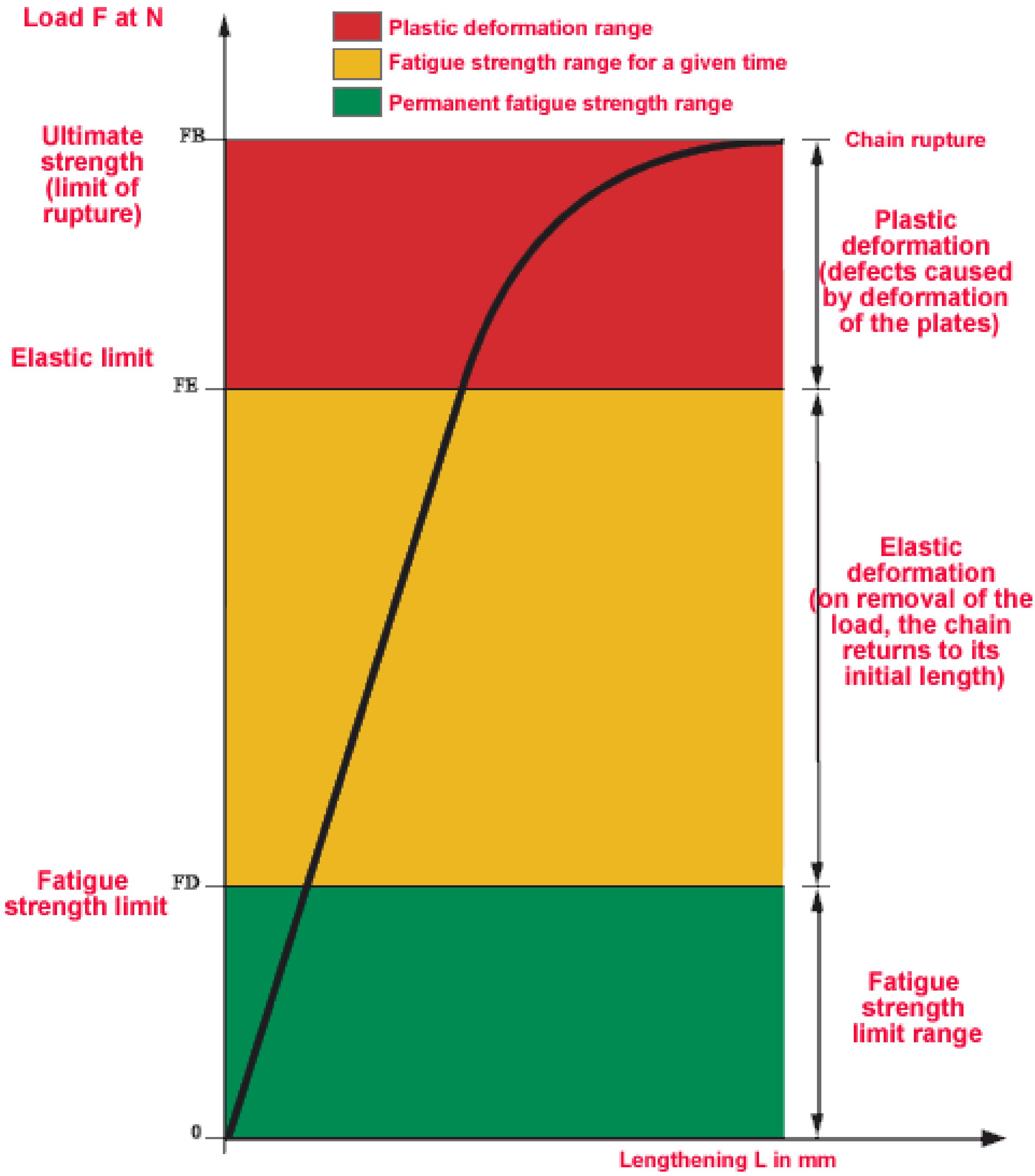


Figure 200: Quality criteria.

6.4.1. Fatigue strength

This indicates up to what limit the chain can withstand the juddering due to operation, the loads generated by the polygonal effect of the pinions and alternating forces, without breaking.

Besides the effects of the manufacturing techniques and the quality of the materials on the fatigue strength, it is also important to reach a balanced trade-off when determining the ultimate strength.

Too high ultimate strength values are not an advantage, because they cause a reduction in the elasticity and in the fatigue strength.

When a chain's ultimate strength exceeds a certain value, the fatigue strength, the decisive value, decreases significantly.

6.4.2. Elastic limit

This represents the load range below the permanent deformation range.

The operating loads and juddering that do not exceed the elasticy limit only cause an elastic deformation that only lasts for the time the overloading is effectively applied.

The elastic limit is therefore of considerable importance because all the loads below that limit, fixed by the permanent deformation, cannot be used for the chain.

6.4.3. Rupture load

The level of the rupture is of secondary importance because a lasting deformation occurs before the rupture load limit is reached, that is to say from the elasticy limit, when the chain has already become unusable.

7. REDUCTION GEARS

7.1. REDUCTION GEAR FUNCTIONS

In mechanical terms, a reduction gear is a gear system whose transmission ratio is lower than 1, in order to increase the drive torque of a rotation and decrease the output shaft's rotation speed.

The mechanical transmission components are sensitive elements in modern industries, maintenance must be preventive and just-in-time working no longer authorises any long production shutdowns.

Figure 201: Parallel shaft reduction gear

Amongst the technical solutions made available to mechanical engineers for transmitting power, gear transmissions without the slightest doubt represent the best trade-off from the efficiency and precision viewpoint.

We must first of all situate the reduction gear in its context:

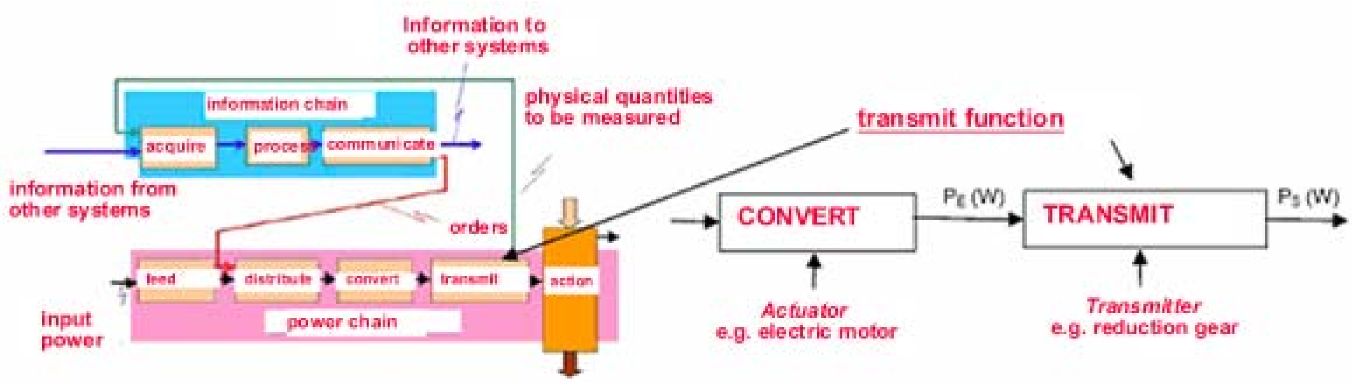


Figure 202: Position of a reduction gear in a power chain

A reduction gear is made up of several components (gears, bearing blocks, shafts) which each a decisive role to play in the mechanism's overall behaviour.

7.1.1. Notion of reduction ratio

For a power transmission system, and in particular for reduction gears, the transmission ratio represents its key characteristic.

This is the output shaft's rotation speed (or frequency) ratio with respect to the input shaft.

Lower than 1 (one) in the case of a reduction, it is often replaced by its reverse, called the **reduction ratio.**

The input power P_E is defined as:

$$\mathbf{P_E = C_E \,.\, \omega_E}$$

Where C_E : the input torque (N.m) and ω_E : angular speed (rad/s)

The output power P_S is defined as:

$$\mathbf{P_S = C_S \,.\, \omega_S}$$

Where C_S : the output torque (N.m) and ω_S : output angular speed (rad/s)

In the case of a rotation movement:

The "input-output" law is equivalent to establishing the ratio between the angular speeds as follows:

$$\mathbf{\omega_S / \omega_E = r = 1 / d}$$

r is called the reduction gear's reduction ratio.

<u>Note</u>: a reduction ratio is lower than 1

7.1.2. Calculating the reduction ratio for a reduction gear

7.1.2.1. Reduction gear with one gear

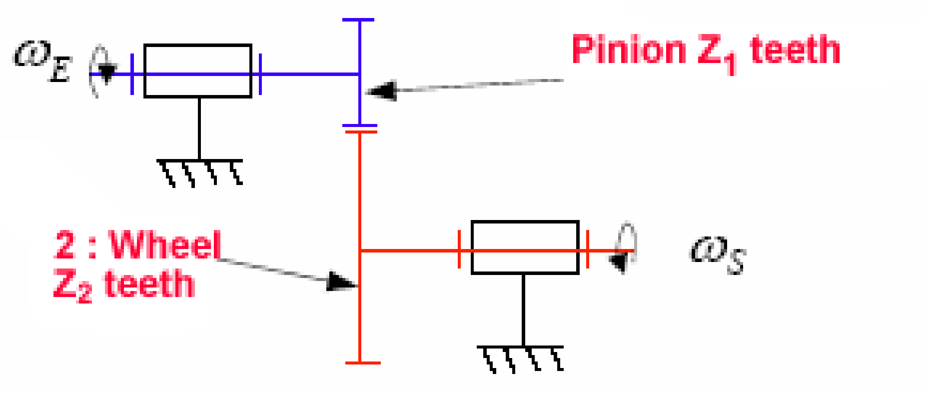


Figure 203: Reduction gear

By definition, the speed reduction ratio is equal to:

ω_S / ω_E = r

and in this case:

$$r = \frac{\omega_S}{\omega_E} = -\frac{Z_1}{Z_2}$$

7.1.2.2. Reduction gear with several gears

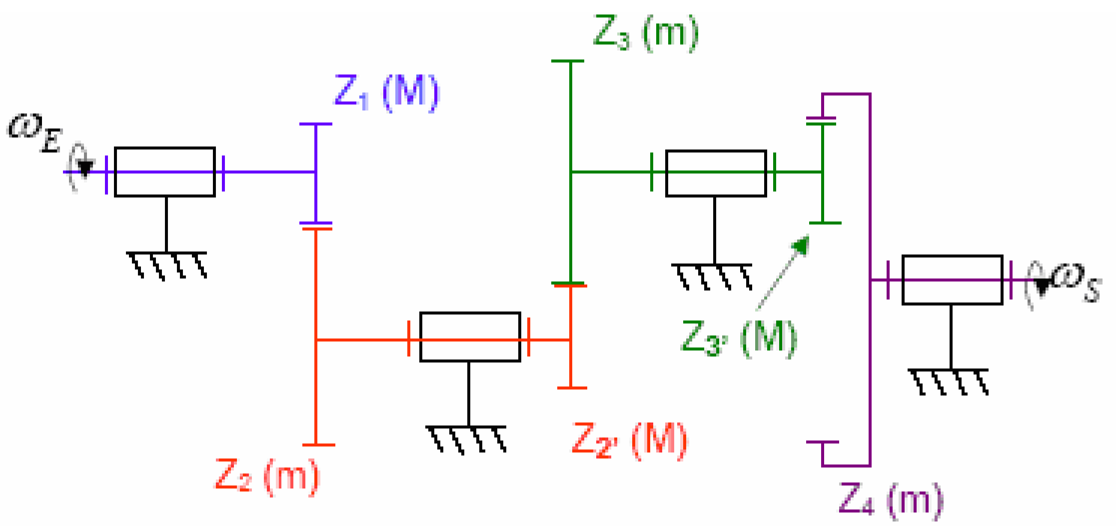


Figure 204: Reduction gear with several gears

In the previous figure, in the gear (1-2) :

- Z_1 is driving and is noted Z_1 (M)
- Z_2 is driven and is noted Z_2 (m)

In the case of a gear train (several gears in cascade) the general definition of the reduction ratio is:

$$r = (-1)^n \times \frac{\text{product of } Z_{\text{Driving}}}{\text{product of } Z_{\text{driven}}}$$

The exponent n corresponds to the reduction gear's number of external contacts. In the figure, there are two of them (gear (1-2) and gear (2'-3)).
In this case:

$$r = (-1)^2 \times \frac{Z_1 \times Z_{2'} \times Z_{3'}}{Z_2 \times Z_3 \times Z_4} = \frac{\omega_S}{\omega_E}$$

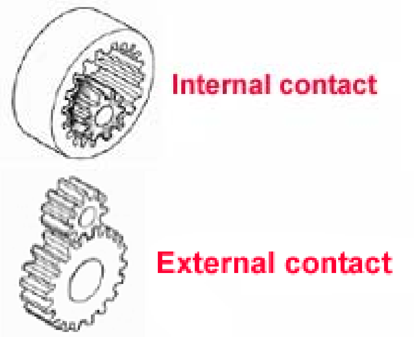


Figure 205: Different types of contact

7.1.2.3. Planet reduction gear (epicyclic)

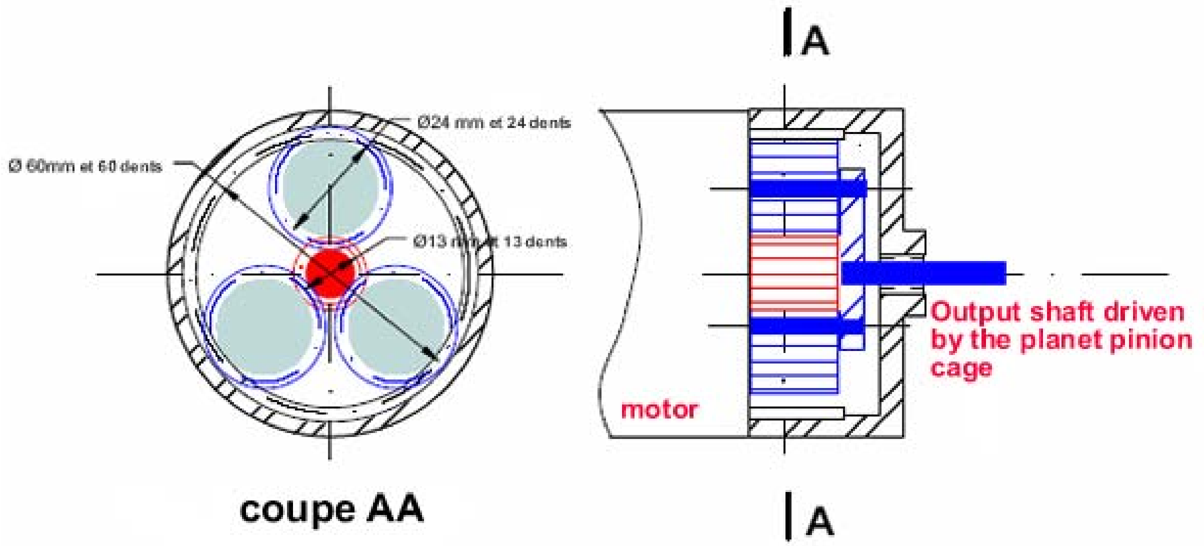


Figure 206: Diagram of an epicyclic gear train

One of its major advantages is its compactness. In the diagram, the outer ring has **60** teeth, the small pinion 13 teeth and planet gears **24** teeth.

This gives a reduction ratio of: **(60 + 13) / 13 = 5.6** in a diameter of 65 mm.

A reduction gear of this type can provide a large amount of power.

Thanks to the presence of planet gears, the ratio between the number of teeth on the wheels that mesh together is higher for a given reduction ratio.

The reduction ratio is **5.6** even though the ratio between each pair is at the best **60 / 24 = 2.5**

This ratio us highly favorable for the good running of gears.

In order to transmit power, a frequently used concept is to have at least three planet gears to obtain a well-balanced assembly.

The pressure on the teeth is therefore three times lower, which is very good for efficiency and makes it possible to transmit a large amount of power on small moduli.

When it is necessary to obtain very high reduction ratios, it is easy to stack reduction stages one after the other, where the output pinions from the first stage serves as the input stage for the second stage, and so on.

For applications requiring less output power, and reduction ratios that are not too high, there is the solution of using belt reduction gears, which can transmit considerable levels of power while remaining economical.

7.1.3. Reduction gear efficiency

All systems have an energy efficiency and in mechanics it is often calculated from a ratio between the input power P_E and the output power P_S, it is noted η (êta) and is defined by:

$$\eta = \frac{P_S}{P_E} \qquad (\eta \leq 1)$$

In the case of a reduction gear:

Figure 207: Reduction gear input/output power

$$\eta = \frac{P_S}{P_E} = \frac{C_S \times \omega_S}{C_E \times \omega_E}$$

But because $\frac{\omega_S}{\omega_E} = r$, we can write: $\eta = \frac{C_S}{C_E} \times r$

And when we are seeking to establish the value of the output torque C_S, we can then set out:

$$C_S = \frac{\eta \times C_E}{r} \text{ or } C_S = \frac{\eta \times P_E}{\omega_S}$$

<u>Note</u>: in the case of several systems mounted in series (e.g.: energy chain), the **outputs from the various systems are multiplied and, most importantly, not added to each other.**

In order for a reduction gear's output to be satisfactory, there must not be any slippage at the level of the teeth.

This is achieved by means of their shape: **involute gear teeth* which are designed in such a way that they mesh together without slipping with respect to each other. *(*profile used practically universally for transmitting power).*

Regular running is also required, which means that one tooth must engage well before the previous tooth has finished meshing.

Everything is fine for conventional gears up to reduction ratios that must not exceed 4 or 5 for normal-sized teeth (the work 'modulus' is used for the size of teeth).

Figure 208: Planet reduction gear (1)

If the reduction ratio increases, running will be degraded (there will be more than one tooth meshed at a time), and it will no longer be possible to have the ideal shape of involute gear tooth.

The solution to this problem is to reduce the tooth modulus or increase the diameter of the pinions.

If the modulus is reduced, the teeth are smaller and can no long transmit a sufficient amount of power and, anyway, they become too fragile.

If we increase the size of the pinions, the dimensions will be very large, hence the limitations on single-stage reduction gears which hardly go beyond a ratio of 4 (exception: there are reduction gears with ratios as high as 11, but the levels of power to be transmitted are low, which means that very small teeth can be used).

Beyond a reduction ratio of 5, the teeth are very fine, thus creating a problem of fragility.

The biggest possible modulus will be used for a lower reduction ratio.

Figure 209: Planet reduction gear (2)

Once the limits have been reached, planet reduction gears (with epicyclic train) will have to be used which have many advantages.

7.2. DIFFERENT TYPES OF REDUCTION GEARS

7.2.1. Planet reduction gears

The epicyclic train is a mechanical transmission device. Its particularity is that it has two degrees of mobility, that is to say that, by means of two mathematical relations, it associates three shafts running at different speeds.

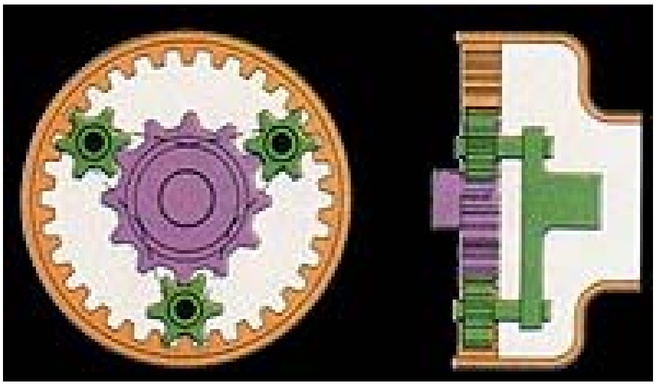


Figure 210: Diagram of an epicyclic train

Figure 211: Epicyclic train

This device is often used to reduce speed because of the high reduction ratios authorised by the configuration (compared with a single gear).

This type of reduction gear is used, in particular, in automatic gearboxes, electric motor reduction, gears, winches on sailing boats (>>> winch fixed to the deck to multiply the traction exerted on the rigging)

Figure 212: Sailing boat winch

In a gear configuration we generally find the following elements:

- Two coaxial shafts, called planets
- Planet pinions meshing with the two planets and rotating around their shared axis
- The planet pinion cage
- The frame

Figure 213: Automatic gearbox

Figure 214: Electric motor reduction gear

There are several possible planet (or epicyclic train) reduction gear configurations:

- Parallel trains
- Spherical trains

7.2.1.1. Parallel trains

In the case of parallel trains, the two planets meshing with the planet pinions may be situated around them (outer planets) or at the centre (inner planets).

There are therefore four configurations:

- Planet pinion with single set of teeth
- Planet pinion with double set of teeth and one planet
- Planet pinion with double set of teeth and two outer planets
- Planet pinion with double set of teeth and two inner planets

Operating principle:

Starting from the simplest train, we eliminate one degree of mobility by fixing the outer planet, which is also called the ring.

The input shaft, by rotating, forces the planet pinion to roll inside the ring. Through its movement, it drives the planet pinion cage as if it was a crank handle.

The planet pinion cage constitutes the device's output shaft. In this configuration, the output rotates in the same direction as the input but at a lower speed.

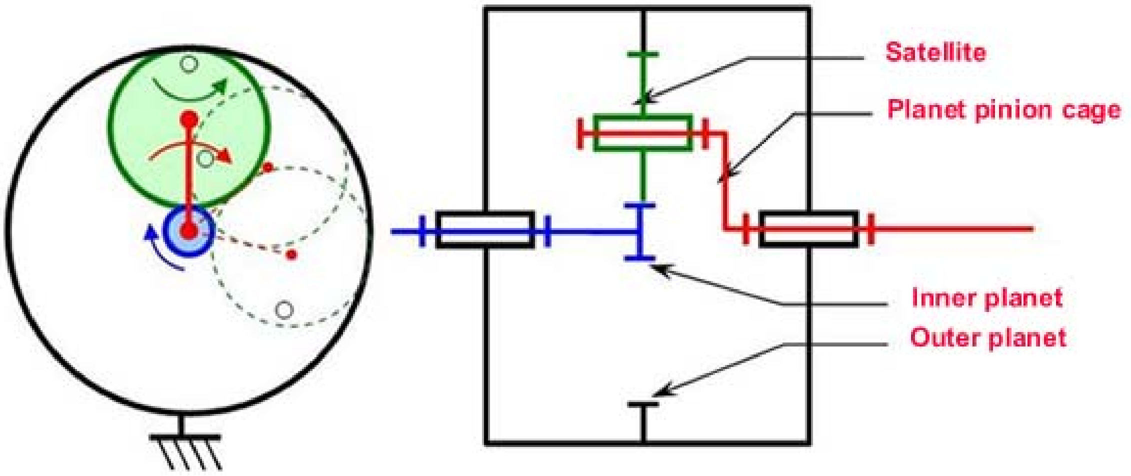


Figure 215: Parallel train operating principle

In all cases, the planets and the planet pinion cage have a common rotation axis.

Planet pinion with single set of teeth: one inner and one outer planet

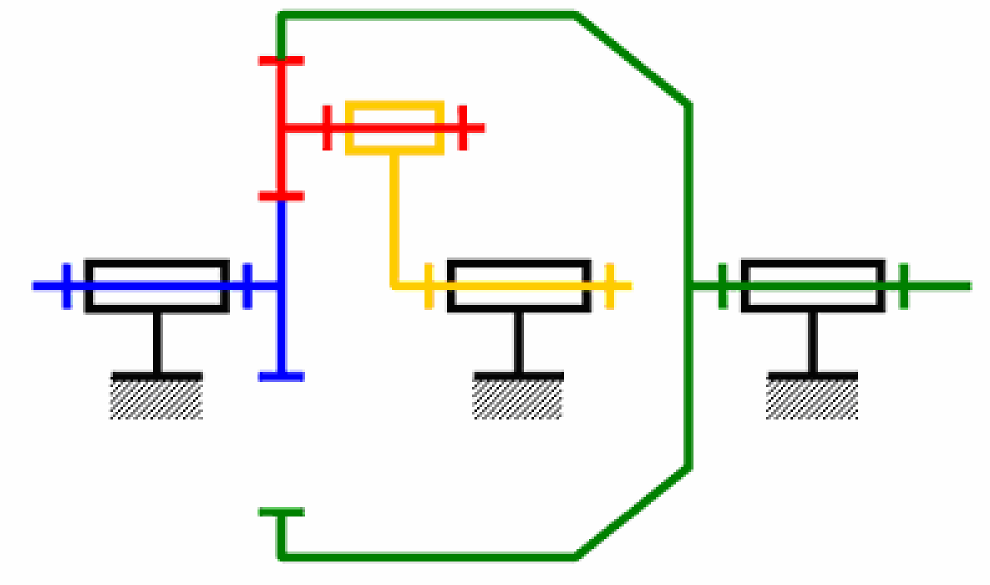


Figure 216: Single set of teeth.

Planet pinion with double set of teeth and one planet: one inner and one outer planet

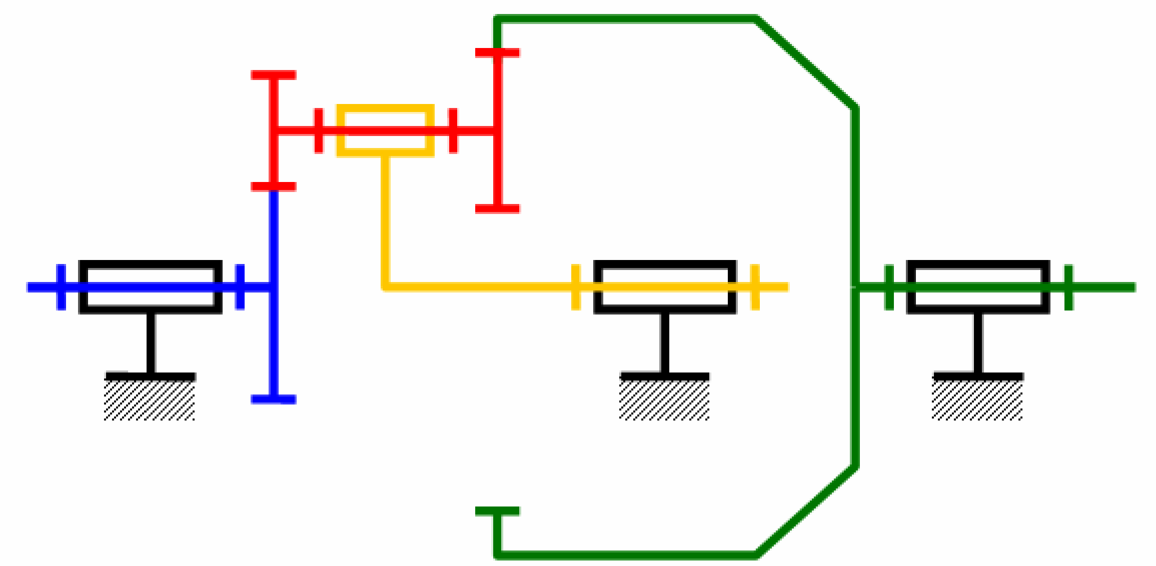


Figure 217: Double set of teeth

Planet pinion with double set of teeth and two outer planets: 2 outer planets

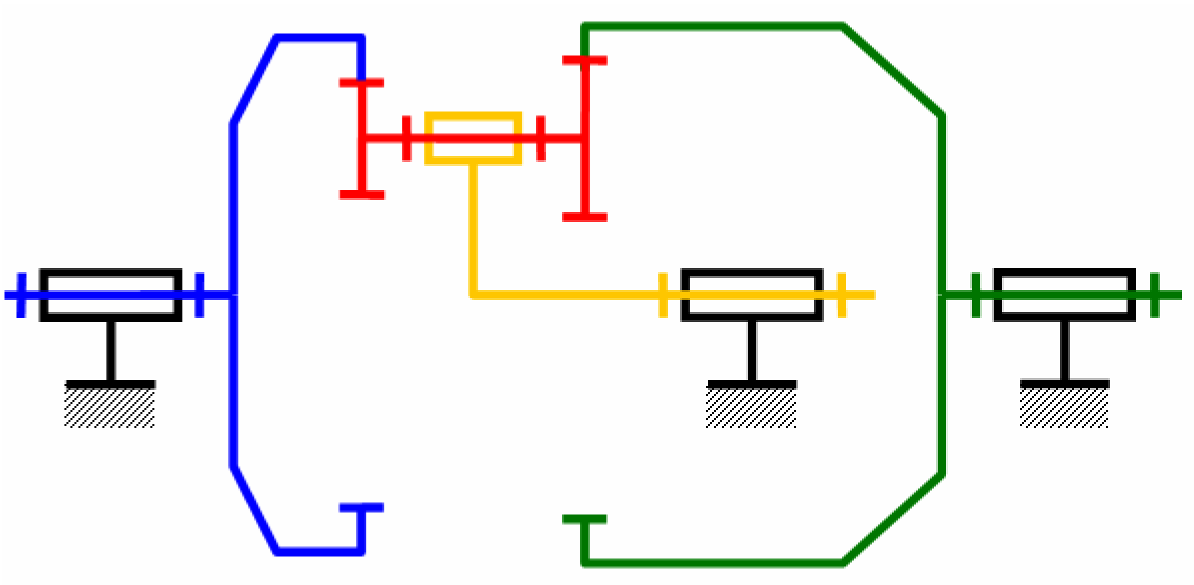


Figure 218: Two outer planets

Planet pinion with double set of teeth and two inner planets: 2 inner planets

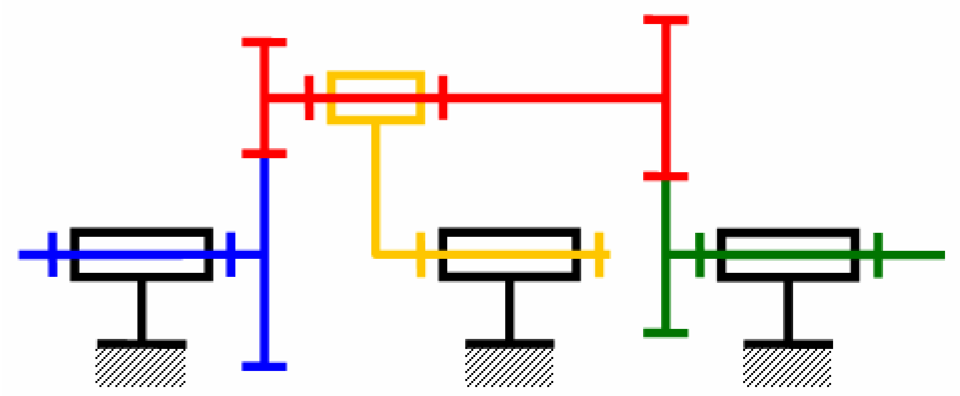


Figure 219: Two inner planets

7.2.1.2. Spherical trains

This configuration is above all used for differential gears (automobile).

The rotation axis of the planet pinions (often in pairs) is perpendicular to that of the planets. The gears are therefore bevelled.

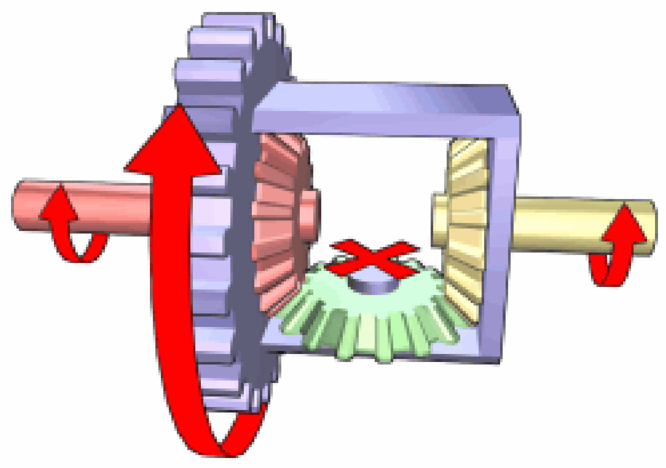


Figure 220: Differential gear principle

In the figure, the planet pinion cage (blue) is the device's input, and the two planets (red and yellow) are the outputs whose rotation speed may be different.

If the planet pinion does not move with respect to the planet pinion cage, the two planets will have the same rotation speed. When the planets become offset in speed, the planet pinion rotates, transmitting the power.

A differential gear is a mechanical system whose purpose is to distribute a rotation speed by sharing out the kinetic force, in an adaptive, immediate and automatic way, to meet the needs of a mechanical assembly.

The system functions in an adaptive way, that is to say when you brake one of the two shafts slightly (clamping, friction) that shaft's rotation speed is reduced and the other shaft's speed increases by as much.

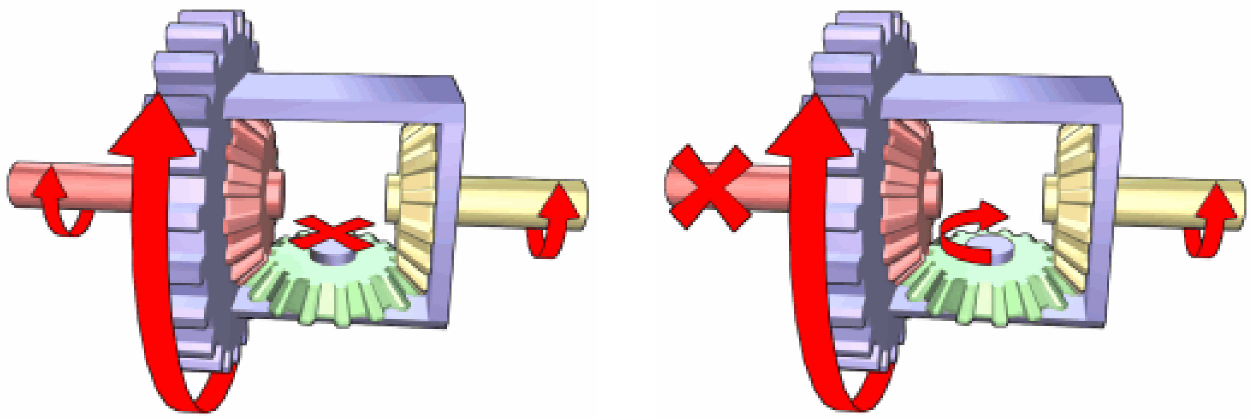


Figure 221: Spherical train operation

In the diagram on the left, the two output shafts (red and yellow) rotate at the same speed. The rotation force is therefore distributed evenly and the intermediate pinion (planet pinion) does not rotate.

In the diagram on the right, the red shaft is braked. The intermediate pinion is then driven and transfers an additional rotation to the yellow shaft which then rotates at a higher speed.

Differential gears consist of a bevelled pinion integral with the drive shaft, perpendicularly driving a bevelled toothed ring supporting a planet pinion cage, which in turn drives two planet pinions integral with the driven shafts.

In a bend, as the inside wheel (on the side that you are turning into to), has a shorter distance to cover, it rotates more slowly than the outside wheel. Thanks to the differential gear, the drive is maintained while enabling the speed difference between the wheels. It this ensures better roadholding (without a differential gear the vehicle would tend to go straight on) and makes it possible to limit the wear on the tyres.

Figure 222: Internal view of a differential gear (1)

For your information, the differential gear mechanism was invented in 1827 by the French mechanical engineer, Onésiphore PECQUEUR (1792-1852).

This mechanism was used as early as 1860 in the first steam-powered road vehicles.

The differential gear is most widely used in the drive mechanism of vehicles.

Figure 223: Internal views of differential gears

Naturally, in all likelihood you will never see a differential gear on an oil production site, but it is nevertheless a good thing to know that they belong to the speed reduction gear family.

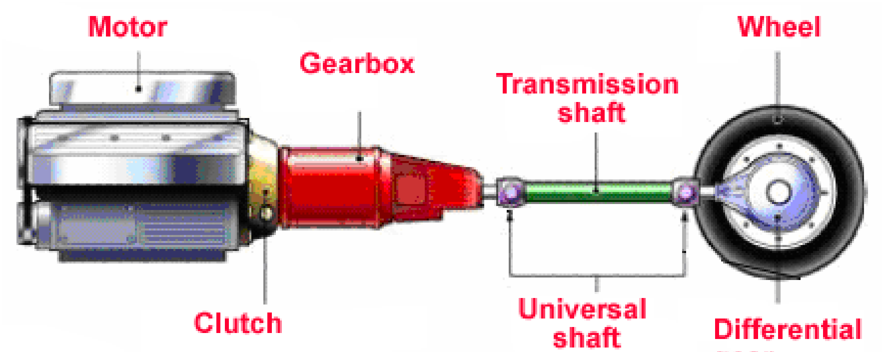
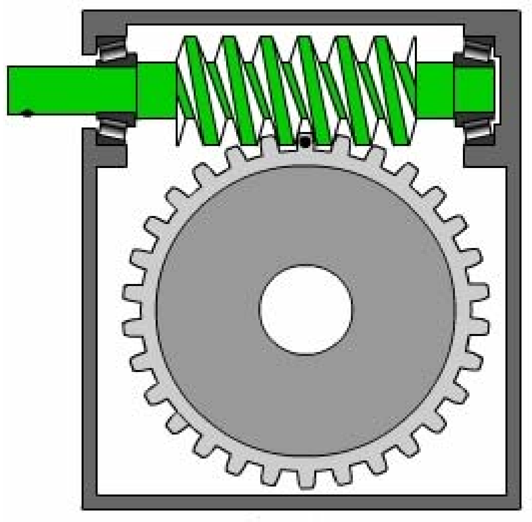


Figure 224: Position of the differential gear

7.2.2. Worm reduction gears



This type of reduction gear is driven by a wormscrew (also called wheel and screw gear).

A wormscrew consists of a long narrow cylinder, with a continuous helical tooth, similar to the thread of a cylindrical screw, meshing with a helical-tooth wheel.

Figure 225: Detail of a worm gear

Worm gears differ from helical-tooth wheel gears in that the teeth of the wormscrew mesh continuously by sliding along the teeth of the driven wheel, but do not directly apply a rotation force.

Wormscrews are mainly used to transmit a rotation, with a great reduction in the speed, between two orthogonal shafts.

Figure 226: A wormscrew reduction gear

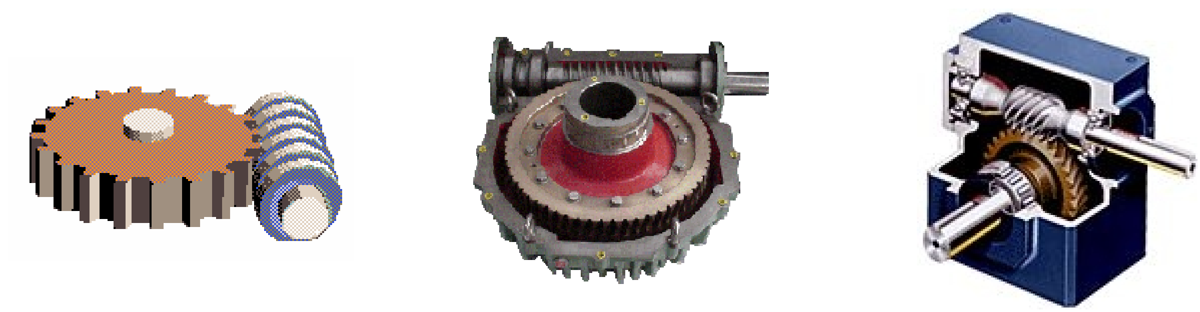


Figure 227: Examples of worm gears

7.2.3. Bevel gears

These are robust angle drive gears, suitable for all mechanical applications requiring a small-dimension setup.

Bevel reduction gears are used in cases where a transmission of power at 90° is required.

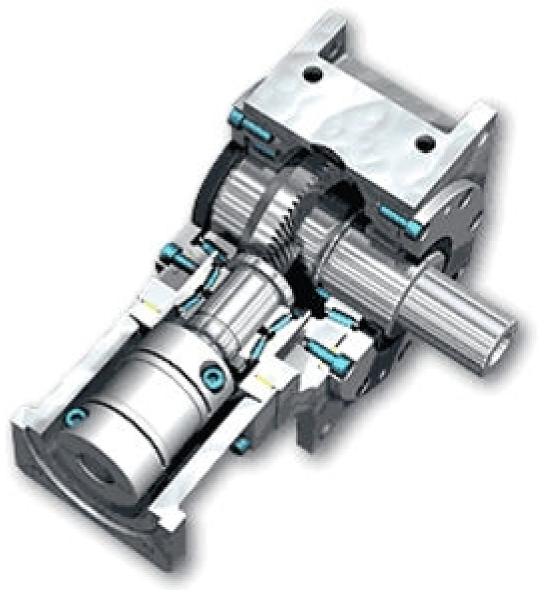


Figure 228: Exploded view of a bevel reduction gear

They are very high-performance gears, particularly for applications requiring precision, efficiency, high speeds (up to 6,500 rpm depending on the size) and heavy loads.

The wheels of these gears are not cylindrical but tapered. There are bevel wheels with straight teeth, and bevel wheels with oblique and spiral teeth.

Figure 229: Exploded view of a bevel reduction gear

All these gears are used to transmit the rotation between shafts with intersecting axes.

Figure 230: Straight teeth

Gears with spiral teeth (forming an arc of a circle), are the most commonly used because they make less noise.

Figure 231: Spiral teeth

7.2.4. Parallel shaft reduction gears

These reduction gears have small dimensions thanks to the favourable layout of the reduction gear casing.

A large choice of setup and operating positions makes it possible to install them in a wide variety of configurations, including in the most unfavourable conditions.

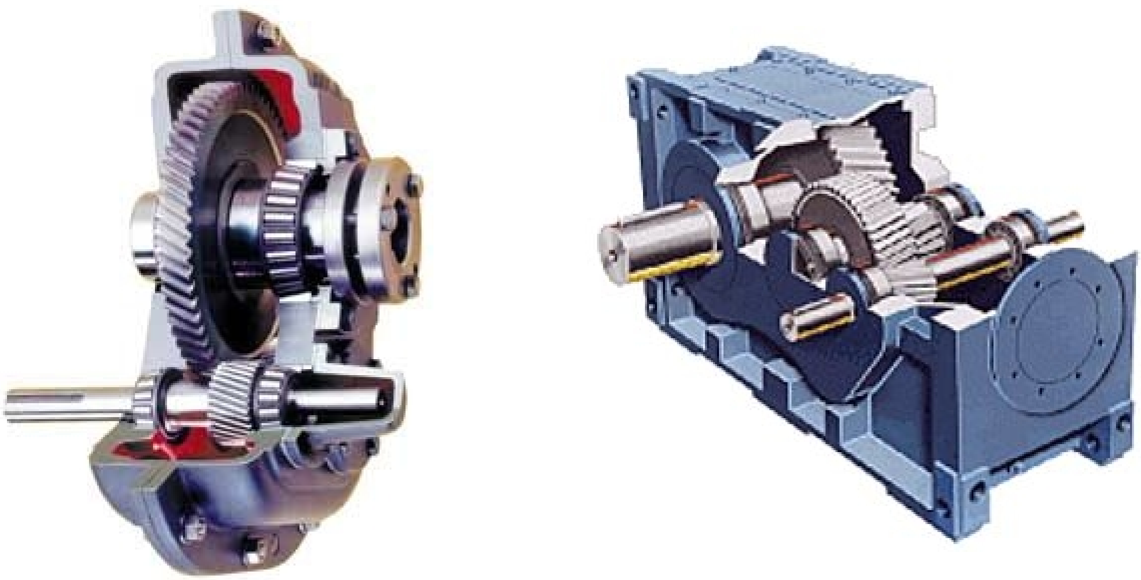


Figure 232: Parallel shaft reduction gears

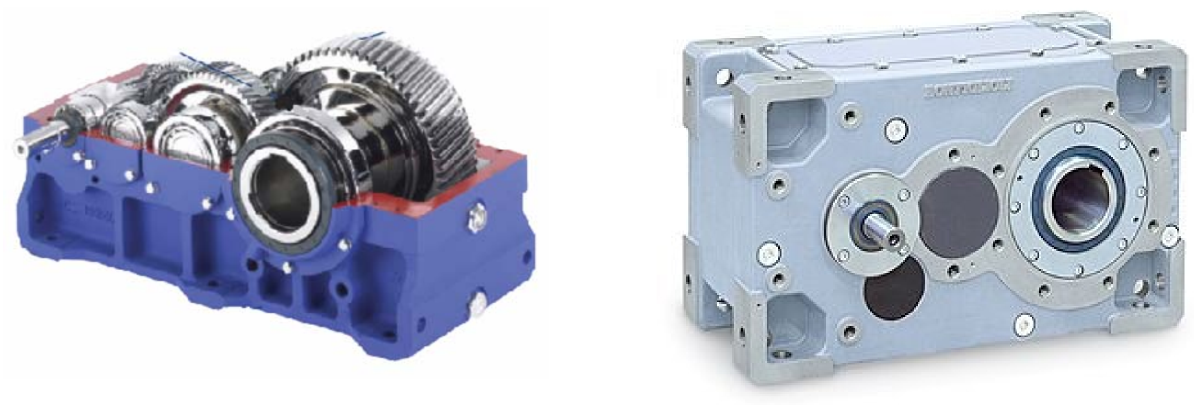


Figure 233: Parallel hollow shaft reduction gears

7.2.5. Industrial reduction gears

This type of reduction gear is generally used for large installations.

The size of the reduction gears is proportional to the size of the installation.

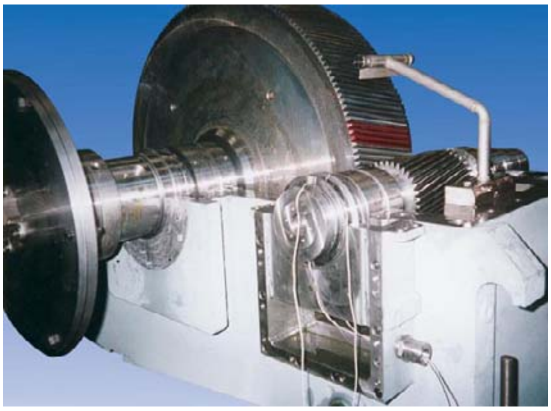


Figure 234: Open reduction gear

Figure 235: Cement works mill slewing gear

7.3. GEARS

These are widely used movement and power transmission systems (high levels of transmissible power, transmission precision, reliability).

In practice, small obstacles, called teeth or cogs, are placed on the two circumferences. This is a gear.

The wheel is then called a cogwheel, and if it is small with respect to the other cogwheels in the system, we will use the term pinion.

Gears belong to the category of obstacle-driven power transmissions.

7.3.1. Straight-toothed straight gear

These are the easiest ones to make (and therefore the most economical). They are used to transmit power between two parallel axes.

The teeth's shape generatrix is a straight line parallel to the rotation axis.

Figure 236: Straight tooth (1)

The shape of the wheels varies with the dimensions. The smallest of the wheels (fig.33) is often the one that drives the assembly (also called the drive wheel).

This is the most commonly used type of tooth.

Figure 237: Straight tooth (2)

It must be noted, however, that these gears are noisy in operation. This is due to the fact that the teeth hit each other as they come into contact.

7.3.2. Helical-tooth straight gear

This transmits the movement between two parallel shafts. The angle of the teeth (helical angle) is the same for both wheels, but in opposing directions. The teeth's shape generatrix is a helical line whose axis is the same as the rotation axis.

Thanks to the progressivity of the contact (unlike gears with straight teeth), they are silent, higher performing in terms of the level of transmissible power (and reliability). The transmission is also more flexible, more progressive and generates fewer vibrations.

There is a slight drawback, all the same: given the shape of the contact, axial forces are generated on the shafts supporting the cogwheels. However, this type of tooth generates an axial force whose intensity depends on the angle of the teeth. The size of the bearings or bearing blocks must be calculated to take up this force.



Figure 238: Helical teeth

The axial thrust can be neutralised by using on each of the two shafts two reverse helical tooth wheels or a single wheel with two sets of symmetrical teeth (called double helical or herringbone teeth).

The axial forces acting on the gear are balanced out, which means that it is not necessary to oversize the pivot bearings supporting these cogwheels.

This tooth shape was invented by André CITROËN (1878/1935), French "Polytechnicien" (engineering graduate), and founder of the Citroën automobile industrial empire in 1919.

Figure 239: Herringbone teeth

7.3.3. Crossed axis helical gear

This type of gear makes it possible achieve an angle transmission.

Meshing is gradual thanks to the angle of the teeth. A large number of teeth are engaged which ensures a good degree of meshing continuity.

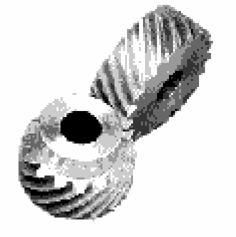
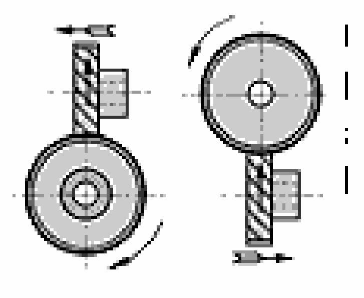


Figure 240: Crossed axis helical gear

The angle transmission thus obtained is gentler and quieter than that obtained with straight bevel gears.

A crossed axis helical wheel with teeth tilted to the right meshes with crossed axis helical wheel with teeth tilted to the right.



The low efficiency due to the axial thrust causes the transmission to heat up, but this can easily be reduced by means of good lubrication.

Figure 241: Operating principle

7.3.4. Bevel gear

Transmission of power between two intersecting axes. Here we have the same problem as with straight-tooth gears at high speeds, that is to say: operating noise, high pressure on the teeth.

Figure 242: Bevel gear (1)

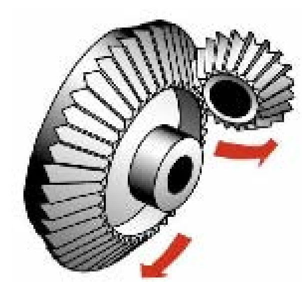


Figure 243: Bevel gear (2)

By adopting a spiral-bevel teeth configuration, it is possible to reduce the noise at high speed and ensure a more gradual transmission.

Figure 244: Spiral-bevel gear

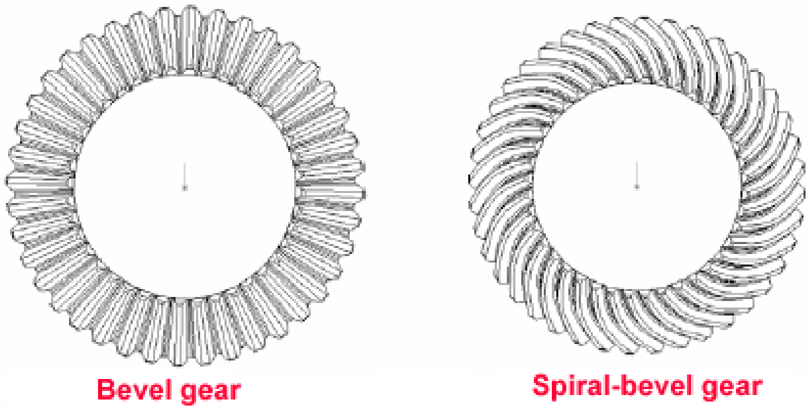


Figure 245: Top view of bevel gears

7.3.5. Worm gear

A worm screw is a cylinder with a helical spline (sometimes several), which makes it look like a threaded rod. Associated with a pinion, it constitutes a skew axis gear (the two axes are in different planes), in which it behaves like wheel with one tooth (or several teeth according to the number of splines).

This system is called a wheel and wormscrew.

Figure 246: Wheel and wormscrew (1)

The screw is usually integral with the shaft supporting it, with the spline sometimes being directly in the shaft.

The gear formed is generally irreversible: the screw can drive the pinion, but the reverse is not true.

Contrary to the majority of other gear systems where the drive is obtained by rolling one tooth profile on the other, here the drive is obtained by slipping.

The advantages of this gear are the very high reduction ratios obtained with small dimensions on the one hand, and the possibility of inserting irreversibility in a mechanism, which is often sought to ensure operating safety in an installation.

Figure 247: Wheel and wormscrew (2)

7.4. MAINTENANCE, SERVICING OF REDUCTION GEARS

Like for all mechanical parts in movement, speed reduction gears require a minimum amount of maintenance.

This maintenance passes through a periodic and regular verification of the general condition of the gears, tooth wear, correct operation of the lubrication (in the case of forced lubrication).

There are certain potential hazards when carrying out reduction gear maintenance. They can be avoided provided the safety instructions are correctly applied.

After prolonged operation, gears generate high temperatures and can create an oil mist or vapour that may create a risk of fire and explosion in the presence of a flame in the vicinity. Wait for the installation to cool down before any intervention.

Gear transmissions develop high operating speeds and may generate noise levels that are dangerous for the hearing.

Figure 248: Chipping

Two surfaces in contact that are used to transmit forces and/or are subject to relative movements may be damaged in several ways.

Figure 249: Fatigue

Certain contacts can cause permanent deformations of the surface or contact fatigue leading to chipping (tearing off of material).

Pressure and relative movement cause wear. The environment and electrochemical effects lead to damage by corrosion or by microcracking.

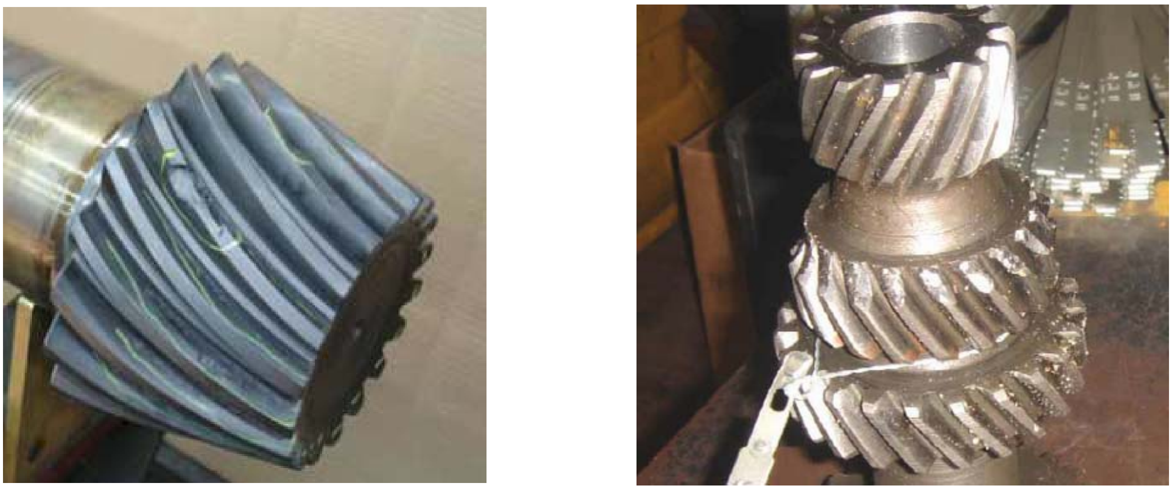


Figure 250: Damage to cogwheels

Surface damage may often be combined with another mechanism and result in a sudden clean break.

Reduction gears are usually lubricated by oil-splashing but it can also be performed by a pump coupled to or independent from the installation (but always using the installation' oil).

Figure 251: Japy pump

In the case of a coupled pump, it is preferable to ensure pre-greasing of the installation before it is put into operation, by means of a "Japy" type hand pump (or even a small electric pump).

The oil level is checked by means of a gauge, overflow plug or oil sight. This level must not in any case exceed the indicated maximum level.

An excess, just like a lack, of oil is detrimental to the good operation of the reduction gear either due to emulsion, over-pressure, heating or a lack of greasing.

Always check the oil level before starting up an installation and also some minutes after startup once the oil flow is well-established.

Scrupulously apply the maintenance instructions relative to the various items of equipment (oil change periodicity, quantity, etc.).

Certain small reduction gears are lubricated for life, which means they are ready to function once they have been put in place and without the need for any change of oil during their lifetime.

8. VARIABLE SPEED DRIVE UNITS

In mechanical applications, a variable speed drive is a device with pulleys and belts that is used, instead of a gearbox, to change the gearing of motors.

A piece of equipment is often designed with the possibility of having a variable speed making it possible to maximise its production and increase its cost efficiency. A variable speed drive makes it possible to synchronise pieces of equipment in series or to change the speed for a variable process.

Most variable speed drives, whether mechanical or electrical, do not increase the torque when they lower the speed. They function according to the constant torque principle.

This notion is important, because a variable technology is not designed to take the place of a speed reduction achieved by means of a belt, chain or gearbox. When we use a fixed speed reduction we multiply the torque or the force, but a variable speed drive will not do this. When the speed is reduced using a variable speed drive the torque remains unchanged.

There are essentially two categories of variable speed drive:

- Mechanical variable speed drives
- Electric or electronic variable speed drives

Despite the very rapid growth of electronic solutions (efficiency, safety, price, etc.), mechanical solutions are still used (no need for an electrical power supply).

8.1. MECHANICAL VARIABLE SPEED DRIVES

8.1.1. Variable speed drives for industrial machines

8.1.1.1. Roller mechanical variable speed drive

By means of a movement between two disks, one or more rollers ensure the transformation of a variable speed.

Whatever the rotation direction, this drive is rigorously positive thanks to an automatic pressure device slaved to the resistive torque.

Figure 252: Roller variable speed drive

This type of variable speed drive is usually lubricated for life. It can be used in all types of atmosphere thanks to its sealed casing.

8.1.1.2. Cam and rod mechanical variable speed drive

This is a solid and sealed casing with four freewheels, cams and rods inside, that transform the input shaft's movements firstly into a linear movement, then into the rotation of the output shaft.

The output speed is adjusted very easily and precisely by means of a control lever and its handle which has a locking system to maintain the settings.

Figure 253: Cam and rod mechanical variable speed drives

This type of variable speed drive is designed to function in one rotation direction or the other at its output. Variable speed drive equipped with a reverse lever and a neutral position. Furthermore, the output and input shafts can be placed on the same side and the speed can be adjusted either when at a halt or in operation.

Lubrication is provided for the variable speed drive's total lifetime.

8.1.1.3. Expandable pulley and belt variable speed drive

An axial movement d reduces r1, the spring moves the other pulley, increasing r2.

As the belt has a constant length, we obtain a continuous variation ratio.

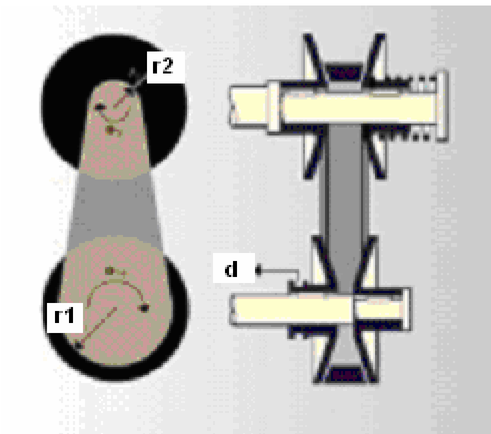


Figure 254: Pulley and belt variable speed drive

8.1.1.4. Variable pulleys variable speed drive

The variable pulley was one of the two predominant technologies before the arrival of electronic variable speed drives for DC motors.

These pulleys, which use their adjustable diameter to crate the speed variation are still very commonly used in ventilation systems and older pieces of equipment.

Figure 255: Variable pulley

The variable pulley remains a simple and robust technology and may be preferred in an application generating difficult loads.

Figure 256: Belt variable speed drive

8.1.1.5. Epicyclic variable speed drive

The epicyclic variable speed drive consists of a pressure-moulded aluminium casing.

The planets are made of special tempered steel, which maximises the length of their life.

They function with an oil bath for silent, high-efficiency and vibration-free operation.

Figure 257: Epicyclic variable speed drive

This type of variable speed drive is equipped with a filler plug, level indicator and a vent making it possible to adapt it to any installation position.

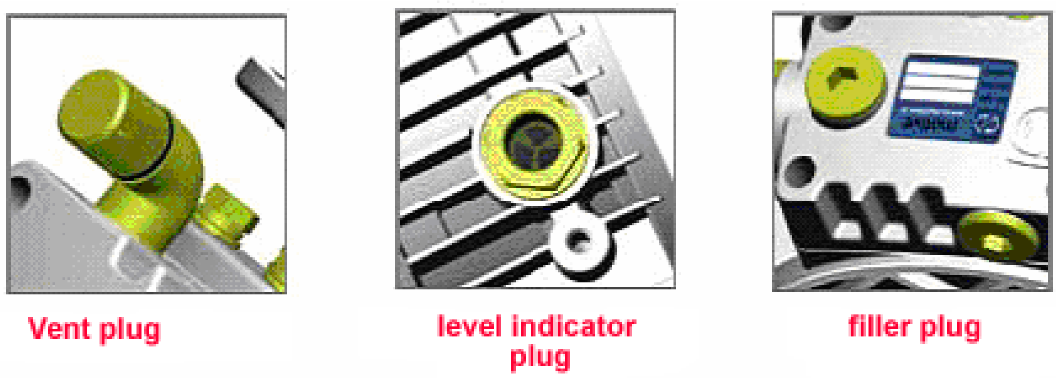


Figure 258: Detail of the oil indicator

Furthermore, it can rotate in both directions with the output and the input rotating in the same direction. The drive shaft has a double output and is therefore accessible from both sides.

Operation:

The inner ring **(10)** mounted on the shaft, and the fixed ring **(11)**, compressed by the cup washers **(12)**, transmit the rotation to the planets **(7)**.

The latter move on the two outer rings **(6 and 9)** until the planet pinion cage **(2),** integral with the output shaft to which they are connected through the sliding bushings **(3)**, starts to rotate.

When the control wheel is turned, the ring **(6)** also turns and moves axially.

This movement is due to the action of the balls **(5)** on the rings of the two opposing cams **(4 and 6)** and it acts on the bevelled flanks of the planets which move star-wise inside the rings **(10 and 11)**, by overcoming the resistance of the springs **(12)**.

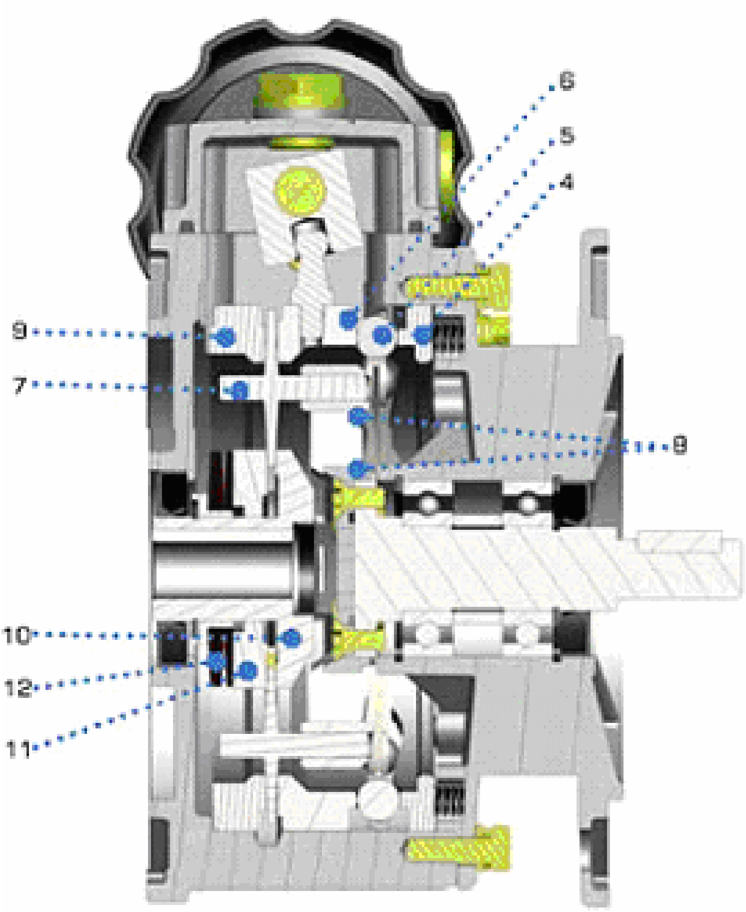


Figure 259: Epicyclic variable speed drive operation

In this way, the variation in the contact position on the flanks of the planets determines the variation in the speed of the planet pinion cage and, as a consequence, of the output shaft.

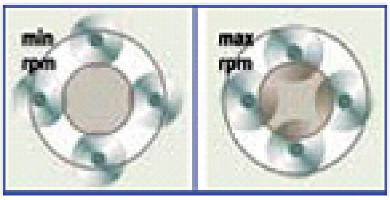


Figure 260 : Position of the planets

This type of variable speed drive can be mounted in every possible position. For this reason, care must be taken when installing the vent.

Figure 261: Mounting positions

Correct lubrication is a fundamental characteristic for an efficient and lasting service life.

You are advised never to mix two oils of different qualities. In the case of a change of oil, rinse out the variable speed drive with the new oil before filling with that same oil.

8.1.2. Variable speed drives for combustion engines

8.1.2.1. Injection advance flyweight variable speed drive

The centrifugal advance consists of a flyweight carrier plate whose deflection, under the effect of centrifugal force, is limited by an advance control valve linked directly to the hub.

Under the effect of centrifugal force, the two flyweights gradually separate.

The movement of the flyweight roller is transmitted to the advance control valve whose angular position with respect to the flyweight carrier plate varies and causes the desired injection advance.

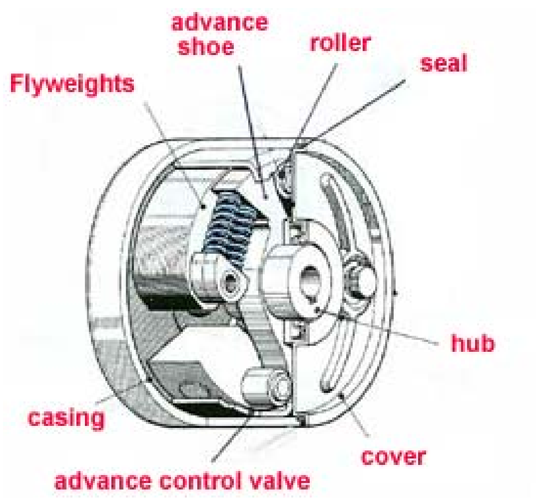


Figure 262: Flyweight variable speed drive

8.1.2.2. Injection advance cam variable speed drive

This variable speed drive, whose mechanical design is not very different from the flyweight type, functions according to the same principle.

The pairs of cams are fitted into the advance shoe and guided by the casing's bosses.

The flyweights include pivots that are housed in the advance cams' boreholes and receive springs in pairs.

Centrifugal force moves the flyweights apart outwards and causes the cams to rotate. The position of the hub is thus modified with respect to the casing.

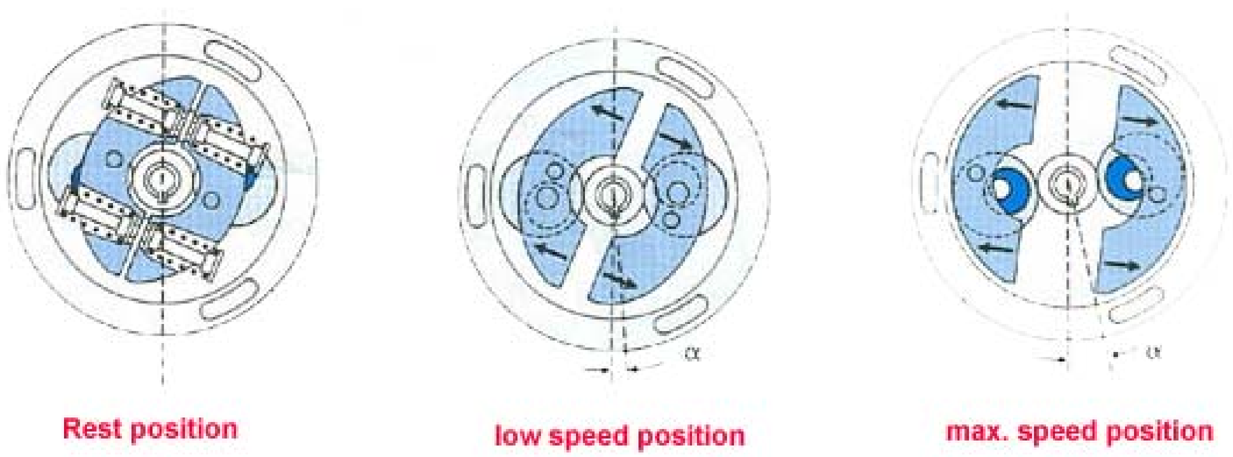


Figure 263: Cam variable speed drive

8.2. ELECTRIC AND ELECTRONIC VARIABLE SPEED DRIVE

8.2.1. Electric variable speed drive

This type of variable speed drive is an electro-technical item of equipment that supplies an electric motor in such a way as to make its speed vary progressively from a halt up to its nominal speed.

Figure 264: Electric variable speed drive

8.2.2. Electronic variable speed drive

In electronics, a variable speed drive is called a potentiometer.

A potentiometer is a type of variable resistor with three terminals, one of which is connected to a cursor that is moved along a resistive strip ending with the other two terminals.

Figure 265: Electronic variable speed drive (1)

This system makes it possible to collect a voltage, on the terminal connected to the cursor, that depends on the position of the said cursor and on the voltage to which the resistor is submitted.

Nowadays, digital potentiometers are very widely used in numerical control analogue electronics.

Figure 266: Electronic variable speed drive (2)

9. GEARBOXES

The gearbox is the second link in the torque transmission chain from an engine to the wheels of a vehicle. The gearbox proposes several ratios between the engine shaft's rotation speed and the drive wheels' rotation speed.

The gearbox is a mechanism designed to modify, under given conditions, the ratio between the engine's rotation speed and that of a vehicle's drive wheels.

In this definition, the gearbox is used for engine-driven vehicles. In the oil industry, the gearboxes that we use are reduction gears and variable speed drives the description and operation of which has been explained in chapters 3 and 4 of this course.

We are nevertheless going to explain briefly the principle of a gearbox for cars as this may be a 'plus' for the maintenance technician.

9.1. GEARBOX OPERATION

Situated downstream of the clutch, the gearbox is divided into a certain number of forward ratios (5 or 6 for a modern car and between 10 and 16 for a 40 tonne truck), so-called reduction or overdrive ratios, and one reverse gear.

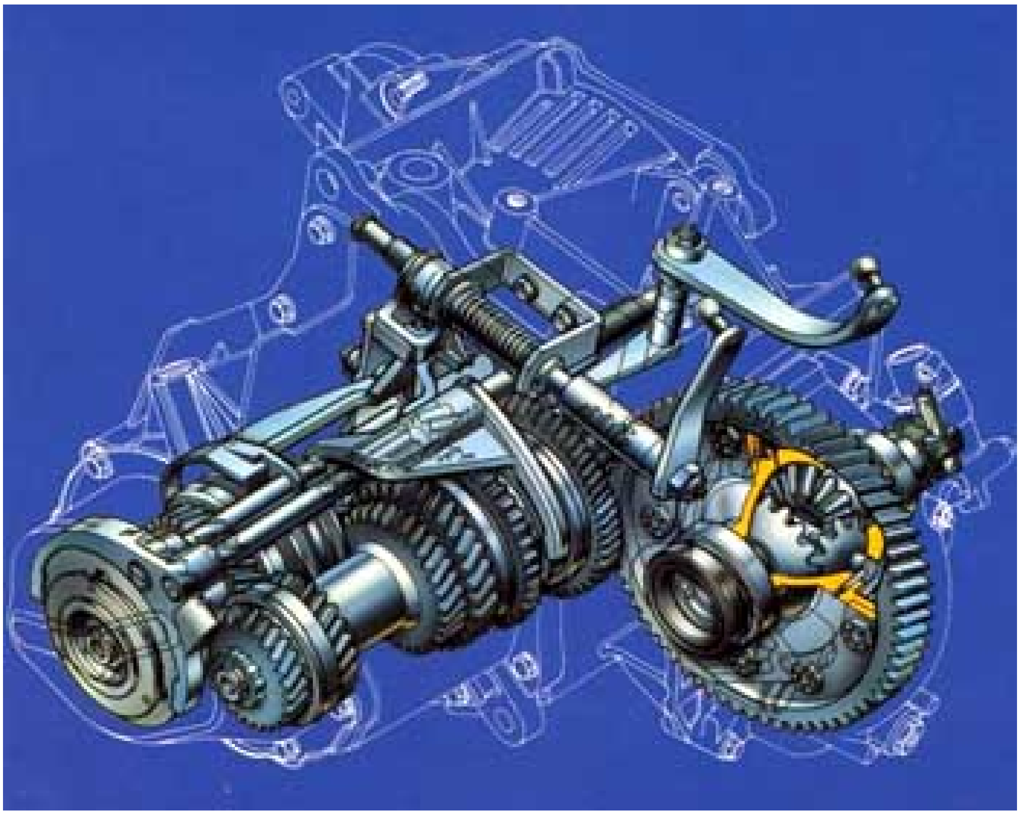


Figure 267: Manual gearbox

These ratios are generated by gears that constitute rotary lever systems. A ten-tooth pinion driving a forty-tooth wheel gives a reduction ratio of 4, that is to say the cogwheel will rotate 4 times slower than the pinion.

As the power is the product of the torque multiplied by the rotation speed, this means that the forty-tooth wheel's torque will be four times greater than the torque applied to the ten-tooth pinion, if we ignore the losses due to friction.

The drive wheels convert this torque into a traction force. This force is proportional to the torque exerted on those wheels. So, all other conditions being equal, the traction force is proportional to the gearbox's ratio. It can be deduced that the speed is inversely proportional to the reduction ratio.

A great deal of traction is needed to start a truck on an upward slope, so a high reduction ratio (short ratio) will be required. But, on the contrary, so that the engine does not race at maximum revs when the vehicle is at its cruise speed the traction force required is reduced, and a low ratio (long ratio) will be required, possibly even an overdrive ratio.

Between these two extremes, all sorts of conditions may be encountered each requiring a different ratio. In practice, we content ourselves with a trade-off because we cannot infinitely multiply the number of ratios in a gear transmission, if only because there must necessarily be a whole number of teeth.

Car gearboxes are constantly engaged gears, but where one of the two pinions is idle-mounted (it can rotate independently) on its shaft. In neutral, none of the gears is locked to the two shafts. As for the sliding gears they are driven by their shaft while being able to slide axially along it. The gearstick actuates the rods (1) to which forks (2, 3, 4) are attached in which the sliding gears rotate.

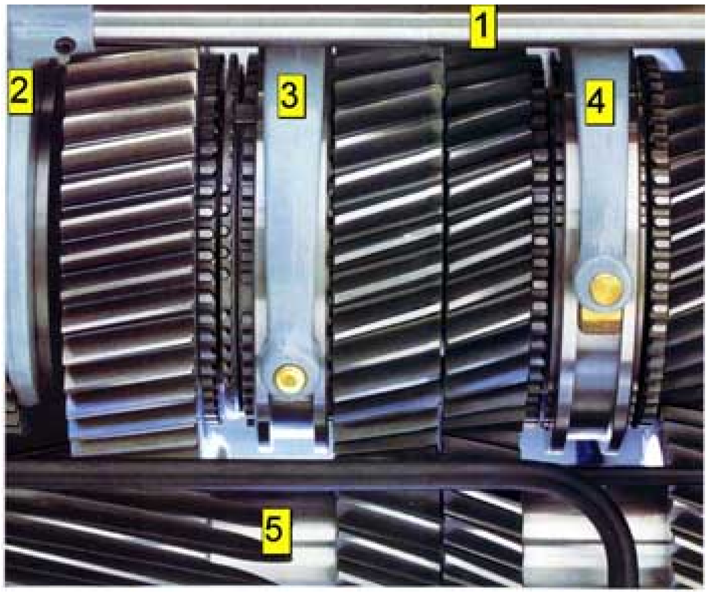


Figure 268: Detail of a gearbox

Each fork is actuated by a different rod, and when you move the gearstick transversely to neutral, you go from one fork rod to the other thus placing yourself in a position to command another sliding gears. In figure 61, the sliding gears 2 and 4 are in neutral whereas gear 3 has been engaged by shifting the gearstick longitudinally. Before engaging a sliding gear, you must necessarily disengage the other one, and therefore return the gearstick to neutral.

9.2. THE DIFFERENT TYPES OF GEARBOX

9.2.1. Mechanical gearbox

The mechanical gearbox remains the "type of gearbox" used in the majority of the cars used in France. It takes part in the transmission of power from the engine to the wheels.

A conventional mechanical gearbox is placed between the clutch upstream and a rear axle assembly or differential gear downstream. Furthermore, the gearbox consists of pinions (gears) mounted on shafts. Lastly, a gear selector allows the driver to choose the ratio he/she wants to engage.

9.2.1.1. The main body of the gearbox

A casing contains two shafts in general. The primary shaft includes pinions (one for each ratio from first to reverse gear) directly machined in the shaft. This shaft is linked to the engine.

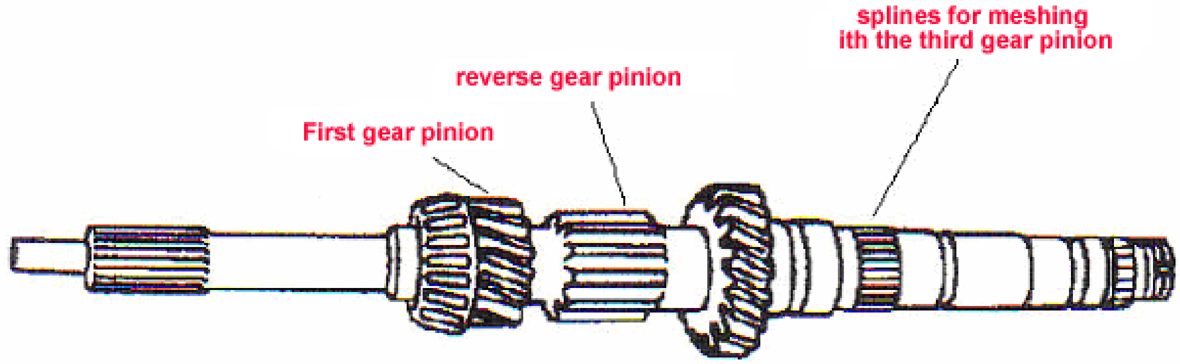


Figure 269: Gearbox primary shaft

As you can see, the pinions are integral with the primary shaft (machined directly in the shaft or added by means of splines maintaining them in rotation and held in translation by a nut). In all cases, the pinions on the primary shaft are built into it. A secondary shaft, linked to the vehicle's wheels is place opposite the primary shaft in the casing.

This secondary shaft contains gears (one per ratio, from first to reverse gear) which will be meshed at all times (except for the reverse gear pinions) with their counterparts on the primary shaft. As for the secondary shaft's pinions they are free on this shaft: they are said to be idler pinions or hinge jointed. For example, the third pinion is built into the primary shaft and is constantly meshed with the third pinion, on the secondary shaft, which is loose on the shaft. This is also the case for the other ratios.

We can conclude that a first gear ratio, for example, is formed by two gears (one on the primary shaft and the other on the secondary shaft) of different sizes. It is precisely this difference of size that constitutes the ratio.

The wheels are therefore linked to the engine by means of a reduction ratio. However, since all the gears are linked in pairs, some of them must imperatively be idler, because you cannot couple the wheels and the engine with all the different reduction ratios at the same time.

When the driver actuates the gearstick, he/she is in fact deciding to couple such and such a gear on the gearbox's secondary shaft and therefore to link the engine to the wheels with that ratio and only that ratio. The other ratios continue to be meshed but each one includes an idler pinion on the secondary shaft.

9.2.1.2. The synchro-mesh gear

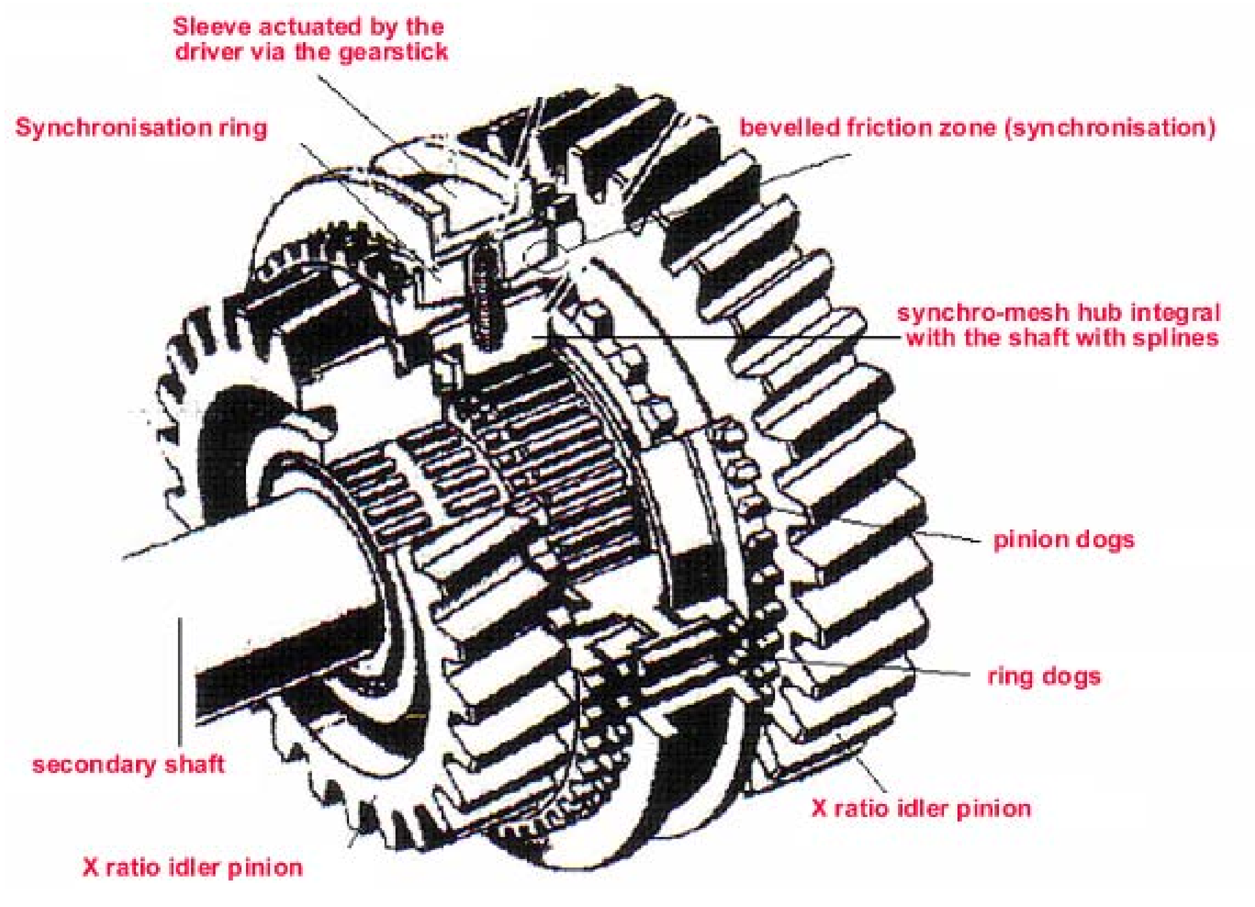


Figure 270: Detail of the synchro-mesh

The synchro-mesh is the device that locks an idler pinion with the secondary shaft.

In fact, to lock the idler pinion to the secondary shaft to make it integral with it, the driver acts on the synchro-mesh. At the end of his/her action, he/she will therefore have engaged one and only one ratio.

Furthermore, it should be noted that the sleeve encloses dogs, which can be seen in the following diagram:

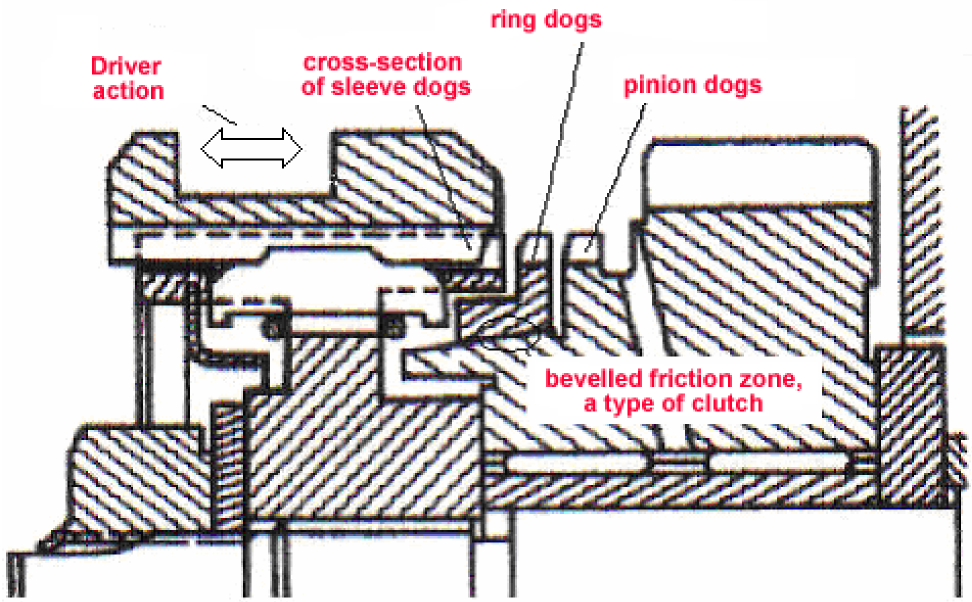


Figure 271: Detail of the dogs

There is therefore a succession of three dogs.

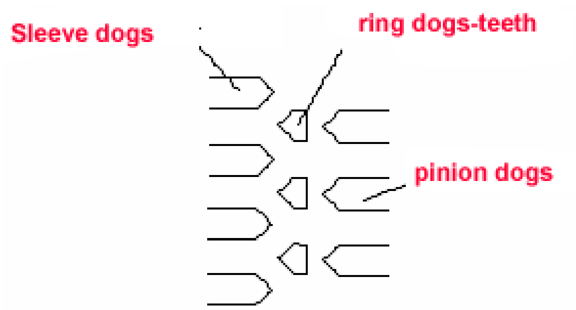


Figure 272: Succession of dogs

So, when the driver chooses a ratio, he/she acts on the synchro-mesh in the following way:

- He/she pushes the sleeve towards the pinion he/she wants to be locked to the shaft.
- The sleeve dogs push the ring dogs.
- Due to its shape, the bezelled ring gradually synchronises the sleeve linked to the shaft, and the pinion that was idler until then. Friction is created between the bezelled part of the ring and the bezelled part of the pinion
- Once the pinion and the synchronisation ring rotate at the same speed, the sleeve's dogs will mesh in the pinion dogs. This is what creates the link and ensures the power transmission between the shaft and the pinion.
- Because the pinion is itself connected to its counterpart on the primary shaft, the power is transmitted from the engine to the wheels.

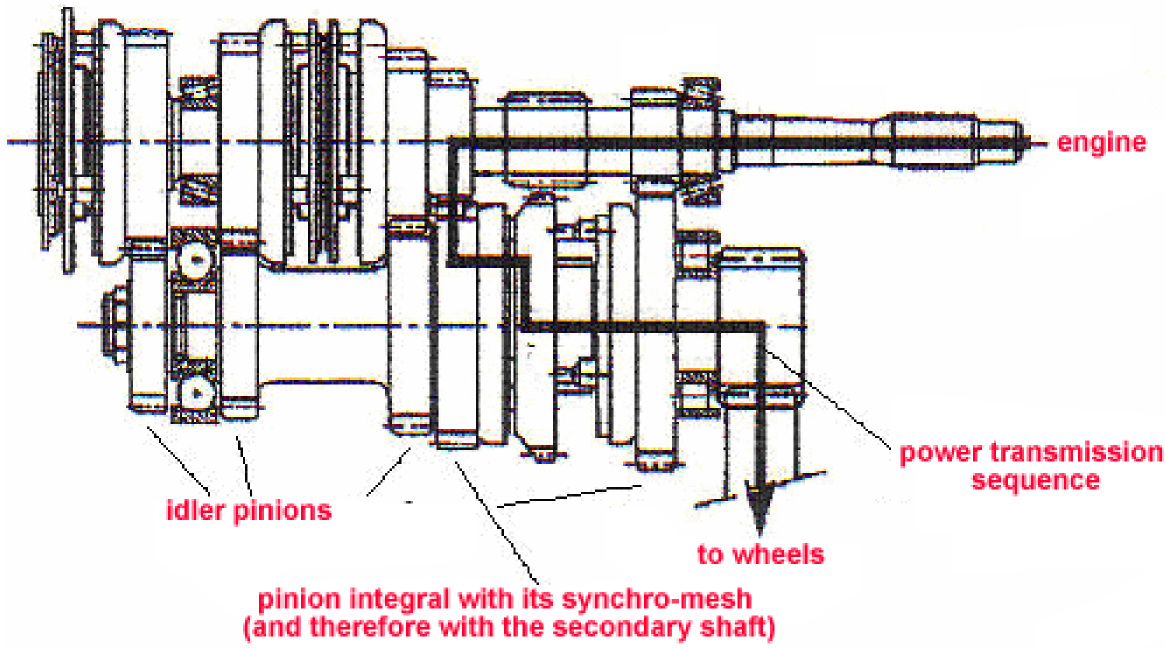


Figure 273: Power transmission

9.2.1.3. Reverse gear

Reverse gear is somewhat different because it does not have a synchro-mesh, except on top of the range vehicles. The primary and secondary shaft pinions are not in contact. It is a third gear on the last intermediate shaft that comes between them and ensures the coupling of the assembly then formed of three pinions.

Because there is an additional pinion, three instead of two, the wheel rotation direction is reversed. Because we have to insert a pinion, we must do it at a halt (as there is no synchro-mesh), and with straight-toothed pinions (the other ratios have helical teeth).

9.2.1.4. Final reduction gear

The speed between the engine and the wheels must be reduced very considerably.
So, when the engine is running at 4,000 rpm, the wheels are only turning at 300 rpm, for example, and the torque is multiplied by 13. It is therefore necessary to have gears that are capable of transmitting this torque.

Furthermore, a small primary pinion and a very large secondary pinion are required which gives a cumbersome size. We therefore prefer to have two successive reductions, one of which is common to all the ratios: this is the final reduction gear. It is also quite practical because, generally, the reduction gear's ring houses the differential gear in its centre (space saving).

9.2.2. Automatic gearbox

These are gearboxes that are capable of changing their ratios on its own. These changes of gear are carried out gradually. This type of gearbox manages vehicle starting and the selection and changing of ratios after the vehicle has been started.

The automatic gearbox consists of a torque converter, epicyclic trains, multi-disk clutches, a selector in the passenger compartment for the driver, a device (oil pump) making it possible to lubricate the box's mechanism.

9.2.2.1. Hydrodynamic torque converter

The converter is the mechanical device that makes it possible to transmit the torque and speed parameters between the engine (input) and the gearbox's primary shaft (output). The converter is made up of three parts. The first part is the pump, the second the turbine and lastly, the third part is the stator.

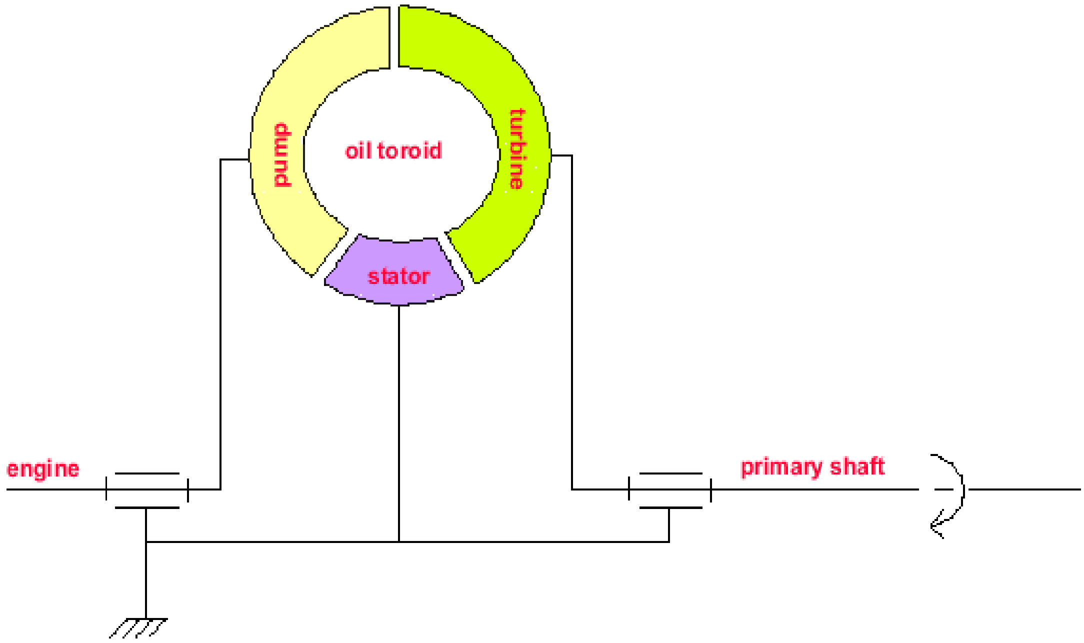


Figure 274: Schematic diagram of an automatic gearbox

The pump is linked to the engine (crankshaft input), the stator to the chassis (via the gearbox casing) and the turbine to the primary shaft (output) of the actual gearbox.

The running engine drives the pump, which is integral with it. The oil transmits this force to the turbine, which then in turn ensures the rotation of the primary shaft, and of the gearbox which is integral with it. The link between the turbine and the pump (therefore between the engine and primary shaft) is ensured by the oil. It is therefore a flexible coupling, but one on which the driver does not act. The stator redirects (more or less) the oil flow to the pump.

9.2.3. Continuously variable transmission (CVT)

A continuously variable transmission consists, more or less, of two variable diameter pulleys (one drive and one receiver) linked to each other by a metallic belt.

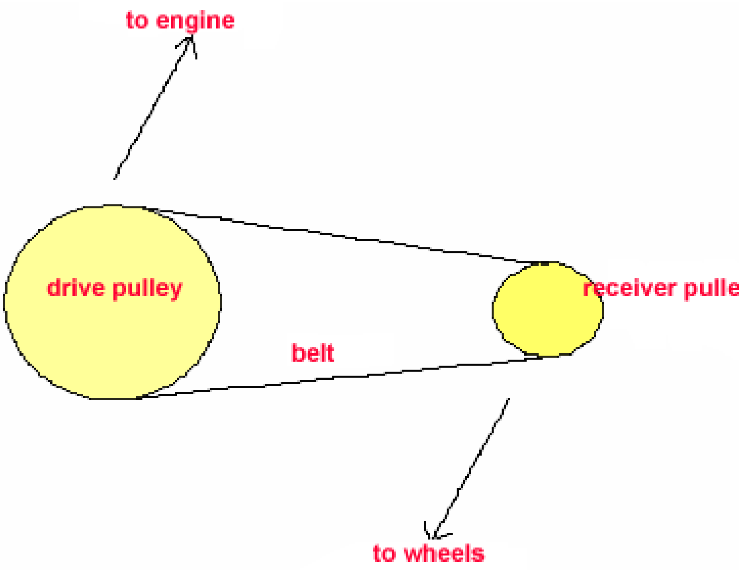


Figure 275: CVT diagram

The drive pulley is linked to the engine and the receiver to the wheels.

If the diameter of the drive pulley is very small compared with the diameter of the receiver pulley, we will have a great multiplication of the engine torque to the wheels: ratio for starting with severe constraints, for example.

If, on the contrary, the diameter of the drive pulley is very large compared with that of the receiver pulley, we will obtain a high wheel rotation speed: ratio for reaching the vehicle's maximum cruise speed. This electronically managed system is quite practical because it means that the engine can always be operated at a given speed: maximum torque speed or minimum specific consumption speed.... Lastly there is a mode that allows the driver to take control and change the virtual ratios by hand. These ratios are given by fixed pulley diameter combinations.

The CVT represents a veritable revolution in the area of transmissions. Indeed, this variable speed drive gearbox no longer uses a few pre-selected ratios, but a very broad range of ratios. This system only uses two gears linked to each other by a belt which transmits the movement from one disk to the other. The down gearing varies according to the distance separating the disks. In other words, the ratios vary gently (no more juddering and no more noise), and the engine can be greatly accelerated in a short ratio and benefit from low fuel consumption in the longest ratio.

These gearboxes may even include the possibility of switching to manual mode, while keeping the inherent flexibility of the CVT, even with sporty driving.

9.3. POSITION AND COMPOSITION OF THE GEARBOX

The gearbox is placed downstream of the torque converter, with respect to the engine.

Engine
→ **Hydrodynamic torque converter**
→ **Gear box**
→ **Rear axle assembly (differential).....**
→ **Wheels**

It consists of epicyclic trains so that the ratios can be changed without having to interrupt the mechanical continuity between the engine and the wheels.

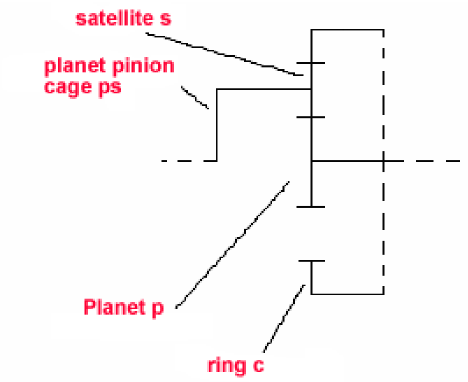


Figure 276: Epicyclic gear train

Reminder of the epicylic gear:

By means of a hydraulically managed multi-disk clutch (with calculator), it is possible to immobilise **s, p, c** in turn, which will give different ratios.

9.3.1. The differential gear

When a vehicle goes round a corner, the inner wheel covers a shorter distance than the outer wheel, and as these two distances must be covered in the same time interval, the angular speed of the two wheels must be different.

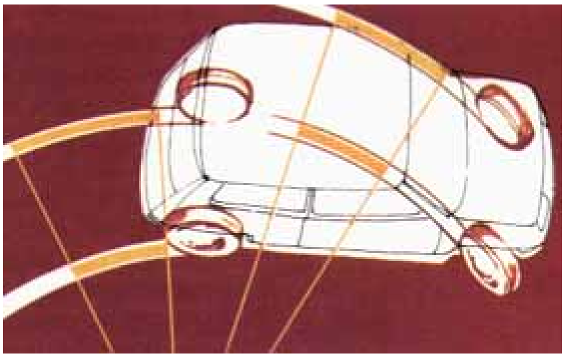


Figure 277: Difference in the rear-wheel speed

And this is where the differential gear comes in. Without this mechanism, one of the wheels would skid on the road (which would be a very bad thing for the length of the tyres' life and for roadholding; the car could even go into a spin); the rear half-shafts would also be subjected to a torsion force which could, sooner or later, lead to their rupture.

9.3.1.1. Driving in a straight line

The trajectories covered by the wheels are identical, the rotation speeds are therefore the same. The planets do not rotate; the planet pinion cage rotates under the effect of the torque while transmitting the movement to the planet gears, which receive an equivalent torque equal to half of the main torque.

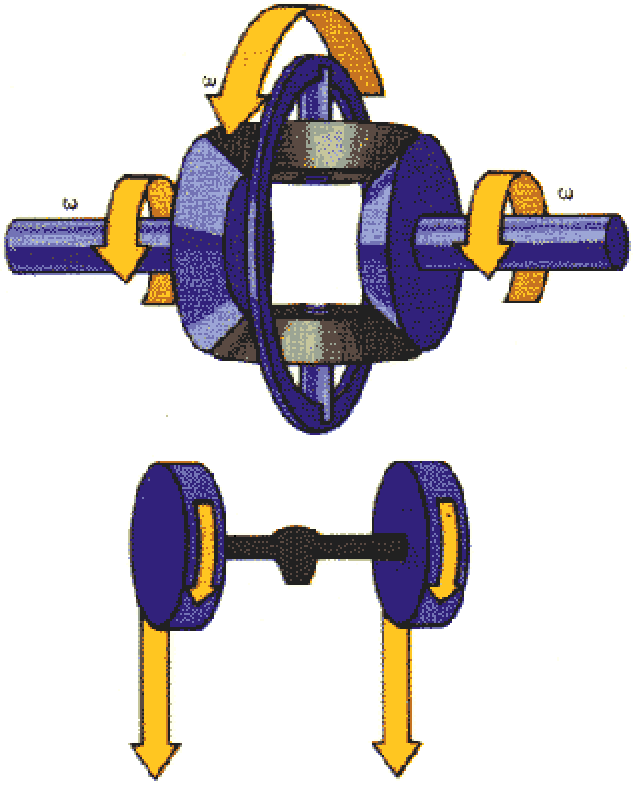
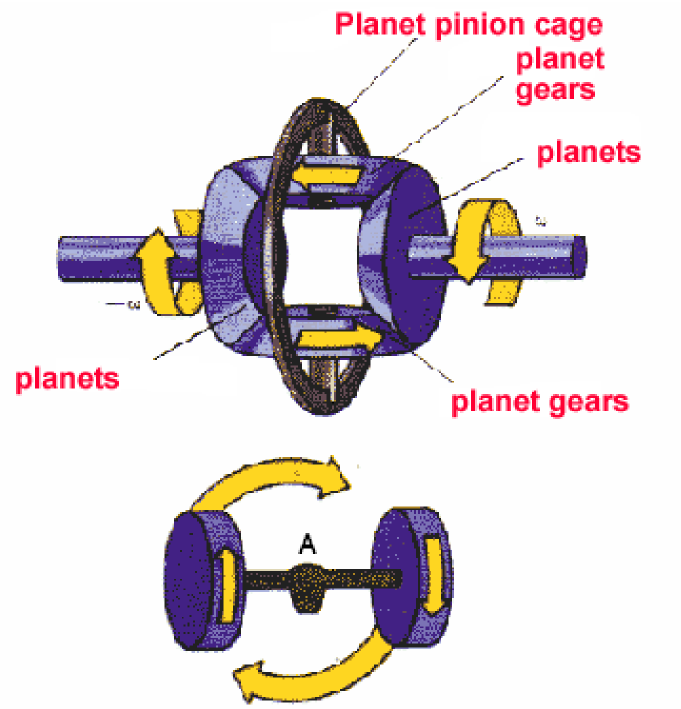


Figure 278: Same speed in a straight line

9.3.1.2. Rotation around point A



If you lift the drive wheels off the ground and turn one of the wheels, the other wheel will rotate in the opposite direction because of the movement reversal caused by the planets.

This would correspond to a rotation around a point **A** situated in middle.

Figure 279: Reversal of rotation direction

9.3.1.3. Rotation around point B

If you block one wheel, the planet pinion cage and the planets turn while transmitting all the engine torque to the other half-axle which will therefore rotate at double speed. The wheel concerned will turn at twice the speed as it would in a straight line.

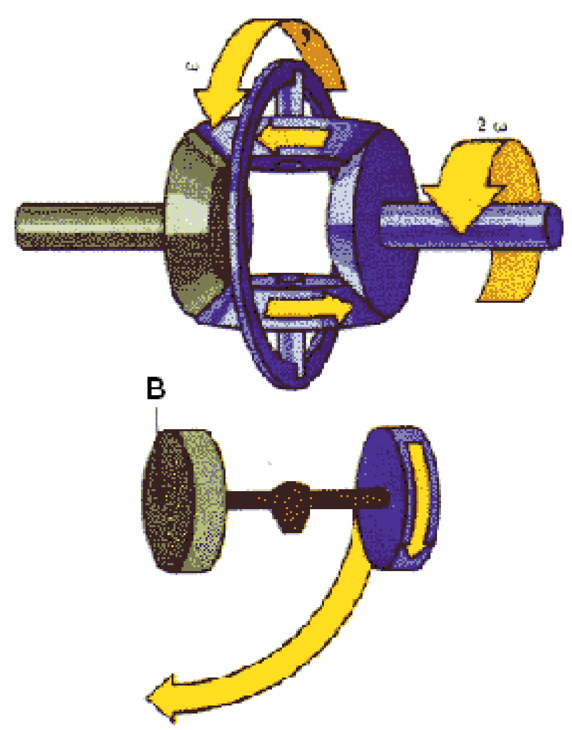


Figure 280: Case of a blocked wheel

As the planets' shaft is not fixed, the differential gear is a spherical epicyclic train (the shafts of all the pinions intersect). The planet gears and the planets have straight teeth, given their moderate working speed and the low percentage of time during which these wheels are subject to a relative movement (corners).

Its ends have two hollow shafts (to allow the half-shafts to pass through) mounted on ball bearings in the protection casing. A large ring is bolted to this cage, which with the drive pinion form the bevel gear.

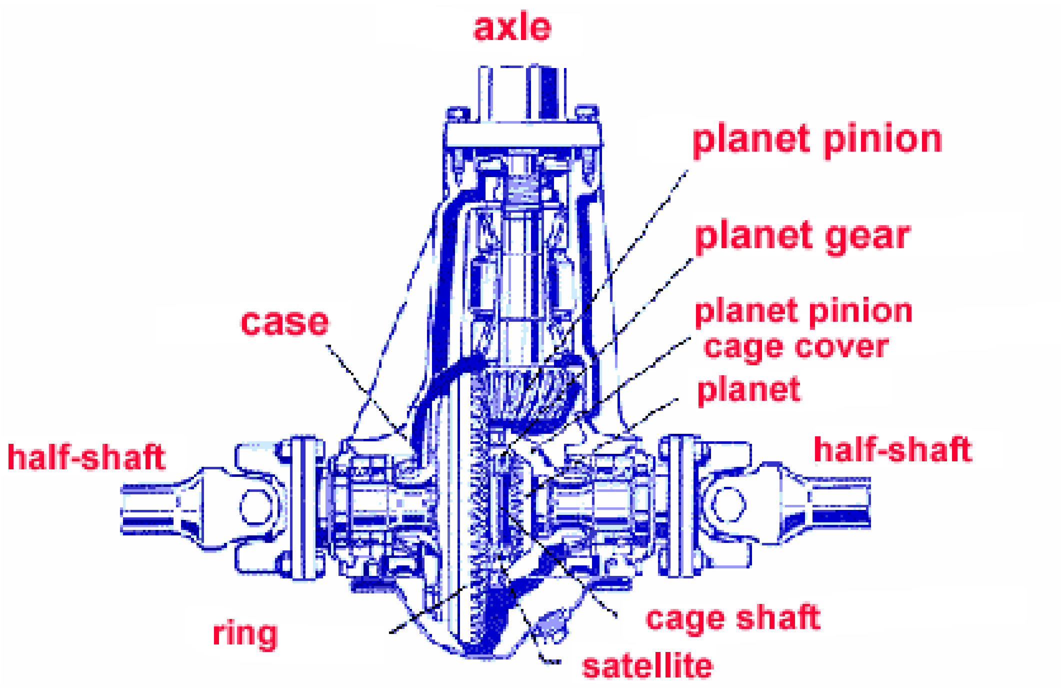


Figure 281: Front engine/rear-wheel drive

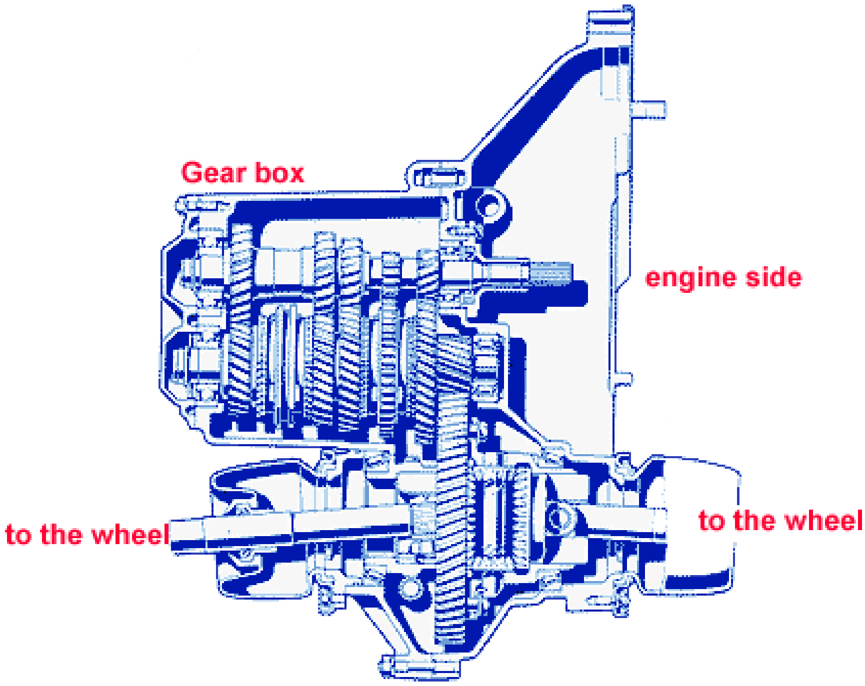


Figure 282: Front engine/front-wheel drive

9.4. GEARBOX LUBRICATION

For modern gearboxes with the pinions always engaged, lubrication by oil splashing is the most commonly adopted solution.

However, part of the pinions is idle on the shaft and it will be necessary to ensure their lubrication by means of pipes. The best results are therefore obtained by forced lubrication using a special pump.

The quality of the oils used for gearboxes is different from that for engines.

10. LIST OF FIGURES

11. LIST OF TABLES

12. ANSWERS TO THE EXERCISES

1. Why are belts used?

   Power transmission

2. Give the possible types of misalignment?

   - angular and parallel
   - angular
   - parallel

3. List the possible types of drive that use belts?

   - by adhesion
   - by obstacle

4. What criterion does transmission efficiency depend on?

   Tension of the belt and contact between the belt and the pulleys

5. What is the maximum permissible misalignment for a V-belt?

   6° max.

6. List the drawbacks of belts?

   - irregular transmission ratio (slippage for smooth belts)
   - need for a belt tensioner

7. What type of pulley is used for a smooth belt?

   Smooth pulley

8. What causes belt wear and aging?

   Gradual decrease in the installation tension

9. What is the name of the device that is used to avoid having to adjust the tension of an installation?

   Belt tensioner

10. What are the main factors responsible for problems?

    - the tension of the belts
    - the alignment of the pulleys

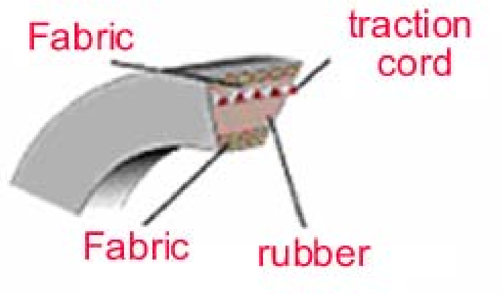
11. What causes uneven wear on a belt?

- presence of a foreign object in the pulley
- pulley in poor condition

12. What materials are used to make belts?

- polyurethane
- rubber
- leather

13. Composition of an envelope V-belt?



V-belt

14. What is this type of transmission called?

Orthogonal

15. What type of transmission is obtained with a chain?

Transmission by obstacle

16. What method is used to increase the tension course on long transmissions?

Installation of several tensioners

17. List the drawbacks of chains.

- Compulsory lubrication
- High sound level
- Longitudinal vibration
- Limitation on the transmission ratio

18. Can you join together two chains with different pitches? Explain.

No. A worn chain does not have the same pitch as a new chain and does not mesh in the same way on the pinion

19. Definition of the chain pitch.

It is the distance between two pins

20. What parameters must be monitored closely when using the ceiling speed range?

- Beating and vibrations
- Snapping noise
- Fatigue strength
- Lubrication

21. What is the maximum permissible lengthening of roller chains?

3% >> 30mm per metre of chain

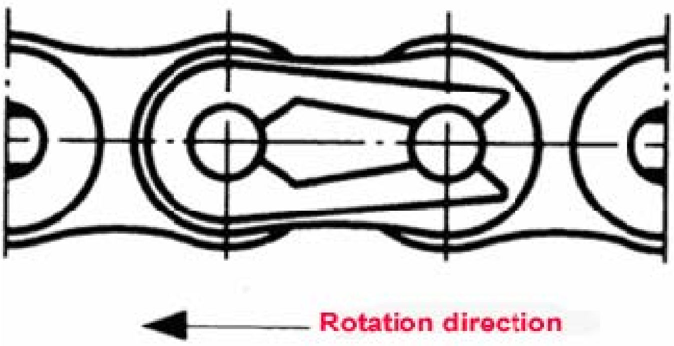
22. List the various chain lubrication methods.

- Manual lubrication
- Oil splash lubrication
- Drip lubrication
- Oil pump lubrication

23. What is the name of tool used to join chains together?

Chain link pliers

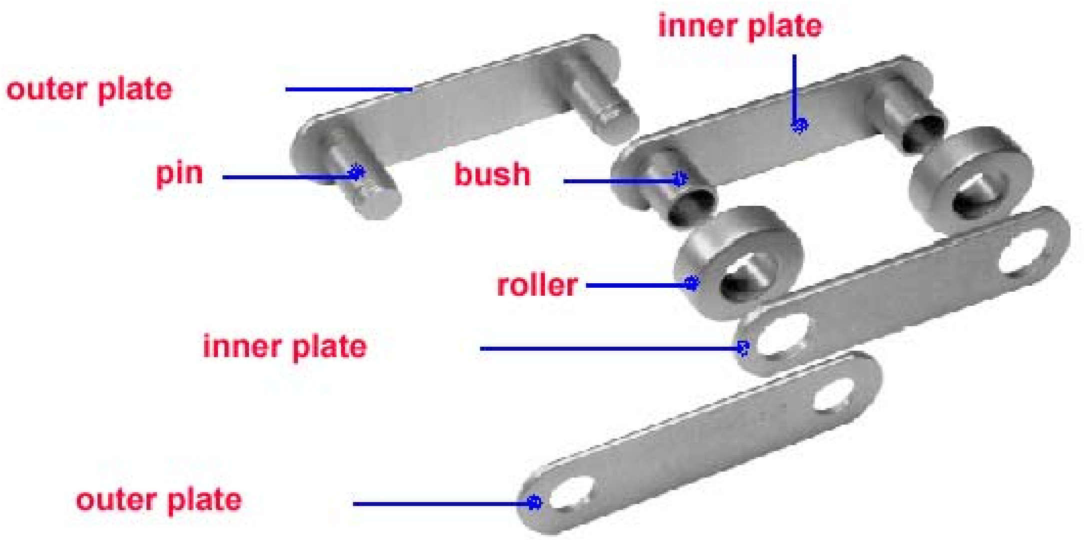
24. Indicate the chain rotation direction.



25. What type of pinion must you use to avoid having a polygonal force?

    A pinion with the greatest possible number of teeth

26. Complete the diagram.



27. What role is played by the fasteners.

    They make it possible to adapt the basic chain to all specific handling applications

28. Why isn't it an advantage to have too high a rupture value,

    It will cause a reduction in the elasticity and in the fatigue strength