

Textbook for Vocational Training – Machine Elements and Assemblies and Their Installation

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Preface

This Textbook covers the fundamentals of machine elements and assemblies and their installation. It is intended for trainees in metalworking and engineering trades.

The different installing technologies are explained on the basis of the most important machine elements for connecting, elements to transmit motions and forces, and elements to transmit and convert motions.

Trainees are familiarized in a convenient manner with the principal machine elements and assemblies that they will often encounter in their future careers. The text is profusely illustrated and backed by many tables for a lucid presentation of the subject matter.

The aim of the Textbook is to enable trainees to complete simple installation work involving connecting elements and assemblies.

Important points and rules have been emphasized with the prefix ‘Note’, plus a vertical line in front of the text.

Each section ends with a series of self-tests on the comprehension of essential subject matter.

1. Introduction

Man must observe the laws of nature to survive. But the further development of human society requires more. The satisfaction of the needs of man demands conscious application of the laws of nature. During a process of evolution over a period of many thousands of years, man has created present-day technology to control

nature and to use its resources.

Technology is the entirety of measures, activities and tools (instruments of production) employed in material production to exploit nature for man's purpose.

The production instruments – tools, fixtures, machines and complete automatic installations – exert a major influence on the extent to which man is able to exploit the resources of nature for his purpose.

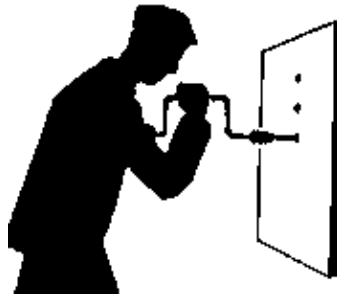


Figure 1/1 Manual work

Depending upon their application, a distinction is made between:

Manual work. Workpieces that are worked manually only with the help of hand tools.

Small-scale mechanization. Manual work is replaced by powered tools and simple jigs and fixtures. The human effort is no longer the sole source of power. Man guides and advances the tool.

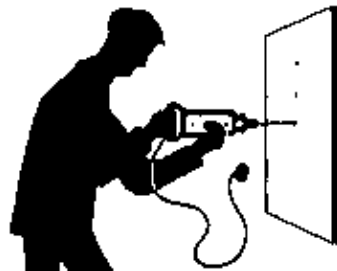


Figure 1/2 Powered hand tools

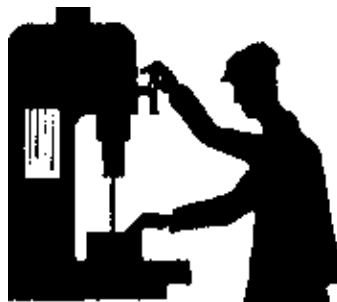


Figure 1/3 Machine work

Partial mechanization. Individual machines are operated for certain jobs to largely eliminate manual work. The machines can be lathes, cranes, conveyor belts, lorries, cranes, etc. Man operates and controls these machines.

Comprehensive mechanization. The operation of a system of complementary machines of matched capacity to mechanize all jobs within a working process, Man still has to control the flow of work.

Automation. Automatic machines not only complete the jobs but also deal with the requisite measuring and controlling jobs.

Machines convert the different forms of energy of nature into technically useful energy. Other machines perform work by transforming materials (production of raw materials, manufacture of industrial and consumer

goods), or by transporting products (e.g., lifting gear, motor vehicles). The scientific and technological revolution has brought about a big demand for machines that will process information.

A machine is a technical system created by man on the basis of the laws of nature to simplify physical and intellectual work and to increase productivity. It replaces human work or functions of human organs partially or entirely.

1.1. Classification of Machines

Machines can be classified by different aspects. The following distinctions are of particular importance for analysing the set-up of machines and for their systematic classification.

1.1.1. Classification by the Achieved Transformation

Energy Machines

These machines convert natural energy into technically useful energy, or convert one form of technically useful energy into another form. This category includes power generating and converting machines and driving machines. Examples: Combustion engines, gas water and steam turbines, steam engines, windmills, water mills, generators, transformers.

Working Machines

This category includes all machines that complete some form of mechanical work –changing the shape, properties or position of materials. They are powered by driving machines. “Machines” that are driven by muscle power are known as devices.

Examples: Woodworking and metalworking machines, plastics processing machines, building machines, machines for the textile, paper, printing, glass, earthenware and food industries, farm machinery, motor vehicles, rail-bound rolling stock, lifting gear, fans.

As much as these machines may differ, they all have one common point:

Each one of them performs a specific mechanical job, be it that it manufactures or processes something or that it transports something.

Information Machines

These machines gather information (data) which is transmitted, processed and stored. Examples: Radio and telephone equipment, data processing machines, computers.

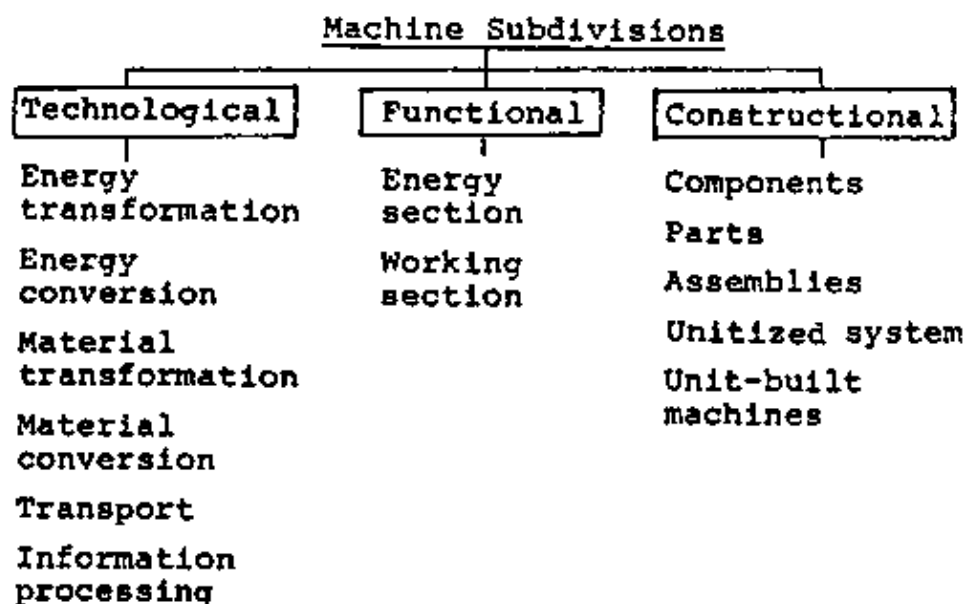


Table 1/1: Classification of Machines by their Characteristics

1.1.2. Classification by Machine Characteristics

All machines can be distinguished by technological, functional and constructional characteristics. Their classification requires the analysis of the machines by the listed characteristics. Such an analysis will furnish an understanding of the functions and design of the given machine.

1.1.3. Classification by Manner of Action

The machines are classified by the scientific and technological laws of the production–technical process prevailing at the point of action.

Examples: Combustion, cutting, transporting and conveying machines, steam engines, electrical machines.

1.1.4. Classification by Purpose of Application

Table 1/2: Classification of Machines by their Purpose of Application

Main group:	Machine tools	Building machines	Transport machines
Sub-group:	Lathes	Excavators	3-side tippers
	Drilling machines	Grading machines	Dumpers
	Milling machines	Tower cranes	Lorries
	Grinding machines		Rolling stock

Question:

1. Explain the principal difference between energy machines and working machines.

1.2. Machine Analysis

1.2.1. Flow of Energy, Material and Information

1.2.1.1. Power Transmission

Power can be transmitted, divided, stored and converted by machines. The flow of power represents the course of power transmission. The driving elements of a machine form the active mechanism of power transmission.

Mechanical energy is still the dominating form of effective power machines. This energy is actively transmitted by differing elements and driving units along the path of work.

Power transmission for solids is by pulling, pressing, bending and by torsional forces; and for liquid and gaseous substances only by pressure forces. There are also other forms of energy, namely electrical, optical, thermal and chemical energy, and each one has its own specific principle of action.

The path of power transmission in a machine can be indicated by arrows (fig. 1/4).

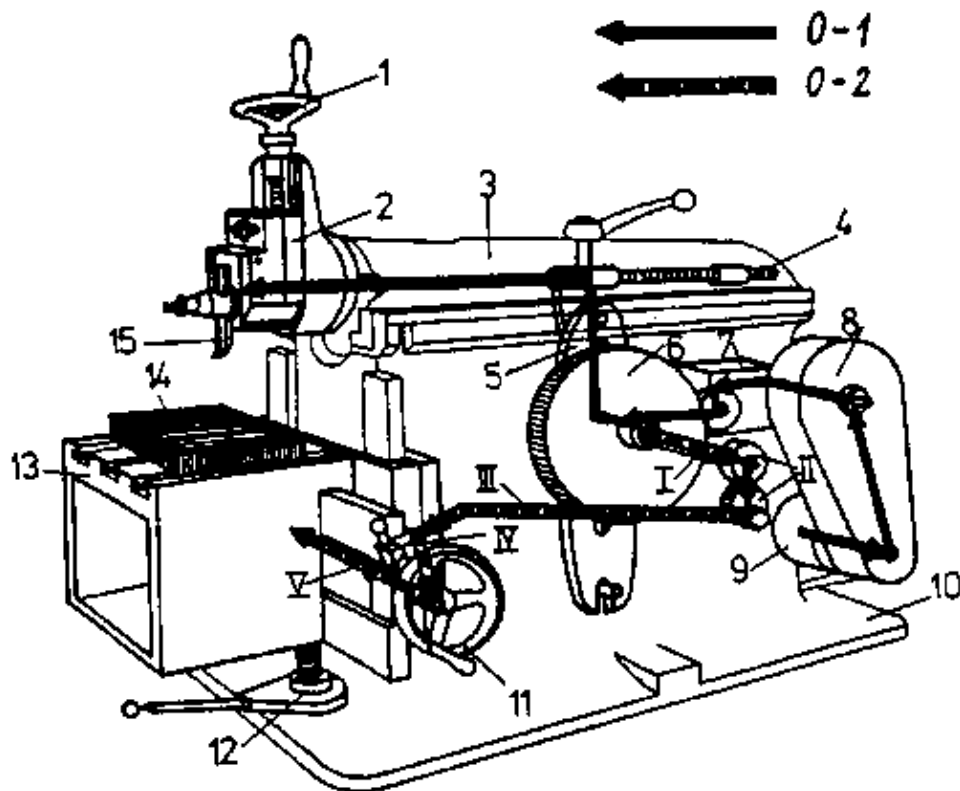


Figure 1/4 Power transmission in a shaping machine

1 manual spindle to set the shaping depth, 2 ram head, 3 ram, 4 spindle to set the working range, 5 crank arm, 6 disk crank, 7 gearing, 8 belt transmission, 9 electric motor, 10 machine frame, 11 hand wheel for lateral adjustment of the work table, 12 spindle for height adjustment of the work table, 13 work table, 14 workpiece, 15 tool.

I disk crank shaft, II gearwheels, III connecting rod, IV ratchet pawl, V table spindle.

0-1 main path of power transmission,

0-2 secondary path of power transmission.

The indicated path of power transmission is known as the power transmission chart. It clearly reveals the manner of action of a machine.

1.2.1.2. Flow of Substance

A flow of substance (substance transport) takes place in working and power machines that use substances as energy carrier.

Substance carriers hold the substance that is to be processed, worked or transported by positive or non-positive action. Often the working assemblies, or one of their working elements, take on the function of the substance carrier.

Differing substances require differing methods to deal with them within the flow of these substances, e.g.:

Collecting (winding, bagging, stacking)

Conveying (pumping, pouring, scooping)

Arranging (distributing, sorting, aligning)

Branching of the flow of substance is often necessary in a machine or in a group of machines.

The representation of substance transport in a machine or installation is known as the substance flow chart (fig. 1/5).

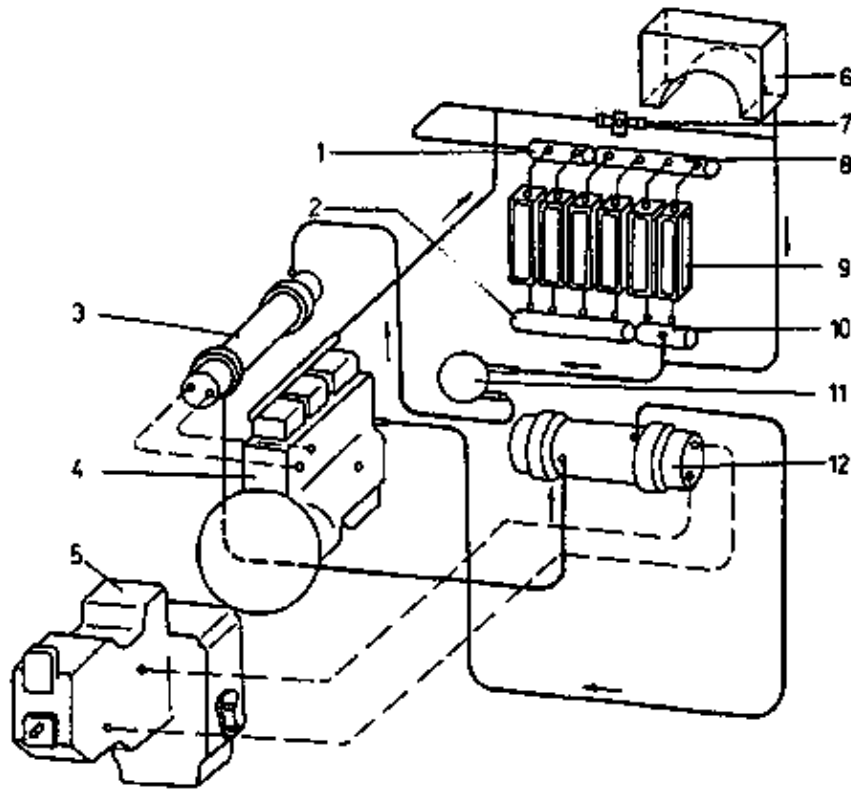


Figure 1/5 Substance flow chart (cooling circuit)

1 collecting pipe for cooling water, 2 collecting pipe for cooling water, 3 heat exchanger for engine lubricating oil, 4 diesel engine, 5 gearing, 6 cooling water supply tank, 7 short-circuiting valve, 8 collecting pipe for cooling water, 9 cooler, 10 collecting pipe for cooling water, 11 cooling-water pump, 12 heat exchanger for transmission oil.

1.2.1.3. Flow of Information

Information must be fed into a machine so that it will execute the desired working operations. This information can be fed in by man or by program. Information input can cause direct changes at the point of action. This process, however, can also be completed partially or fully automatically by corresponding measuring and controlling devices. Changes that become necessary during the production process require the output of corresponding information that is processed by man or by automatic facilities.

The production process taking place in a machine is always linked to the interaction of a flow of substance and/or energy with the flow of information.

1.2.2. Functional Design of Machines

The design of a machine depends upon the job it is expected to complete. The function of a machine becomes more clearly apparent when it is broken down into its individual sections.

Energy section

(e.g. steam engine, combustion engine, electric motor)

This section takes up the supplied energy (steam, fuel, electricity, hydro-power, energy of the sun or wind) and transforms it into the required working energy.

The working energy is usually a rotary motion at the driving side of the machine.

Working section

The working section makes use of the energy supplied to it in a useful form. The working section includes:

- Supporting elements
- Driving elements
- Matching elements
- Working elements

The supporting elements give the machine its internal constructional stability (e.g. stand, frame, containers).

The driving elements transmit the power from the energy section to the working elements, simultaneously controlling its direction and speed (e.g. transmission gearing, toothed gearing).

The matching elements enable the flow of information to act upon the flow of substance and/or energy. They are elements that control the course of movement and the parameters of movement (e.g. handwheels, locking mechanisms).

The working elements are the ones that produce the desired effect on the substance (e.g. the ram head with tool of shaping machines). Figure 1/6 and table 1/3 show the functional set-up of a horizontal shaping machine.

Table 1/3 Classification of Parts of a Horizontal Shaping Machine (acc. to Figure 1/4) by Function and Purpose

Working section				
Driving section	Supporting elements	Driving elements	Adapting elements	Working elements
Electric motor (9)	Machine frame (10)	Belt transmission (8)	Gearings (7)	Ram head (2) with tool
	Workpiece table (13)	Gearings (7)	Adjustment of working range (4)	Ram (3)
		Crank cam (6)	Hand spindle (1)	Workpiece table (13)
		Crank and rocker mechanism (5)	Gearwheels (II)	
		Ram (3)	Retaining pawl (IV)	
		Crank cam shaft (I)	Hand wheel (11)	
		Gearwheels (II)	Table spindle (V)	
		Connecting rod (III)	Spindle (12)	
		Retaining pawl (IV)		
		Table spindle (V)		

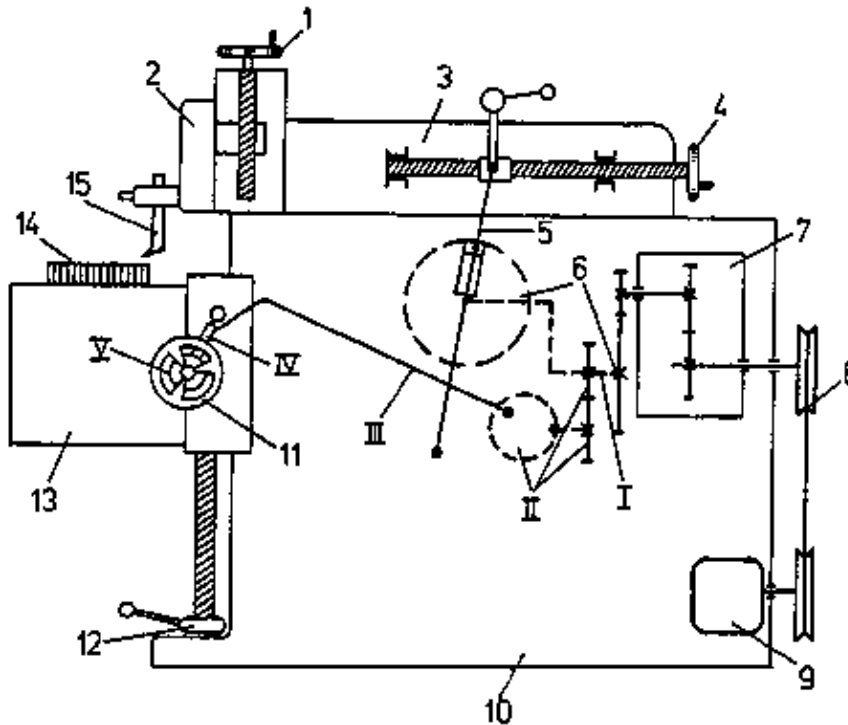


Figure 1/6 Functional set-up of a shaper (based on fig. 1/4).

Parts and assemblies do not always have only one and the same function. They may handle varying functions in different machines:

- | | |
|-------|---|
| Part | Job |
| Shaft | – As a driving element in transmission gears |
| | – As a supporting element within a pair of wheels (e.g. of rolling stock) |
| Chain | – As a supporting element for a stopping device |
| | – As a driving element within chain drives |

Alternatively, parts and assemblies can take on different functions successively in the same machine:

- | | |
|------------|--|
| Switchgear | – As a driving and a matching element |
| Fitting | – As a supporting and a matching element |

Questions:

1. Describe the functional set-up of a machine in your workshop,

1.3. Constructional Design of Machines

1.3.1. Components/Parts and Assemblies

A machine is composed of a multitude of parts. If several machines were to be dismantled one would see that some parts appear to be identical or similar, whereas others are not comparable. One would also see that some of these parts (as a single component) execute a specific function. Against this, there are parts that take on a useful purpose only after they have been combined with other parts, i.e. made up into an assembly (see Section 1.2.2.).

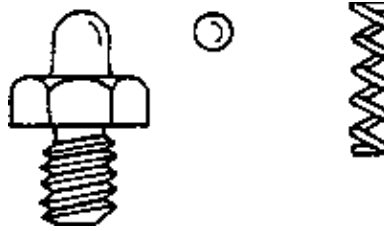


Figure 1/8 Ball-type lubricating nipple consisting of three parts a b c

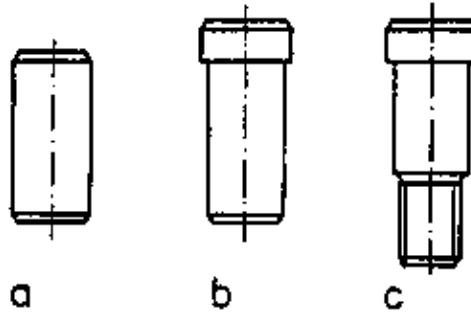


Figure 1/7 Bolt shapes

1 bolt without head, 2 bolt with head, 3 bolt with head and thread.

Components are constructional units that fulfil the same purpose in different machines. Functionwise they cannot be taken apart any further. Constructionally, however, they may consist of a single part (fig. 1/7) or of several individual parts (fig. 1/8).

The parts and materials used for joining are also considered to be components.

Optical, electrical, mechanical, hydraulic and pneumatic components are employed. Components must fulfil differing functions:

- To join a part or several parts
- To support parts
- To transmit power
- To transform motions and energy
- For actuating, switching and controlling purposes in the flow of substance and power
- For the storage, transfer and cancellation of power and information
- As substance and energy carriers

Many components can be optionally employed for several functions, e.g.:

- Threads:
 - For joining
 - To convert motions
- Bolts:
 - For joining
 - To transmit power
- Friction cone:
 - To transmit power
 - To convert power

A machine is not only composed of a sum of components. It is also made up of other individual parts such as support, frame, enclosure, guideway, etc. These are not defined as components.

Components, parts and other individual elements are made up into assemblies.

Assemblies are complete technical units consisting of a sum of individual parts that belong together constructionally and functionally. These assemblies are parts of a machine.

Table 1/4 gives a selected survey of the components employed primarily in mechanical engineering. Some of these components can be classified according to different aspects, e.g. Valves: firstly for switching, and

secondly for the conveyance of substances.

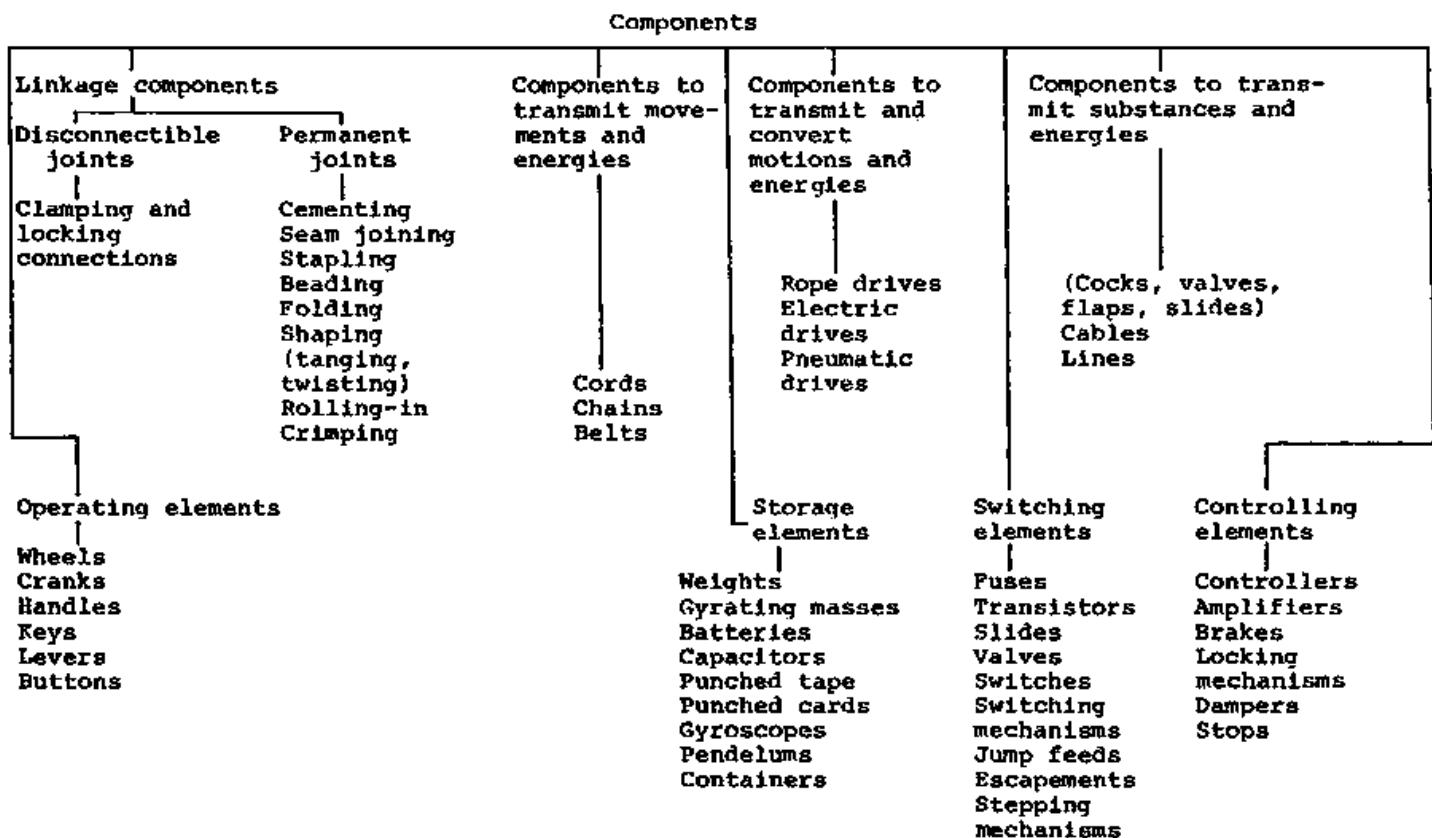


Table 1/4: Survey of Components

1.3.2. Interaction of Assemblies

The interaction of the assemblies of a complicated machine cannot always be made out at first sight. Greater clarity can be established in this respect by producing a schematic representation of the machine (fig. 1/6).

1.3.3. Unitized Construction Principle

A unitized construction principle involves the manufacture of the assemblies of a machine in differing unit sizes for subsequent combination. This means that a certain number of assemblies can be used to produce a larger number of variations (capacity, working length, material thickness that is to be processed) of the same type of machine than if all assemblies had to be especially manufactured for each machine variant.

A unitized construction principle means that the same assemblies can be used for different versions of the same type of machine.

1.3.4. Unit-built Machines

Assemblies for identical purposes are incorporated in different machines. Thus, a machine tool is composed of the support, bed, guideways, drives, transmission gearings, workpiece clamp and tool holder. If these assemblies are standardized one can then employ the same assemblies (units) for different types of machines.

A unit-built machine is made up of standardized units to achieve a specific application.

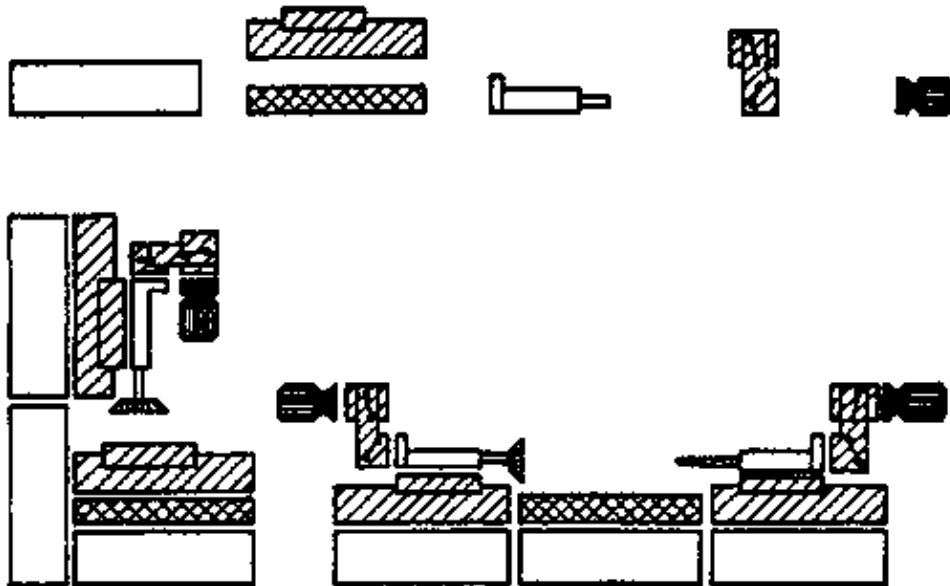


Figure 1/9 Unitized construction system revealing how machines can be made up of basic units.

Figure 1/9 shows how this unitized construction principle has been applied to a drilling machine and to a lathe, i.e. both machines are composed of common units.

Question:

1. Explain the interaction of assemblies of a machine (fig. 1/6).

2. Elements for Joining

2.1. Keyed Connections

Keys are used to mount gears, belt pulleys or levers on shafts (fig. 2/1). These joints can be disconnected and connected again at any time with the same components. The key and the components are not rendered useless by their disconnection. Keyed connections are primarily employed in heavy machine building and for farm machinery.

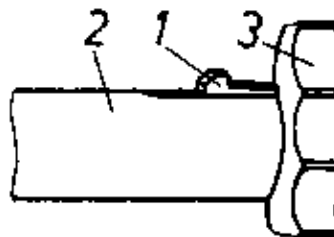


Figure 2/1 Keyed connection between wheel and shaft

1 key; 2 shaft; 3 wheel.

Furthermore, certain parts can be shaped in the form of a key so that they can be firmly connected with each other.

For instance, drills, drill chucks, counterbores and milling cutters are mounted on machine spindles in this manner.

2.1.1. Design

Keyed connections involve the production of conical holes or tapered grooves in the machine parts that are to be connected.

Keys are then inserted in these keyways or keyseats, thereby firmly locking the keyed parts together. The frictional resistance prevailing between the keyed parts keeps them firmly in their relative position to each other (fig. 2/2).

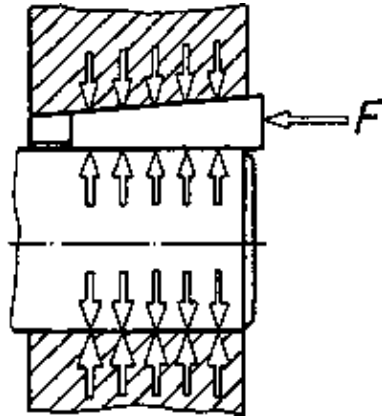


Figure 2/2 Force acting on a keyed connection

The flat key bears upon the shaft and hub with two surfaces (flat surface). The underside of the key rests on the base of the shaft groove parallel to the shaft axis, while the rearside is tapered in relation to the hub groove. The key is driven into the keyseat to hold the parts together. The rearside tapers down in relation to the underside. The inclination ratio is usually 1 in 100, i.e. the height of the key diminishes by 1 mm over a length of 100 mm. Figure 2/3 shows the individual surfaces and dimensions of a typical key.



Figure 2/3 Surfaces and dimensions of a key

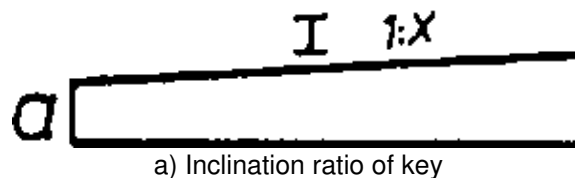
1 rearside, 2 underside, 3, 4 key height, 5 key width, 6 key length.

The material for the key is selected in keeping with the forces it has to transmit. The key must be harder than the shaft and the wheel which it connects. This is because keys with soft surfaces would be easily deformed while they are being driven in, thus rendering them useless.

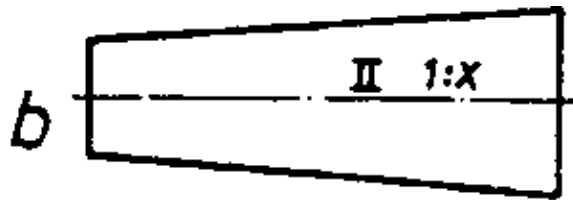
2.1.2. Stresses

Keyed connections act as a result of their inclined plane with which larger weights (or bodies) are lifted with relatively little force.

Figure 2/4 Specifying information on a key and a taper pin



I inclination



b) Taper-pin ratio

II taper

In engineering drawings the inclination of a key is marked on the sloping plane as the ratio 1 in x (fig. 2/4a); for taper pins this information is marked on the centre line as the taper pin ratio 1 in x (fig. 2/4b). Accordingly, a taper pin of 1 in 10 means that the pin diameter changes by 1 mm over a pin length of 10 mm.

The slimmer the taper pin, the higher the transmitting ratio.

This means that rotating parts are keyed eccentrically. Consequently, keyed joints are only applicable for parts that must be absolutely round or which are to rotate at high speeds if these parts (e.g. wheel and shaft) are carefully finished in a mounted condition and are finally balanced with accuracy.

The surfaces at the sides of the key and hub do not participate in torque transmission.

2.1.3. Types

Keyed connections are classified by different aspects (table 2/1).

A difference can be made between the forms of application of the keys, namely between mounting keys (table 2/2) and adjusting keys (fig. 2/5). Keys can also be distinguished by their shape (table 2/3).

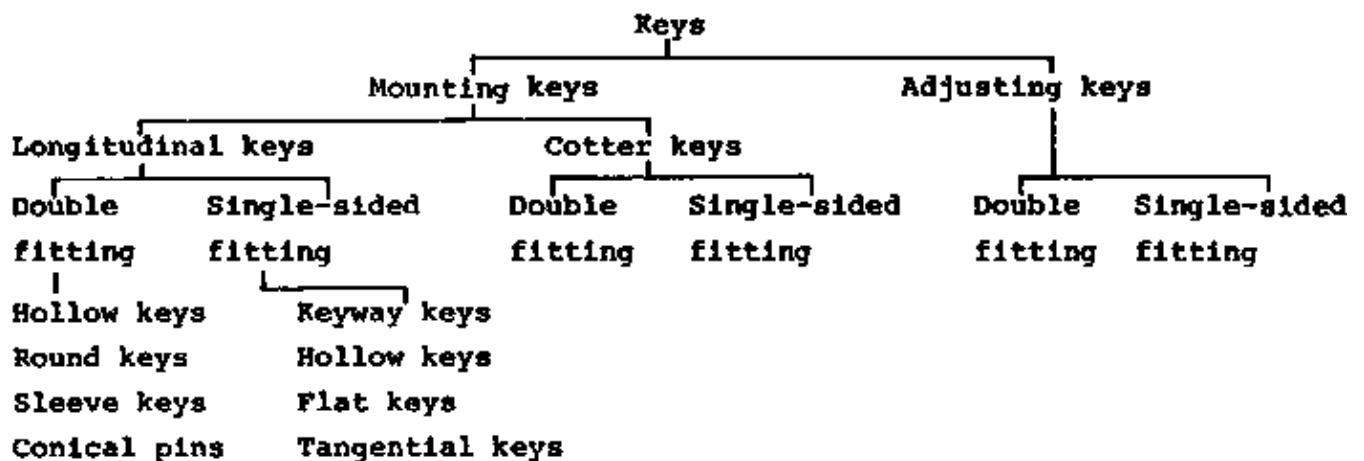


Table 2/1: Kinds of Keys

Table 2/2: Distinction Characteristics of Keyed Connections

Mounting keys	Position in relation to shaft axis
Longitudinal keys	Parallel
Cotter keys	Rectangular

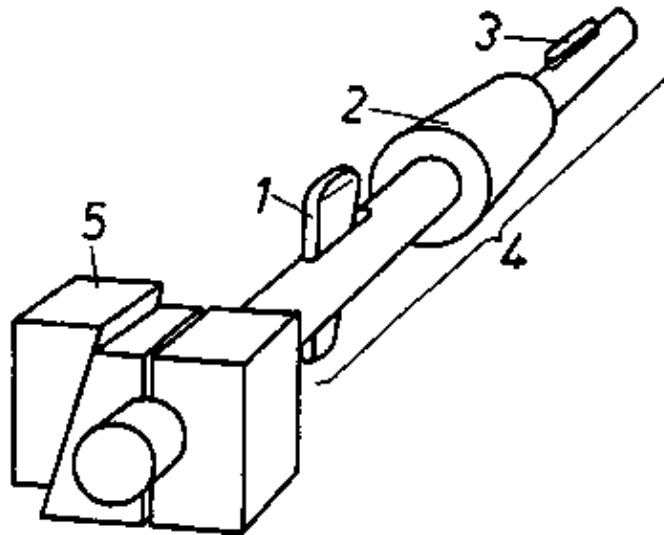


Figure 2/5 Kinds of keys

1 cotter key; 2 sleeve key; 3 longitudinal key; 4 mounting key; 5 adjusting key.

Mounting Keys

Different kinds of keyed connections can be produced between wheels, pulleys and shafts. The distinction is made by the length of the key in relation to the shaft axis.

Figure 2/6 Kinds of longitudinal key connections

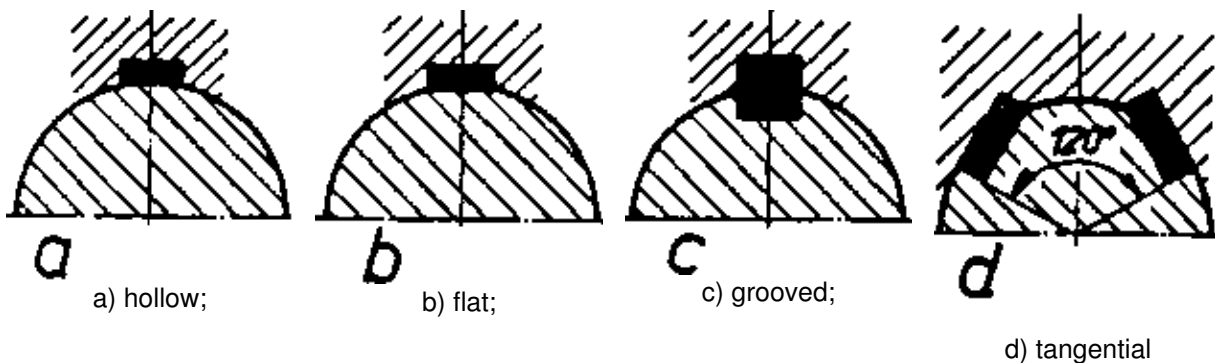
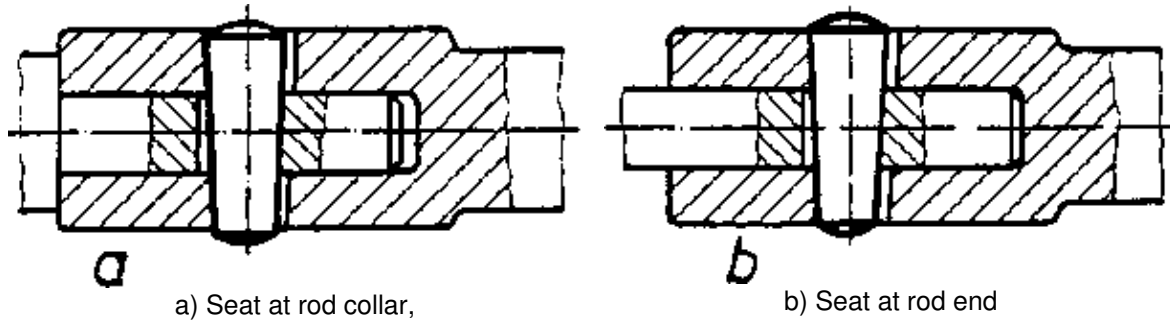


Table 2/3: Distinguishing Keys by their Shape

- | | |
|------------------|--|
| – Hollow key | Underside matches the curvature of the shaft (fig. 2/6a); shock loads may result in torsional sliding. |
| – Flat key | The underside of the key bears on a surface (fig. 2/6b) that was machined into the shaft on the broad side of the underside. |
| – Keyway key | Both hub and shaft have a keyway in which the key is fitted (fig. 2/6c). |
| – Tangential key | Twin tapered keys, displaced by 120° in relation to each other, are tapped in with their tapers in reverse (fig. 2/6d); the fit is obtained at the facing sides, producing a symmetrical 3-point fit between shaft and hub. |

Ordinary (longitudinal) keys: Used to transmit alternating torques. The keys shown in figure 2/6 are used in the sequence of the torque shock stresses.

Figure 2/7 Kinds of cotter key connections



Cotter keys: These join rods that complete longitudinal motions. For this purpose the parts that are to be joined have keyseats in traverse direction to the longitudinal axis (fig. 2/7) in which the cotter keys are driven. The production of such transverse keyseats involves a lot of work and is expensive. Depending upon their application, cotter keys can have an inclination of 1 in 20, 1 in 30 and 1 in 40.

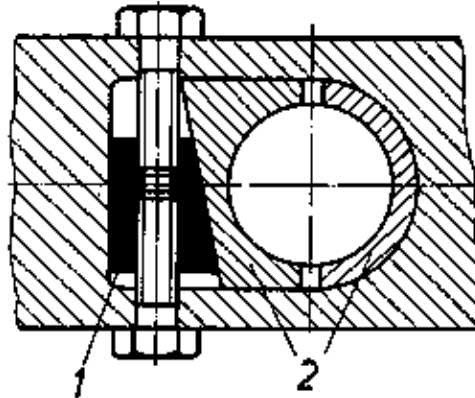


Figure 2/8 Adjusting key to set a sleeve bearing

- 1 adjusting key
- 2 bearing shells

Adjusting Keys

These keys are used to adjust the position of components in relation to each other. The inclined surface of the key is the supporting surface against the other component (fig. 2/8). The amount of clearance of plain (sleeve) bearings can be adjusted by longitudinal displacement of the key. The tension created by cotter keys depends upon the required length of adjustment. For plain bearings it is between 1 in 5 and 1 in 10 to obtain a short length of tensioning in the longitudinal direction for a wide range of adjustment. The steep inclination of such keys, however, makes it necessary to lock them in position, usually by screws, because they are not self-locking, i.e. they will always tend to slip out of the keyseat.

2.1.4. Mounting Technology

Preparing the Workplace

Suitable tools are required to secure keyed joints (e.g. hammer, key driver), as well as the corresponding gauges (e.g. vernier caliper for key grooves). The tools and gauges should be properly laid out on the workplace for convenient access.

Preparing the Parts

Checking keyseat, shaft and hub grooves:

Measurements establish the dimensional stability of the components. Vernier calipers are best suited for the measurement of the key grooves (fig. 2/9).

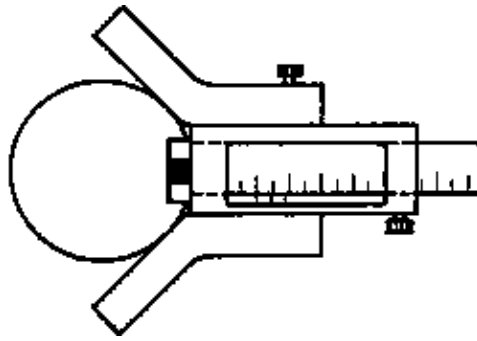


Figure 2/9 Measuring the depth of the key groove with a vernier caliper for grooves

The underside and rearside of the key must rest firmly against the shaft and hub groove to produce a secure key joint. If the key taper does not match the taper of the hub groove, the key will displace the hub, forcing it into a tilted position when the key is driven in.

Seat of shaft and hub: The dimensional difference (allowance) between shaft diameter and hub hole must be very small. As the key is driven in, the hub becomes displaced radially in relation to the axis of the shaft by the amount of existing allowance. This means that the hub will be running eccentrically to the same extent as the amount of allowance. Such eccentricity can cause a strong imbalance at high speeds and with large weights. That is why the closest possible fit must be selected for shaft and hub.

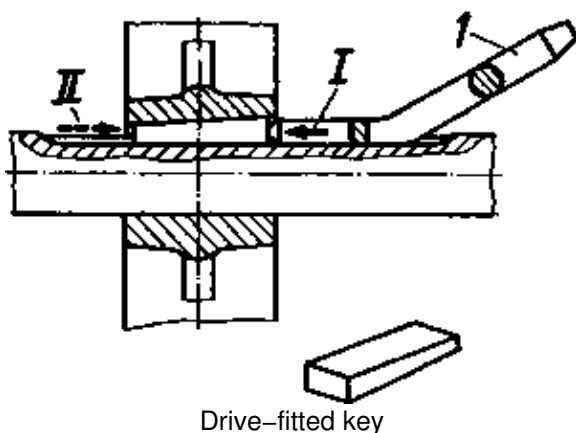
In special cases the hub is pressed or shrunk on to the shaft to eliminate the need for a key.

Fitting ordinary keys: There is a small clearance at the side surfaces of the key. The underside and rearside must fit tightly, and this usually requires reworking. For this purpose the rearside is oversized by an allowance of about 0.3 to 0.5 mm. The key is lightly driven into the grooves of the joined components for testing purposes to establish firm seating of the key surfaces. Chalk or ink is applied to the surfaces. The key is then driven in. The pattern that becomes visible when the key is extracted clearly indicates the bearing and non-bearing surfaces so that reworking can be completed accordingly. The key must be appropriately over-dimensioned in length when it is finally driven into the keyseat.

Checking and fitting the taper pin: A thin longitudinal line is drawn on the pin surface with chalk or marking ink. The taper pin is then inserted in the hole and is turned slightly. The resulting contact pattern on the surface will indicate whether the surfaces of the taper pin are resting uniformly against the walls of the hole. If the chalk or ink has been only partly removed, the taper pin must be covered with grinding paste and turned in the hole until the surface contact pattern reveals a perfect match with the hole after the same chalk tested has been completed once again.

Table 2/4: Fitting Longitudinal Keys

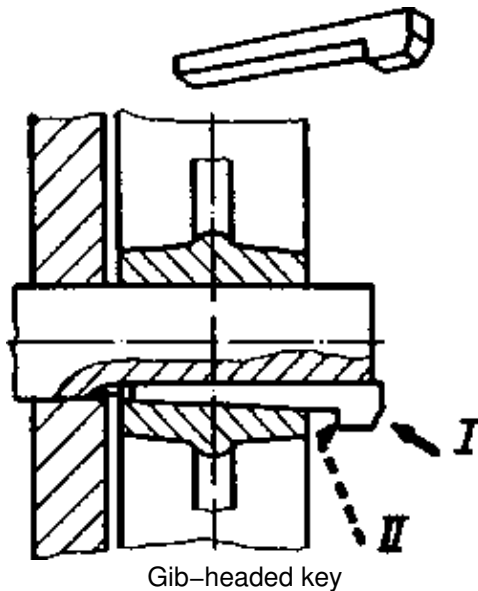
Job (illus.)



Explanations

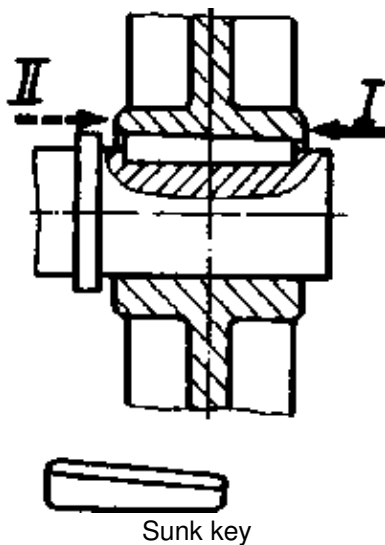
The slot for drive-fitted keys which are not driven in at the shaft end must have double the length of the key because there must be sufficient space to drive in the keys. The face ends must have a chamfer. A key driver is used to drive in and release the keys. The key must not become buckled when it is driven in.

1 key driver; I driving in; II releasing



The thick end of the key has a hook-shaped nose or gib. It provides a better tapping surface and will not buckle so easily when it is being driven in compared with the drive-fitted key. The gib forms an end support for the key puller or lever when it is released. A space of about 10 mm must remain free between hub and gib for mounting work. The protruding gib head is a potential accident hazard! That is why rotating parts must be adequately protected. The key puller is a flat key of long length and little taper.

I driving in; II releasing



A round-ended sunk key is used when there is not enough room to drive-in and knock-out the key. It is placed in the slot milled by an end miller and, if necessary, pressed in.

The rotating body, and not the sunk key, is driven with its hub on the shaft. The key is not buckled by this operation.

I forcing on; II releasing

Driving in the Key

Ordinary keys: The key and the groove should be lightly greased before the key is driven in. This is done to ensure that the key can be more easily removed at a later date. There are different ways to drive in keys (table 2/4).

After greasing, the key can be driven in by powerful blows with a hammer. To make sure that the key is not damaged and that its driving-in head is not deformed, a hammer made of non-ferrous metal should be used or, alternatively, an impact base made of non-ferrous metal and a driver. Care must be taken to ensure that neither the hub nor the shaft are damaged when the key is driven in. Notches in the shaft can impair its function and diminish its service life. Fig. 2/10 shows faulty keyed connections due to improper mounting.

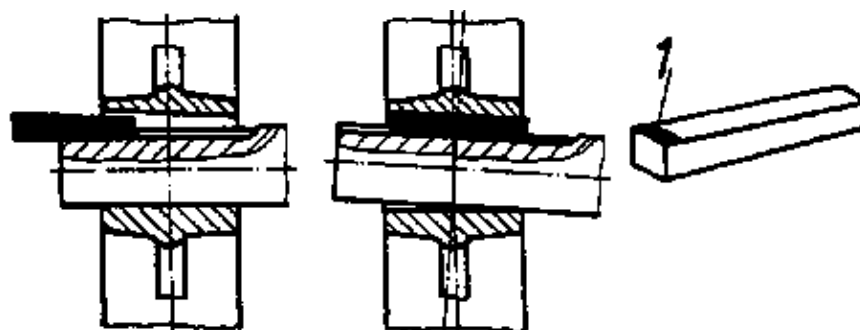


Figure 2/10 Faulty keyed connection due to improper mounting

1 point of deformation

The following procedure is adopted when a keyed connection cannot be released:

- The hub is heated over a gas flame or with a welding torch whilst care is taken to ensure that shaft heating is avoided as far as possible.
- Drive out the key.

Sleeve keys are driven in by light tapping with a mallet. Longitudinal holes are provided in the sleeve to release the joint so that the parts can be separated from each other with a key driver acting as a cutter (fig. 2/11).

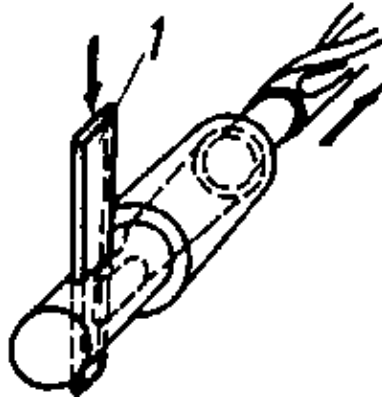


Figure 2/11 Removing a sleeve key with a key driver

1 key driver

Adjusting keys: Steep keys with which the clearance between shaft and bearing shells can be reset (see fig. 2/8) are adjustable with the help of two screws. The gap between the bearing shells contains yielding packing of 0.05 to 1 mm thickness. After removing the packing the key can be shifted upwards by loosening the lower screw and tightening the upper screw. In this manner the bearing shells are pressed against the yielding packing. Very fine adjustments can be made in this manner. The key is locked by tightening the lower screw.

Questions:

1. Explain why the tensioning force of a key increases with decreasing taper.
2. What is the disadvantage of keyed connections for rapidly rotating machine parts?
3. List the characteristics of keys regarding their external shape, their insertion, loads and uses.

2.2. Bolt Fastening

Bolts are often used to secure machine parts together so that they can be separated again for repair work.

A bolt fastening involves the following elements:

- The parts that are to be bolted together
- The bolt
- The nut
- The locking elements

Bolted joints have the purpose of bringing the parts that are to be connected in the desired position by the action of external force.

2.2.1. Design

An external thread and an internal thread are required to produce a bolted joint. The parts that are to be secured together may be threaded themselves or bolts with nuts may be employed for this purpose, often in conjunction with washers and locking elements (fig. 2/12).

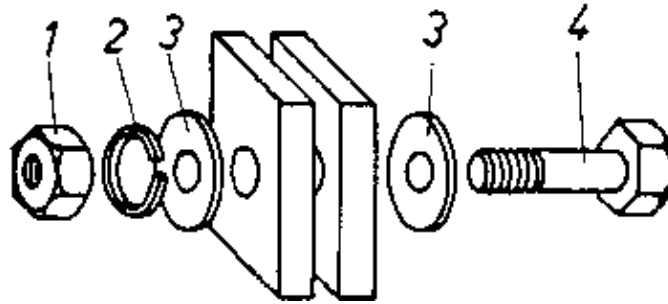


Figure 2/12 Bolt fastening

1 hexagon nut; 2 locking ring; 3 washer; 4 hexagon-head bolt

Proper bolt fastening presupposes matching internal and external thread dimensions (fig. 2/13).

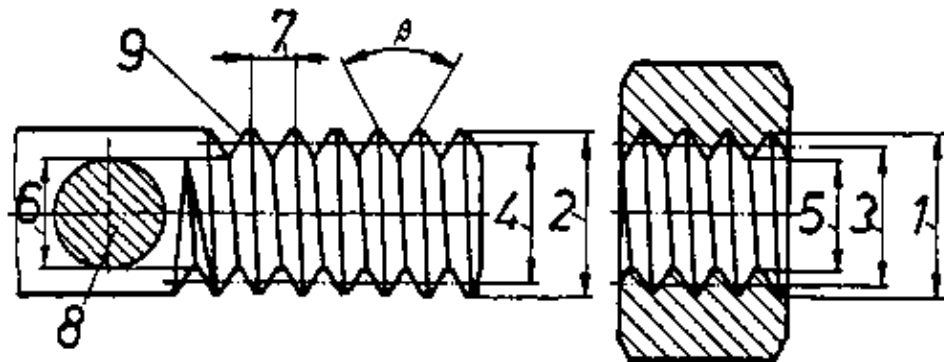


Figure 2/13 Parameters of metric 190 thread

1, 2 thread diameter; 3, 4 effective diameter; 5, 6 minor diameter; 7 pitch; thread angle; 8 core cross-section surface, 9 thread flank.

The threads of the bolts and nuts engage positively when they are screwed together. The friction between the engaged flanks of the internal and external threads of standardized mounting bolts is so large that the screwed connection cannot loosen itself under dead loads, i.e. the bolted connection is frictionally safeguarded against loosening. Pipes are often connected by cutting the required threads directly into the pipe walls so that the two pipe sections can be screwed together (fig. 2/14).

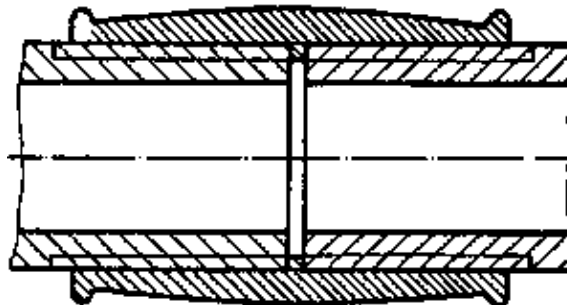


Figure 2/14 Screwed pipe connection

2.2.2. Stresses

The force that has to be applied to tighten a bolt depends on the pitch of the thread and on the length of the spanner. Furthermore, the frictional resistance arising at the flanks of the thread and at the base of the bolt head has to be overcome. This frictional resistance is intentional and desirable as it is responsible for the

self-retention that stops bolted fastenings exposed to dead loads from becoming loose again.

Initial Stress

When two workpieces are bolted together, they are compressed by the bolt fastening. All materials have a certain measure of elasticity. Hence, the tensional force in the bolt shank shortens the workpiece and lengthens the bolt.

Tensional Stress

Bolt and workpiece can only be stressed within the range of elasticity of the materials they are made of. If this limit is exceeded the joint will become useless due to plastic deformation, i.e. the joint will become loose or break. Overloads causes the first thread of the screw-in end of a bolt to break. The strain on the threads of a bolt and nut caused by the stress prevailing in the bolted joint is not distributed evenly to all stress-bearing threads. The force, and consequently deformation, is highest at the first thread. The cross-section of this first thread takes up between one quarter and one third of the total stress (fig. 2/15). This explains why it is always the screw-in point of the bolt that fails, i.e. breaks. The stress-bearing part of the thread rapidly decreases with the increasing screw-in length. That is why the height of standardized nuts is defined as $m = 0.8$ times the thread diameter.

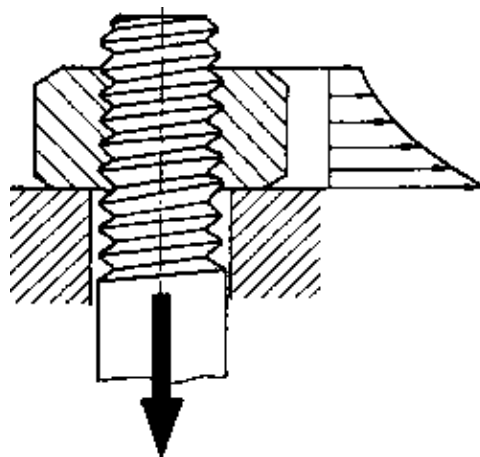


Figure 2/15 Strains taken up by the individual threads

Miscellaneous Loads

Bolted parts subjected to traverse loads in relation to the bolt axis will be shifted in their relative position when the frictional resistance between the parts is overcome (fig. 2/16).

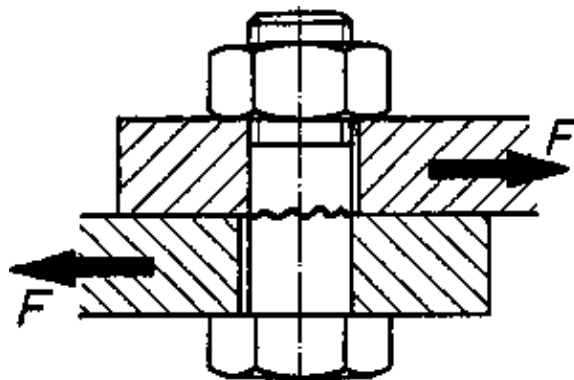
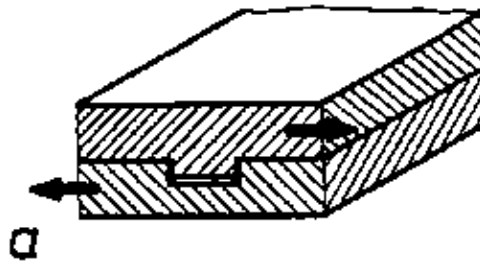


Figure 2/16 Shearing stress of a bolt fastening after the frictional resistance between the connected parts has been overcome.

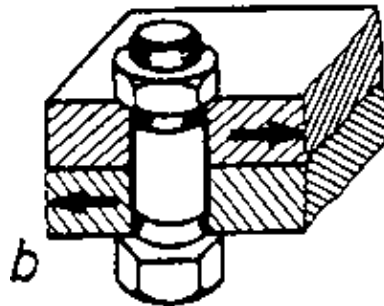
This means that the parts are no longer in the desired position. To remedy this problem one can use reamed bolts, dowel pins, clamp collars or slot and spring connections (fig. 2/17a to c). The seating surface of the bolt head must be at a right angle to the longitudinal axis of the bolt. If this is not the case the bolt will be exposed to a flexural strain (fig. 2/18). The tensile stress and the flexural stress are super-imposed, ultimately leading to bolt breakage. That is why seating surfaces must always be machined with the utmost care to ensure that they are in a perfect right angle to the hole. Where this is not possible for some reason or other, the angle

error has to be compensated by washers of corresponding inclination (fig. 2/19).

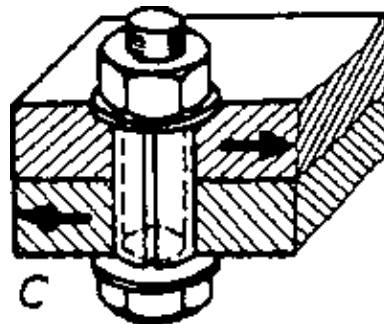
Figure 2/17 Constructional measures to counteract shearing stress on a bolt fastening.



a) groove with hem flange;



b) reamed bolt;



c) clamp collar

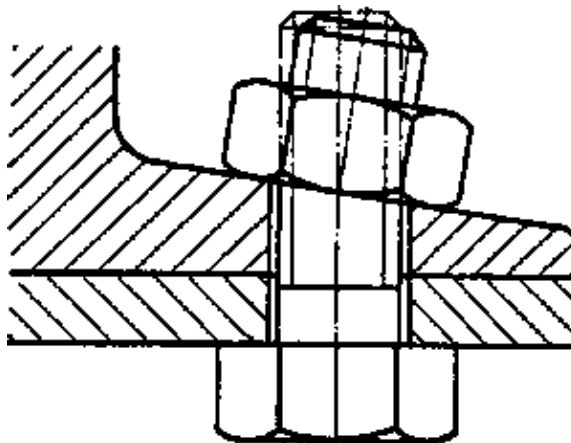


Figure 2/18 Flexural strain of a bolt

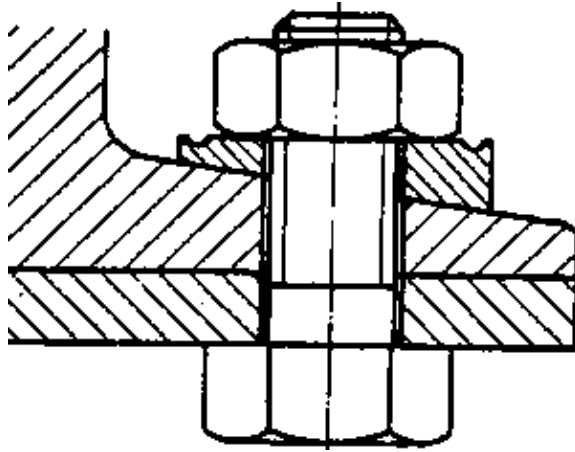


Figure 2/19 Inclined washer to compensate 1 inclined washer

2.2.3. Types

A difference is made between the directly screwed joint and the indirectly bolted joint.

Directly Screwed Joint

Threads are often cut into pipe ends so that they can be directly screwed together (see fig. 2/14). Such directly screwed joints are also frequently employed in fine-limit engineering and for the construction of optical instruments.

Indirectly Bolted Joints

Standardized bolts and nuts with differing threads and bolt heads, as well as with differing thread lengths and thread diameters, are used to produce indirectly bolted joints. The designer selects the bolt and nut that are best suited for the given application. The joint must be easy to secure and loosen.

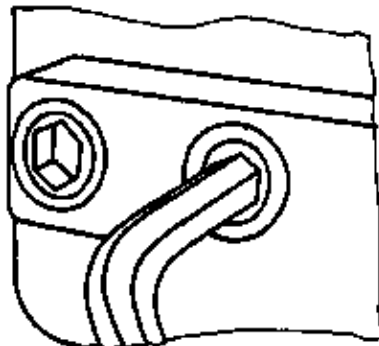
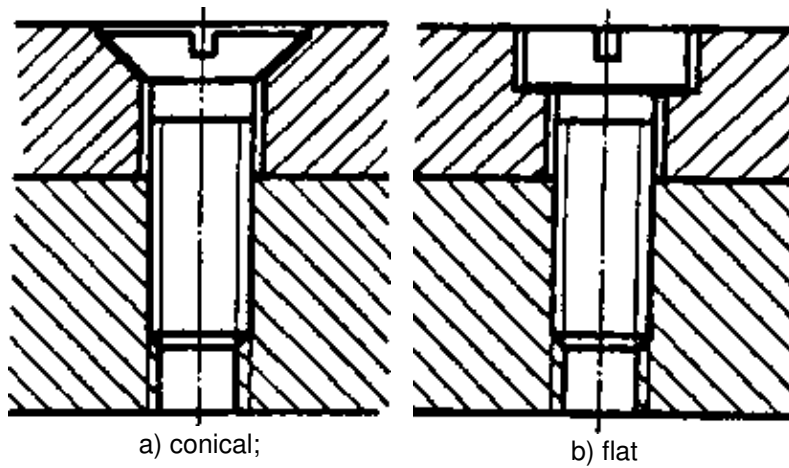


Figure 2/20 Bolt fastening with hexagon socket head

Simple hexagon-head bolts are often employed. If the joint does not provide sufficient space for the use of a spanner, or if bolt heads have to be countersunk, bolts with a hexagon socket head (fig. 2/20) are used.

For reasons of labour safety, bolts that have to secure rotating or moving machine parts are usually countersunk.

Figure 2/21 Seating surface of bolt heads



The seating surface of the bolt head can be flat or conical (fig. 2/21). Bolted joints produced with flat-seated bolt heads allow previous compression of the parts before they are tightened. The extent to which this is possible is determined by the hole clearance, i.e. the difference between the shank diameter and the diameter of the hole. This means that the position of the parts can be precisely adjusted.

Conical seatings for countersunk bolts give the bolt head self-centering properties. The connected parts are forcibly brought into a certain position in relation to each other, depending upon which bolt is the first one to be tightened.

Bolt Locks

Bolt locks are employed when the bolted parts are subjected to oscillations or vibrations so that thread self-retention is no longer sufficient to assure reliable bolting. Bolted connections that are subjected to dynamic loads must be safeguarded by bolt locks so that they cannot loosen themselves (table 2/5).

Materials for Bolts and Nuts

The stress arising during operation determines the kind of material selected for the bolts and nuts. Bolts are made of steel when they have to absorb high stresses. The material has to be corrosion resistant if the bolt is exposed to a corroding medium. Bolts are made of brass when they have to conduct electricity. Wherever possible, the bolts and the parts that are to be bolted together should be made of the same material to prevent corrosion from galvanic action.

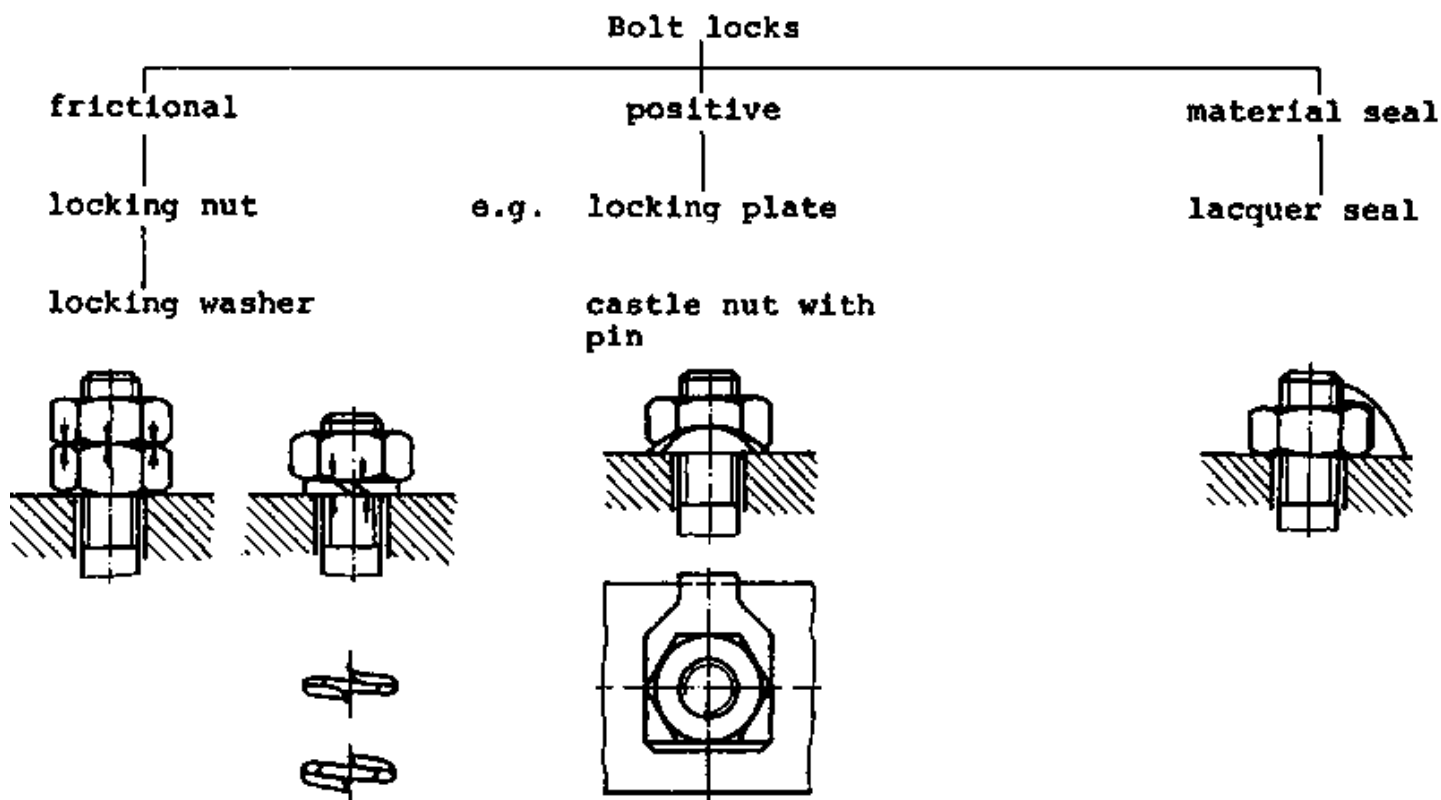


Table 2/5: Distinguishing Bolt Locks by Safeguarding Methods

2.2.4. Mounting Technology

Forms of Mounting

The movement of the bolt is a rotary and a translatory movement. There are three basic forms to produce screwed or bolted connections:

- Manually with a screwdriver for screws or with a spanner for bolts: the rotary and translatory motion is produced by manual effort.
- Mechanized mounting: the rotary motion is produced by a rotary spanner, while the translatory motion is produced manually. Bolt feeding can be automatic.
- Automatic mounting: both the rotary movement and the translatory movement, as well as bolts and parts feeding, are automatic.

The first form is commonest in job production and in repair workshops. Mechanized mounting is widespread in serial manufacture and industrialized repair.

The following points must be observed to produce bolted joints in a minimum of time:

- The correct use of the right kind of tools
- A design that enhances efficient bolting
- An efficiently designed workplace

The mounting time must not be shortened at the expense of the quality of the bolted joint.

Figure 2/22 Blades of screwdrivers



a) for slotted screws;



b) for cross-point screws

Tools for Screwed and Bolted Joints

Hand Tools

Screwdrivers are used for slotted screws (fig. 2/22). The blade of the screwdriver must fit perfectly in the slot of the screw. The blade surfaces at the tip of the screwdriver must be parallel to the same extent as the depth of the slot. The width of the blade should be slightly less than the diameter of the screw head.

A blade that is too small will break.

Wedge-shaped blades will deform the slot in the screw head, thus making it impossible to tighten and loosen the screw with a screwdriver.

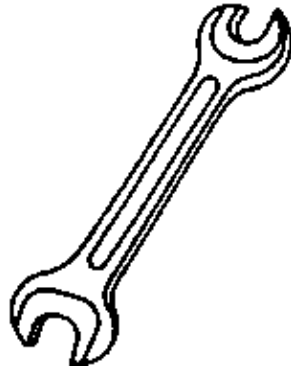
When working with a screwdriver, the left hand should not be in front of the blade when the hand is used to hold the workpiece. This is because the hand will be injured should the screwdriver slip.

The spiral ratchet screwdriver makes work much easier when smaller screws are secured. The exertion caused by the rotary movement of the hand is replaced by the axial movement of the spiral ratchet screwdriver. The screw is driven in right up to the point of head seating. Another screwdriver is used to tighten the screw. Up to 50% time can be saved in this manner.

Figure 2/23 Kinds of spanners



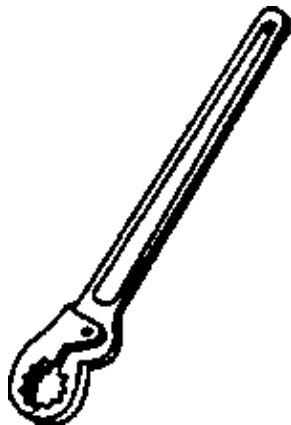
a) Single open-ended spanner with striking head;



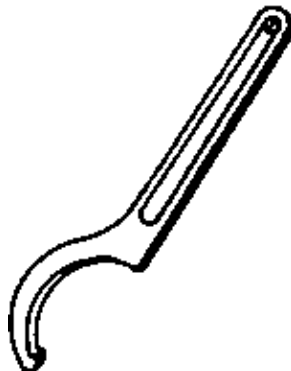
b) Double open-ended spanner;



c) double-offset ring spanner;



d) Adjustable spanner;



e) Hook spanner for fluted nuts;



f) Pin-type spanner;



g) Offset-handle spanner for hexagonal socket heads

Standardized spanners are used to tighten and release hexagon-head bolts and nuts (fig. 2/23). A higher torque can be exerted with standardized ring spanners than with open-ended spanners.

Bolts and nuts must only be tightened with spanners of matching size. The length of standardized spanners is adapted to the thread diameter and to the average arm strength of a man in such a manner that the permissible shearing stress and surface compression are not exceeded. An average arm force of about 150 N is assumed for this purpose. That is why it is impermissible to lengthen spanners by slipping a section of pipe over them to increase their tightening force.

When several bolts of tight boltings for bearings and similar applications have to be tightened with the same tension, it will be unsafe to rely upon one's personal feeling for the measure of tightness. A torque wrench (fig. 2/24) is employed for this purpose. This is because it always applies the same torque. Hence, all bolts are tightened with the same initial stress. This presupposes, however, that the threads and bolt seats are all in the same condition and have the same lubrication.

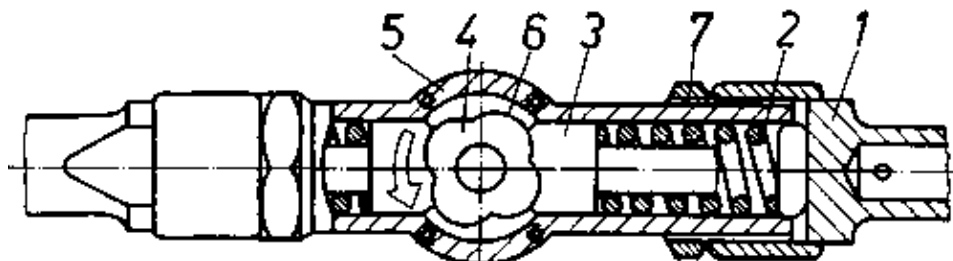


Figure 2/24 Adjustable torque wrench

1 handle; 2 compression spring; 3 pressure stamp; 4 cam core; 5 casing; 6 slide-off surface; 7 connecting thread.

There are two types of torque wrenches:

- Torque wrench with torque display
- Torque wrench with torque adjustment

Screwed or Bolted Joints

Fitting Simple Fastening Screws: Simple machine parts, cover plates and protective covers are often secured with screws. These screws are only subjected to the forces of self-load and the vibrations arising during use.

Simple screw fastenings involving several screws require the following jobs:

- The surfaces of the joint and the screw holes must be cleaned and deburred to remove all irregularities.
- Check the screw holes for matching position and, if necessary, align parts accordingly.
- Screws in the required dimension are lightly greased.
- The parts are fixed in the proper position with at least two screws and then precisely aligned.
- All the remaining screws are then screwed in.
- The screws are tightened in the prescribed sequence.
- The position of surface contact of the screw-fastened parts is checked.

Producing Bolted Joints with Initial Stress: Bolted joints with initial stress require bolts that can transmit the arising operating loads. Such joints must be secured with the utmost care because the reliability and operating worthiness of the product depends upon them. Their failure can endanger life and cause considerable damage.

Load-transmitting bolts must be tightened in such a manner that the tension remains within the range of elasticity of the bolt material.

The magnitude of the initial stress depends upon the following factors:

- Upon the torque which, in turn, depends upon the manner of work of the mechanic or upon the setting of the tools.
- Upon the surface quality and dimensional accuracy of the thread, and on the seating surface of nut and bolt head.
- Upon the lubrication of the thread.

Three situations may arise when tightening bolts:

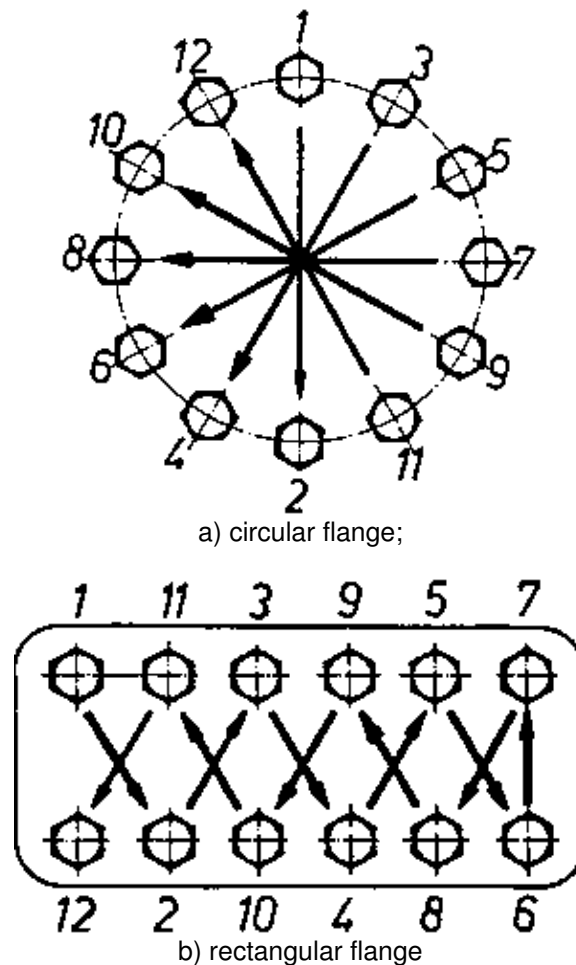
- The torque applied to tighten the bolt was not strong enough so that the initial stress of the bolt is insufficient.
- The correct torque was applied to tighten the bolt so that the maximum initial stress of the bolt is achieved.
- Excessive torque is applied so that the bolt is overturned when it is tightened or when the first operating load is applied, i.e. there is practically no initial stress.

Tight Bolting without Sealing Compound: The cover of a gearbox must be so tight that no oil can ooze out of, or dust get into, the gearbox. The use of sealing compound is inconvenient if the gearbox has to be opened frequently because the elastic packing will have to be renewed each time the gearbox is opened. The following jobs have to be completed when such surfaces are bolted together:

- Check the perfection of fit of the two parts, and refinish if this proves to be necessary.
- Mount all bolts and turn them in up to the point of the bolt heads.

- Gradually tighten the bolts in a suitable sequence during a series of successive operations (fig. 2/25).

Figure 2/25 Sequence of bolt tightening without sealing compound to produce a tight seal.



A pressure-tight seal at the dividing joint between two parts, e.g. gearwheel pumps, requires a very high quality and accuracy of the joint surface. The following jobs must be completed when such pressure-tight joints are bolted together:

- Check the mating accuracy of the pressure-tight surfaces, and complete refinishing and cleaning work should this prove to be necessary.
- Join the parts.
- Lubricate the thread and the bolt-head seal.
- Screw in the bolts manually.
- Tighten the bolts lightly to produce the initial seal.
- Tighten the bolts uniformly and in the required sequence to produce the final tight seal.
- Check the tightness of the seal by pressure testing.

Tight Bolting with Sealing Compound: A sealing compound or packing is employed when the joined parts are rarely disconnected, and when the mating surfaces of the seal are of poor quality (not absolutely smooth). Moisture-proofed electrical appliances are also provided with such a tight seal. The tight seal is produced by compression and deformation of the elastic packing (fig. 2/26). The load that compresses and deforms the packing is produced by the bolt stress. The kind of packing depends upon the operating conditions such as pressure, temperature, chemically aggressive or hazardous atmosphere, etc. The packing compound has to be selected in keeping with the intended application.

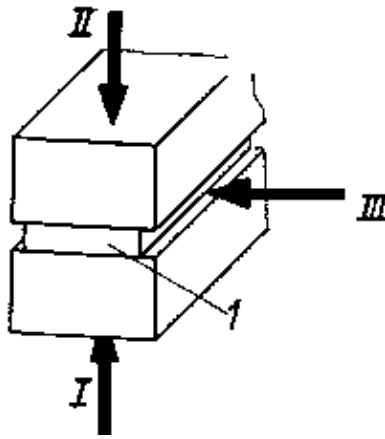


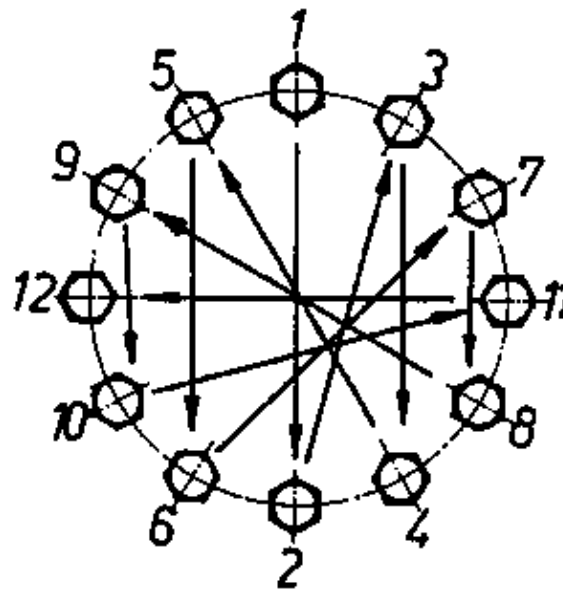
Figure 2/26 Sequence of bolt tightening with sealing compound

I, II bolt face; III operating pressure; 1 sealing compound.

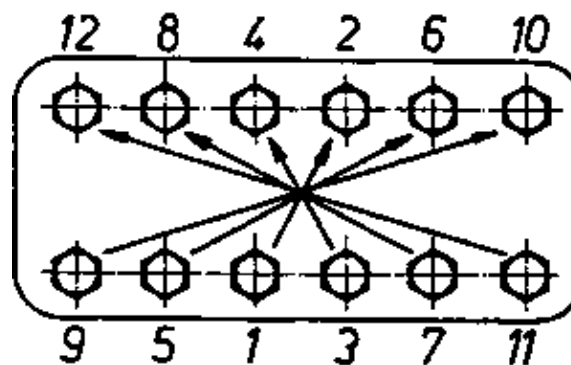
The incorporation of packing seals in bolted joints involves the following jobs:

- The surfaces of the sealing area must not be damaged.
- The mating surfaces must be brought into perfect parallel alignment with each other.
- Check the smoothness of the sealing surface.
- Carefully remove all traces of old packing,
- Insert the packing in such a manner that it cannot become buckled.
- Centre the packing precisely so that it does not protrude over the edges of the surface it is to seal; the shape of the packing must conform with that of the surface that is to be sealed.
- The packing must be cut true to dimension, and it must have sharply defined edges.
- Use the thinnest possible packings.
- It is impermissible to place several packings on top of each other.
- Packings should not be immersed in oil before they are applied; the required adhesion is obtained by applying graphite to the sealing surfaces.
- The packing must be in an immaculate condition.
- Mount the second mating part without damaging the packing or changing its centred position.
- Lubricate the thread and the bolt head seat with oil.
- Insert the bolts manually.
- Tighten the bolts gradually with the required torque and in the proper sequence (fig. 2/27a and b).
- Check the tightness of the seal by pressure testing.
- The bolts should be tightened once again after a brief operating period. This is because flat seals contain vulcanizing additives that are expelled in the presence of higher temperatures.
- Tighten the bolts with the required torque in the proper sequence (fig. 2/27a and b).

Figure 2/27 Sequence of bolt tightening with sealing compound to produce a tight seal.



a) circular flange;



b) rectangular flange

Leaking seals can be the result of any one of the following causes:

- Initial bolt stress is insufficient.
- Packing is either damaged or old.
- Initial stress of the bolts is not uniform.
- The packing is not smooth and not centred,

Locking Bolts and Nuts

Locking with lock nut: The first nut is tightened to give the secured parts the necessary initial stress. The lock nut is then screwed on while the first nut is held firmly in position with an open-end spanner. Tensioning relieves the first nut so that the stress is absorbed by the locking nut.

Locking with a locking plate: After the nut has been tightened the locking plate is bent upwards slightly with a screwdriver. The locking plate is then lightly tapped with a hammer until it is bent up against the nut.

Locking with castellated nut and split pin: The diameter of the split pin must match the diameter of the hole through the bolt. When the slots in the nut are brought into coincidence with the hole through the bolt, the nut must not be turned back again after it has been tightened.

Unscrewing Nuts and Bolts

Repair work involves dismantling jobs. The dismantling job must be completed in such a manner that the secured parts and the connecting elements can be used again.

Dismantling must proceed in the following sequence:

- Loosen all nuts and bolts.

- Unscrew the nuts and bolts entirely.

Corroded threaded joints should be treated with a rust removing agent. The bolts and nuts can be easily unscrewed after the agent has been allowed to act for a while on the corroded part.

Questions:

1. Explain non-positive locking of bolted joints with lock nuts.
2. Why do two spanners have to be used when a lock nut is being tightened?
3. Why should thread and bolt-head seat be lightly greased before they are screwed together?
4. Why is it impermissible to extend the length of standardized spanners by a section of pipe when tightening nuts and bolts?

2.3. Pin Connections

Pins can be used to mount wheels, levers or cranks on shafts, or to link rotating machine parts. The notched nail is a special type of pin that is used to fit type plates on motors.

2.3.1. Design

Pin connections are produced by driving cylindrical or conical pins into the holes of the parts that are to be thus secured. The shape of the pin prevents a vertical shift in relation to the longitudinal axis of the pin when forces are applied (fig. 2/28). The pin is firmly held in the hole due to the fact that its diameter is slightly smaller than that of the hole.

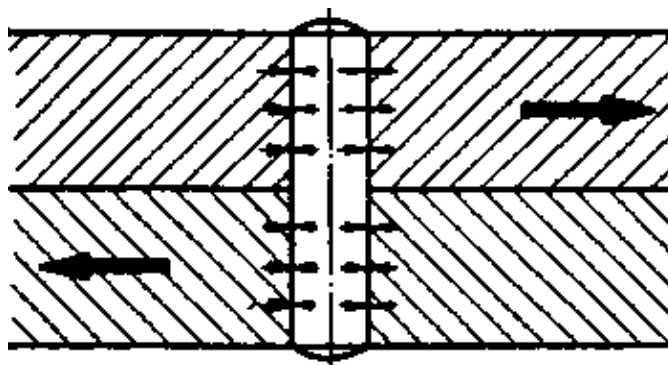


Figure 2/28 Preloaded positive pin connection

All pin connections can be disconnected at any time without destroying the parts. The material of which the pin is made of must always be harder than the material of the parts that are to be secured.

Pin connections are simple so that they can be economically produced.

2.3.2. Stresses

When forces are applied to the connected parts in a radial direction to the pin, then these forces will cause the walls of the hole to press against the surface of the pin, thereby producing what is known as surface or contact pressure. Shearing forces are created in the pin cross-section at the plane of the connecting surfaces (fig. 2/29). Excessive loads will break the pin. This phenomenon can be desirable when pins are used to protect components against excessive loads so that they cannot become damaged. Such pins are therefore known as shear pins.

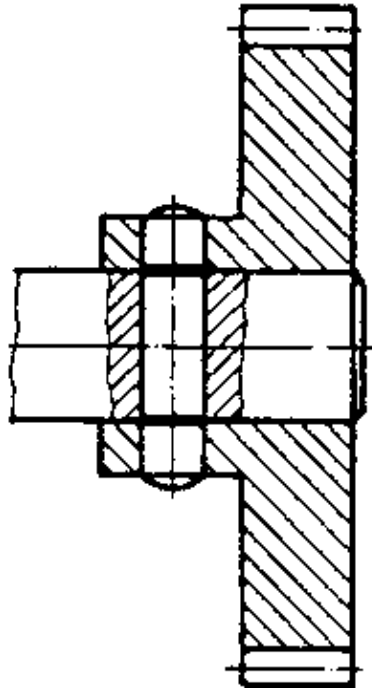


Figure 2/29 Pin that is subjected to shearing forces in two cross-sections

2.3.3. Types

Differentiation by Type of Pin (Table 2/6) **Cylindrical pins:** These tend to be expensive because an accurate fit is required to ensure a safe and firm seating. It can only be produced by reaming. Generally speaking, cylindrical pins can only be used once because secure seating is no longer assured after they have been removed. Thus, the hole in the component concerned has to be bored to the next larger diameter and then reamed. The application of the cylindrical pin is not an economical proposition when close tolerances have to be maintained.

Conical pins: Connections produced with conical pins can be easily disconnected and put together again with the same pins. The holes must also be progressively bored and then reamed. Conical pin connections are not vibration proof so that they can become loose on their own in the presence of vibrations, in spite of a conical ratio of 1 in 50.

Notched pins: Three notches offset by 120 are rolled into the pin. The material displaced out of the notches produces bulges at the edges. This gives the pin its hold in the hole which only has to be produced with a twist drill. The uniformly distributed notches give the pin its self-centring properties. Notched pins can be reused up to 20 times.

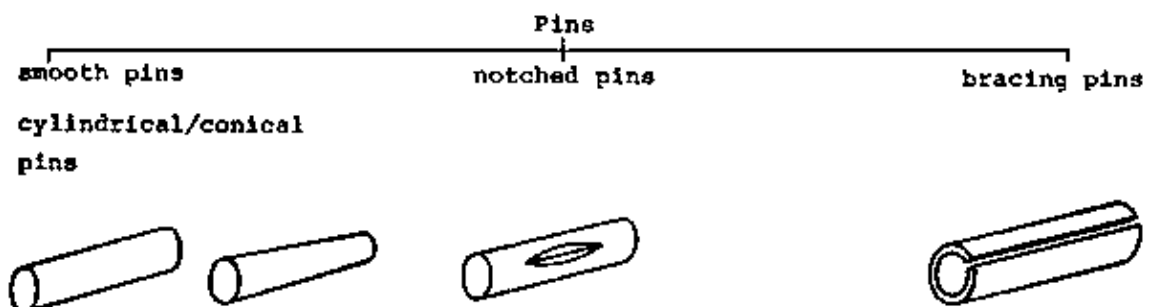


Table 2/6: Types of Pins

Notched nails: These are an economical alternative to screw joints. For instance, a contact spring is mounted in much less time with notched nails than with screws (fig. 2/30).

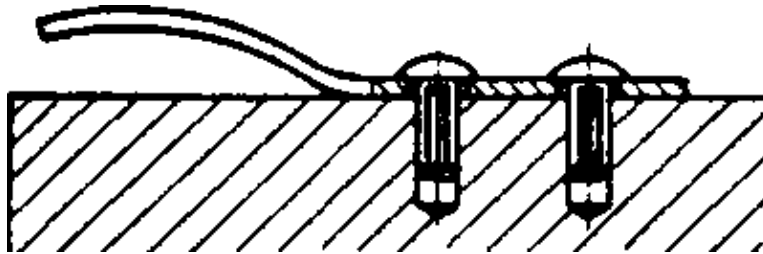
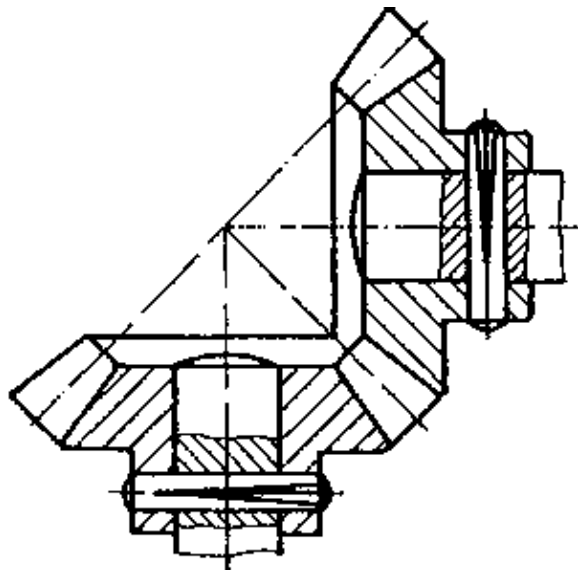
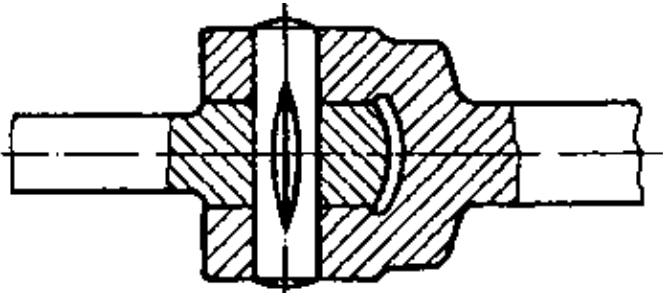
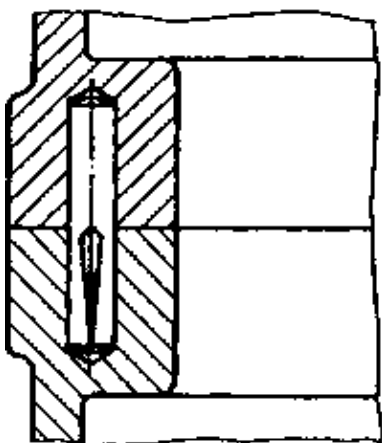


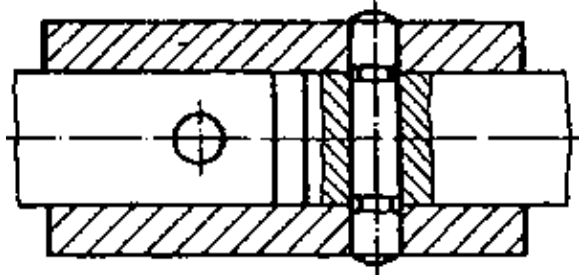
Figure 2/30 Notched nail connection for a contact spring

Bracing pins: These are longitudinally slit sleeves made of spring steel. They can be driven into holes produced by a twist drill, i.e. the tolerance can be large.

Differentiation by the Purpose of the Pins

Table 2/7: Purpose of Pin Connections

Purpose	Designation	Illus.
Mounting two parts by transition fit, e.g. to mount gearwheels or disks on shafts when only small torques are involved; grease-drawn pins in press-fit holes	Connecting pins	
Employed for pivoted or rotating connection of two parts in place of articulated riveting on tools or machines; the pin has a fixed seat in one part, and a loose fit in the other part.	Wrist pins	
Two pins fix two parts in a precise position in relation to each other, also after the parts have been repeatedly dismantled and put together again. The ground pin has a fixed fit in one part, and a loose fit in the other. The spacing between the two pins should be as large as possible.	Dowel pins	

Used to safeguard machine parts against overload; for direct linkage of the parts or as a fracture safeguard in an overload coupling. Shear pins are often prenotched by a groove to establish the fracturing diameter.	Shear pins	
---	------------	--

2.3.4. Mounting Technology

Preparatory Jobs

The following jobs have to be completed in preparation of mounting:

- The individual parts must be carefully cleaned.
- The individual parts are accurately fitted together and matched in the proper position; clamping may be necessary.
- The hole for the pin is produced.
- The diameter of the hole for notched pins must be selected by the nominal diameter. Holes for bracing pins must have an undersize of between 0.1 and 0.2 mm. Holes for cylindrical pins must be produced oversized and then reamed to size. Holes for conical pins must be drilled in successive steps with a taper drill, and then reamed.
- The hole is deburred.
- All chippings are removed and the parts are cleaned.

Driving in the Pins

The following basic rules must be observed:

- The pin is lightly greased before it is driven in, and the hole is blown out with compressed air. The pin is driven into the hole from the same side as the hole was drilled.
- Care must be taken to ensure that the pin is driven into the hole in a perfectly vertical position. Obliquely driven pins become bent so that they will be permanently jammed (compressed) in the hole.
- The pin is driven in by vertical tapping on the head to prevent pin bending or distortion. The weight of the hammer must match the size of the pin.
- Conical pins must be driven in with the utmost care. Excessive driving forces can create harmful stresses within the components.

Questions:

1. What happens when the shearing force within the pin cross-section becomes too large?
2. Why do the holes have to be deburred before the pin is driven in?
3. Why does the material of the pin have to be harder than that of the workpiece?
4. What advantages do notched pins offer?
5. Why cannot cylindrical pins be used several times?

2.4. Feather and Splined Connections

Feathers and splines are used as connecting elements on machines when the gearwheels or belt pulleys must run with precise centricity. If the wheels should be movable in axial direction on the shaft, a torsionally rigid connection between wheel and shaft can be established by feathers engaged in a groove. A single feather is unable to transmit higher torsional forces. This problem can be overcome by machining several grooves into the shaft. The remaining parts then take on the shape of the feathers. Shafts of such cross-section are known as splined shafts.

2.4.1. Design

Shafts and hubs are grooved for feather connections. The feather rests in the groove and carries along the individual parts mounted on the shaft (fig. 2/31). In this manner it transmits the torque from the shaft to the wheels, pulleys, couplings, levers, etc. The direction of power can be reversed. The feathers and shafts can be milled in a single piece (splined connection) for heavy-duty switchgear with alternating directions of rotation.

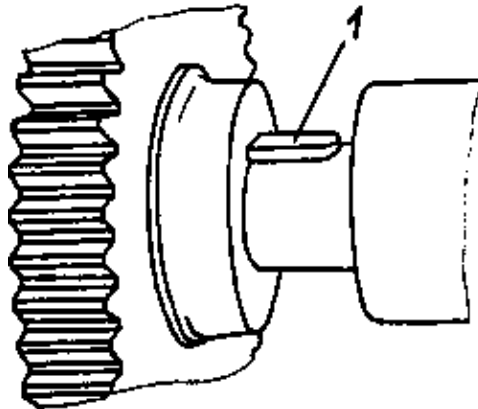


Figure 2/31 Feather assembly of gearwheel and shaft

Feathers and splined shafts produce a torsionally firm link with wheels and levers. That is why they are also known as driving links. The torque is only transmitted by the form of the feather.

Feathers are made of drawn flat steel. The interior profile is machined into the wheels by shaping or broaching machines,

2.4.2. Stresses

No forces act upon the feather connection when it is in a rest state. The operating state produces shearing forces and surface pressures on the feather.

The shearing force can be equated with the force prevailing at the circumference of the shaft. This circumferential force acts as a shearing force on the longitudinal section surface of the feather.

Since feathers have little clearance in the groove, they are not well suited for rapidly changing directions of rotation. But they will withstand alternating loads without shocks if the transmission gear of the machine is only switched when it is standing still.

2.4.3. Types

Feathers are distinguished by their shape and function (tables 2/8 and 2/9).

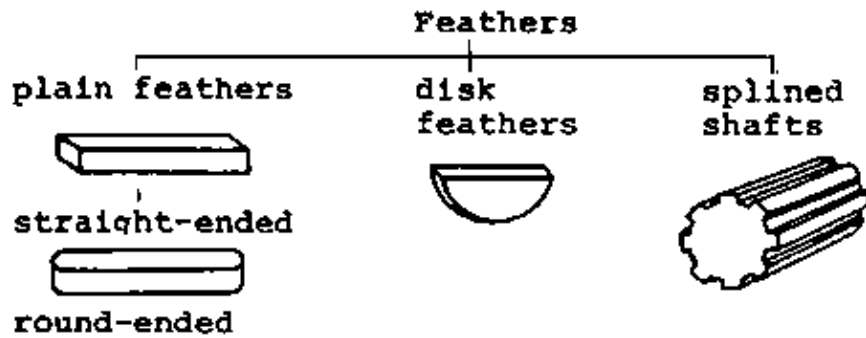


Table 2/8: Classifying Feathers by their Shape

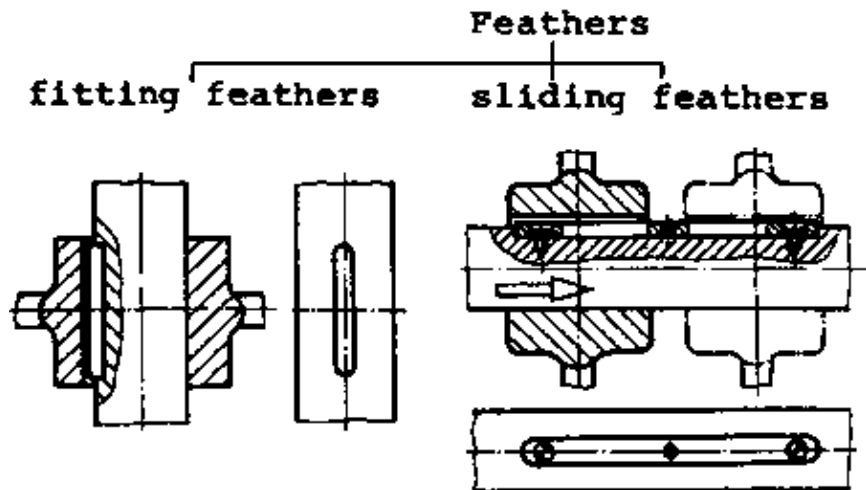


Table 2/9: Classifying Feathers by their Function

2.4.4. Mounting Technology

Checking Geometric, Dimensional and Positional Accuracy

Two fits are simultaneously mounted. Both are previously checked individually.

- Match cylindrical fit of shaft/hub hole
- Match the fit of the feather/shaft groove and feather hub groove

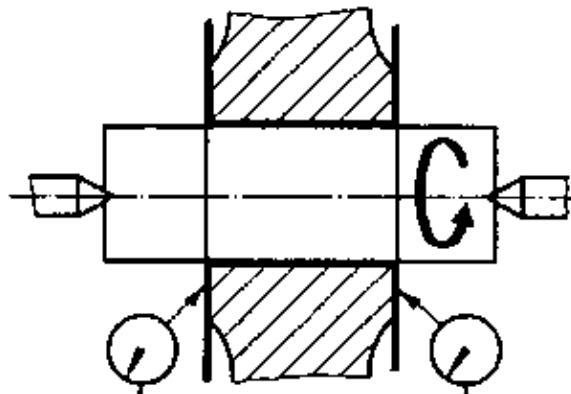


Figure 2/32 Checking face running trueness

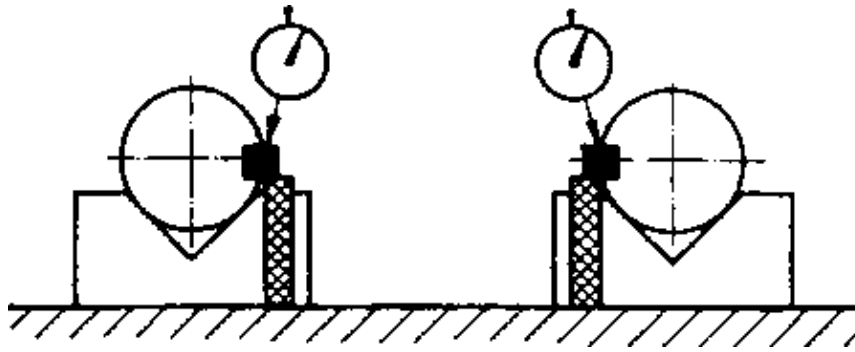


Figure 2/33 Establishing centricity and axle parallelity of shaft groove

- Establish angularity of the hub contact surfaces with the hub hole (face running trueness) (fig. 2/32)
- Establish centricity and axle parallelity of shaft groove (fig. 2/33)
- Establish dimensional and geometric accuracy of the feather

Trial Mounting of the Parts

It is wise to test the fits individually. First of all the cylindrical fit is checked without feather. In this context it is necessary to establish that the shaft collar and hub contact surface are not tilted.

The fit of the feather in the shaft groove and hub groove is then tested. Feather assemblies can cause a lot of work and can be very time-consuming when high demands are expected of accuracy. The feather must fit perfectly in the groove. It cannot be tapped in with a hammer because of the danger of tilt and deformation. This means it has to be fitted in, a job that is nowadays partially mechanized.

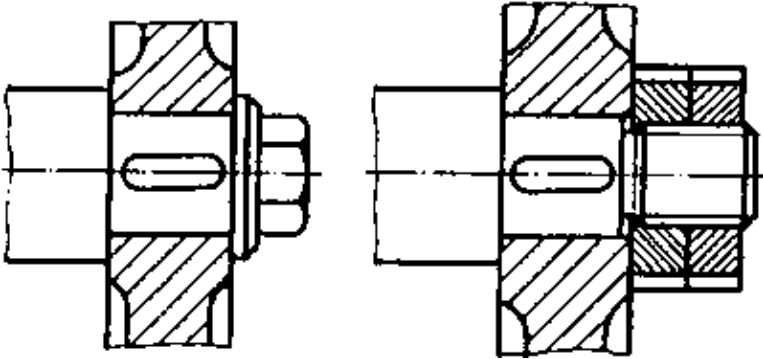
Final Mounting and Bracing of the Parts

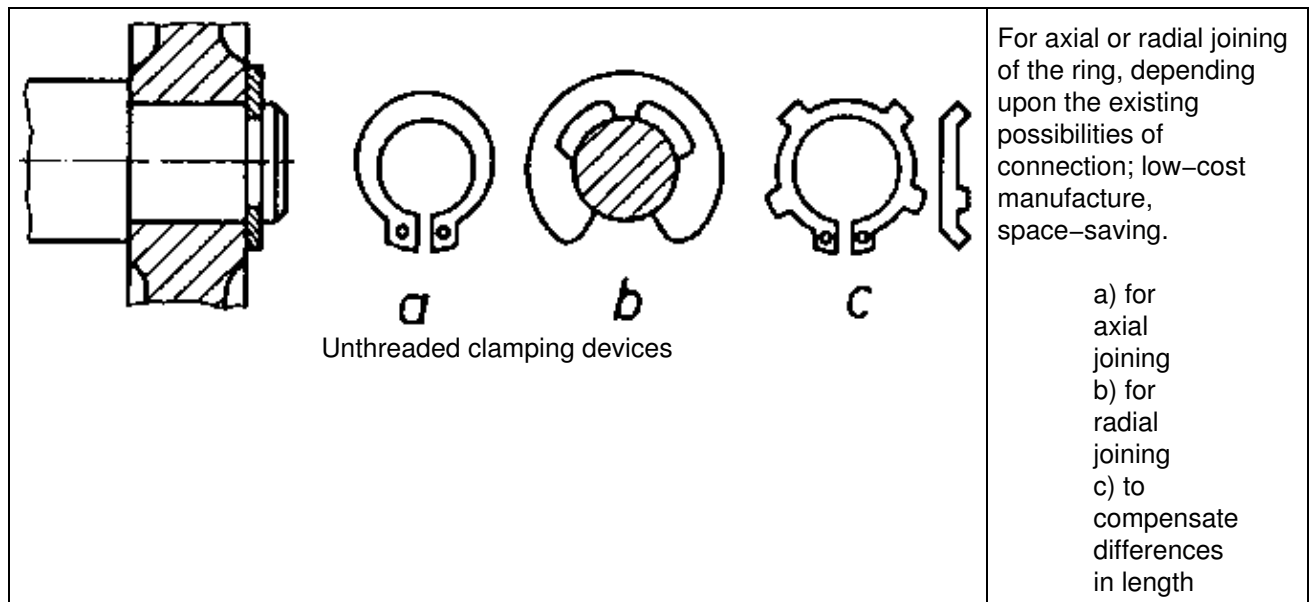
The previously described test fit is now followed by final mounting.

Make sure that the parts are not tilted when they are braced. Remaining burr and particles of dirt, as well as obliquely tightened screws, diminish the quality of the work.

Table 2/10 shows the components suited for bracing and locking.

Table 2/10: Bracing and Locking Components

Type	Remarks
 <p style="text-align: center;">Screwed joint</p>	<p>Suitable for higher stresses; work and cost intensive to cut the threads, and time-consuming to fit.</p>



Sliding feather: These are usually mounted and locked with fastening screws (fig. 2/34). The feather usually has a threaded hole in its centre so that it can be easily dismantled when a forcing screw is screwed into the hole.

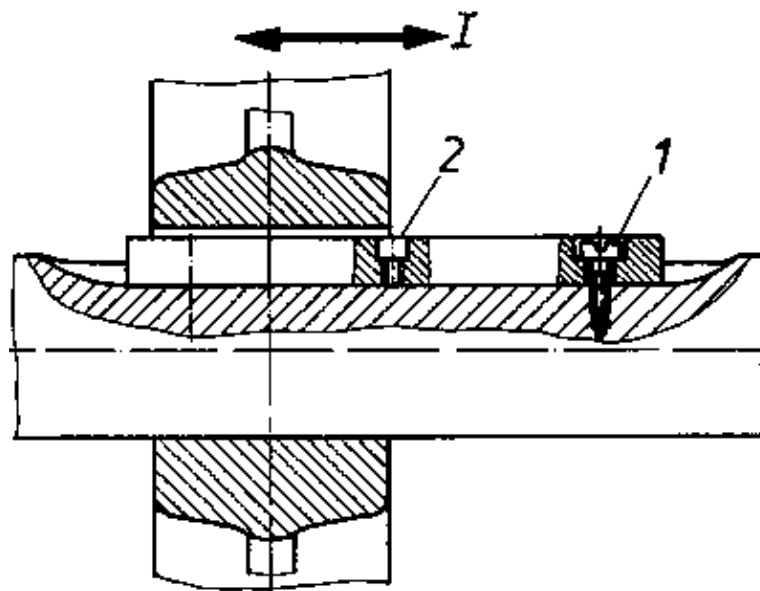


Figure 2/34 Sliding feather

1 retaining screw; 2 thread bore for forcing screw; I sliding direction of hub

Splined shafts: They require less mounting work than the feather and the sliding feather.

- The parts must be perfectly deburred and cleaned prior to mounting.
- The shafts must be examined for external damage, scratches or other faults to prevent jamming during operation.
- Due to the acute danger of tilting, the hub should not be pushed on to the shaft by blows with a hammer. The use of lifting gear is essential when heavy parts are involved.
- Check true running of the face of the hub.

Questions:

1. What are the advantages of splined shafts over shafts with sliding feathers?
2. Explain why feather connections are not suitable for alternating shock loads.

3. Compare the purpose of application of the spline and the sliding feather.
4. Compile the characteristics by which splines and keys differ.
5. Compare the amount of work required to lock and tension bearings with the different means of fastening.

2.5. Resilient Spring Connections

An elastic or resilient connection is often required to link certain parts. This is particularly the case with road and rail vehicles where springs absorb the energy of shocks and jolts. The springs absorb these shocks, transmitting only part of the energy in a damped form to the vehicle frame. Springs are used to press the two halves of couplings together for smooth, jolt-free transmission of the torque. A spring is used as a balance in clocks and watches to produce periodic oscillations or to develop the driving energy when it is wound up. Springs are used as measuring elements in instruments and weighers to produce the measured variables.

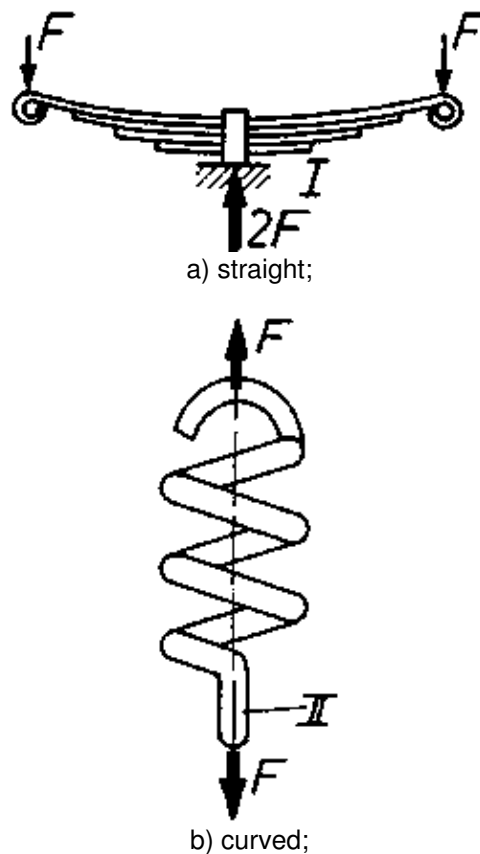
Springs store energy. They dampen shocks coming from moving parts of machines or vehicles, thereby protecting them from damage and overloads.

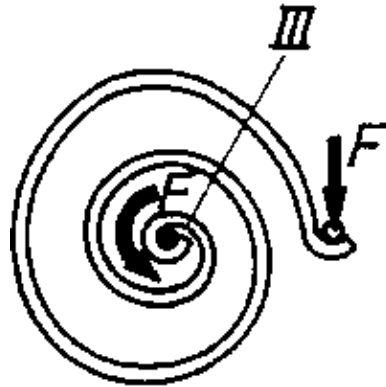
2.5.1. Design

Every spring, irrespective of its shape, requires two points of force application to be effective. These points can be eyes or plane surfaces acting as abutment. The ends of springs can be tensioned or bedded in insulating or compressed materials. They are often mounted by soldering, tanging or by end hooking.

Springs may be straight or curved, and of helical design (fig. 2/35). They may have any cross-section, although round and rectangular ones are the customary ones. The change of length of the spring changes the tension within the spring material.

Figure 2/35 Different feather forms





c) helical;

I, II, III abutments

2.5.2. Stresses

Depending upon the form and direction of the point of force application, springs will absorb flexure, tension, pressure and torsional forces. The size and shape of the spring depends upon its intended application, the required spring force, the spring length, and the amount of space available for the installation of the spring. The maximum force to which any type of spring is exposed must always be within the elastic range of tension of the spring material. The permissible strains for springs subject to oscillating loads and for thick springs are lower than for thin springs or for springs that are statically loaded.

2.5.3. Types

Springs are distinguished by the kind of material they are made of. Hence:

- Steel springs and springs made of non-ferrous metal
- Rubber springs
- Air-cushion springs

Table 2/11 shows a few elastic metal springs.

2.5.4. Mounting Technology

Flat-nose pliers, tweezers and spring hooks will usually be sufficient to fit low-tension springs. For stronger springs, however, it will be necessary to use jacks and fixtures to generate the necessary spring tension.

Care must be taken that the surface of the spring is not damaged when it is mounted with the help of tools. Hand sweat can give rise to corrosion on the surface of the spring. Such surface damage is frequently the cause of spring breakage.

Mounting Leaf Springs

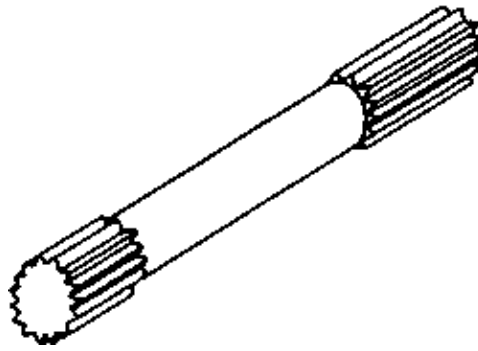
Simple leaf springs, as those used as contact springs in electrical appliances, often have to be aligned after they have been mounted. Flat-nose pliers should never be used for this purpose because the spring is not gripped with the entire jaw surface of the pliers. This may buckle the contact spring, and this will result in cracks. Special-purpose aligning tools are available for this job (fig. 2/36).

Table 2/11: Kinds of Resilient Metal Springs

Metal springs	
Flat springs	Torsion springs



– Leaf springs



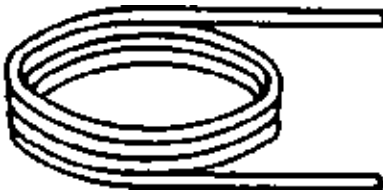
– Torsion-bar spring



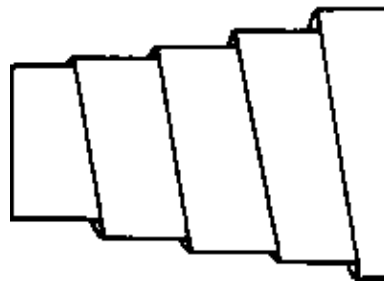
– Spiral spring



– Helical compression spring



– Straight-end torsion spring



– Volute spring

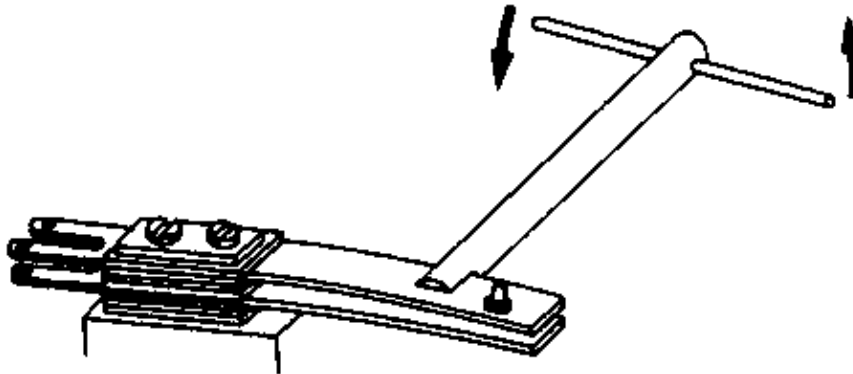
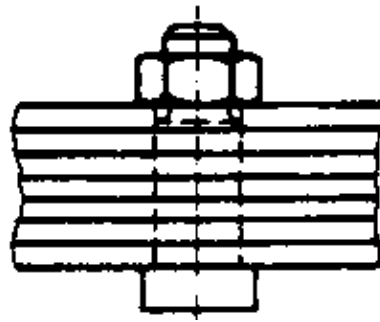


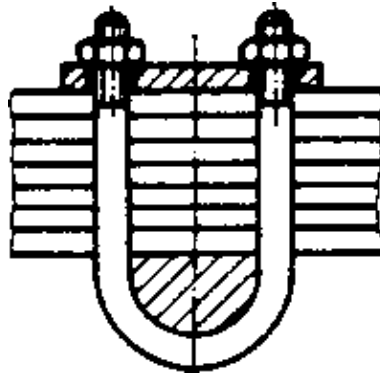
Figure 2/36 Straightening a contact spring with special aligning tool

Laminated leaf springs are compressed together in the centre by core bolts, spring bows and link plates, or by a spring strap with key (fig. 3/37).

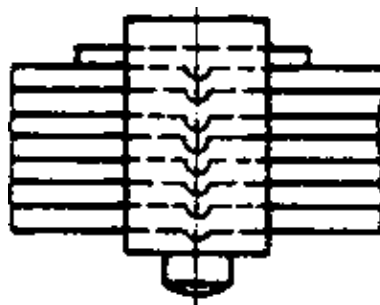
Figure 2/37 Different methods of joining leaf springs



a) core bolt;



b) spring bow and link plate;



c) spring strap and key

A fixture is required to compress the superimposed layers of leaf springs in order to produce a spring package. This requires considerable compression forces. A coating of graphite grease should be applied to the individual spring layers prior to tensioning. This impedes the ingress of water, thus preventing corrosion and diminishing the friction between the individual spring leaves. The remaining friction between the individual leaf-spring layers acts as the shock and vibration damping force.

The forces of initial stress created when leaf springs are mounted can be the cause of very serious accidents when these springs are being dismantled for repair work. All loads acting upon the spring must be completely counteracted by corresponding lifting tackle before dismantling commences.

Mounting Helical Springs

Helical tension springs have differently shaped eyes and hooks at their ends. These ends must be hooked in such a manner that they are not twisted when they are in their normal position (fig. 2/38).

Prior to the installation of a helical compression spring, care must be taken to ensure that the seat of the spring is at a perfect right angle to its axis. Fixtures are used to simplify spring compression when several springs have to be fitted simultaneously.

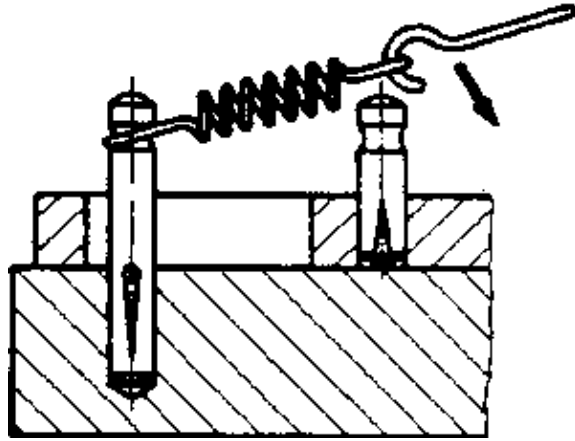


Figure 2/38 Mounting a helical tension spring with a spring hook

Helical springs must not be bent because such a bend will seriously diminish its service life.

Questions:

1. Quote examples of use of springs on machines or vehicles.
2. List the different forms of springs and assess whether friction arises in the springs.
3. Explain the consequences of inadequate lubrication of leaf springs.

2.6. Riveted Joints

Plates can be riveted together to produce large container tanks. The resulting joint is so tight that it cannot be penetrated by liquids or gases. Rivets are extensively used to join components in fine-limit engineering and instrument manufacture. Often rivets are formed as protrusions to make them an integral part of one of the assembled sections.

The outer skin of an airplane is attached by hundreds of thousands of rivets. The more economical process of welding is being employed on an increasing scale to mount sheet walls for rolling stock, and there are also other applications where welding is replacing riveting. Welded structures are between 15 and 20 per cent lighter than their riveted counterparts, and welding involves less technological expenditure.

Hollow rivets are employed to join plastic and metal parts. The forming pressure needed for such hollow rivets is so small that it is easily withstood by the plastic parts.

2.6.1. Design

Riveted joints are only employed where maintenance and repair jobs do not require the disconnection of this permanent joint.

Riveted joints can be disconnected only by destroying component parts or constructional sections.

The rivet keeps the parts together (fig. 2/39). The tensile stress in the shank of the rivet presses the joined parts together with immense force. Very high frictional resistance is created at the contact surfaces of the joined parts, excluding any relative displacement between the parts. If the tensile force acting transversely in relation to the rivet axis becomes higher than the frictional resistance between the joined parts, then these parts will be displaced, subjecting the rivet shank to a shearing action (fig. 2/40).

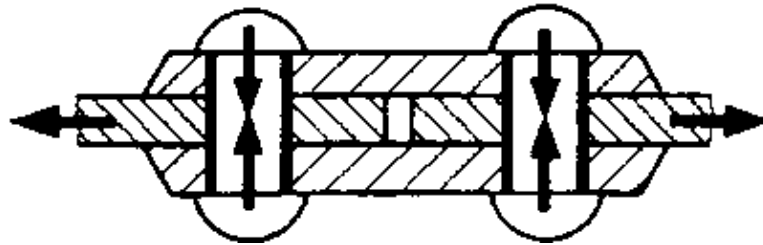


Figure 2/39 Forces prevailing at a riveted connection

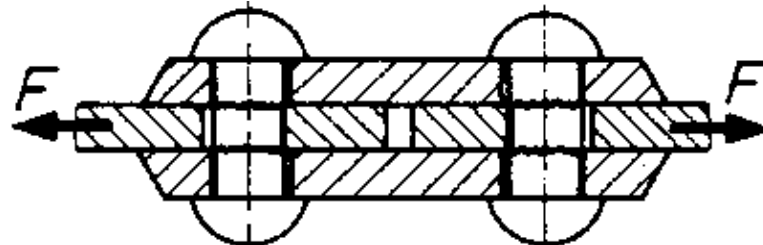


Figure 2/40 Start of shearing

The material of which the rivet is made of must be adequately strong for the job in hand, yet it must be well formable.

2.6.2. Stresses

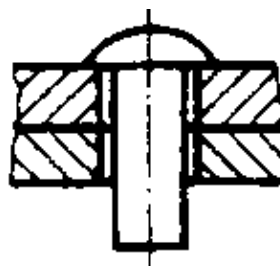
The operating forces acting on the seam are transmitted by the riveted joint. If the joint is produced by only a single rivet, then this single rivet has to take up the entire load. In most cases the forces arising in a riveted joint are transmitted by several rivets. The rivet shank is stressed on two shearing faces with double butt-strap riveted joints. This shows that such a joint can also withstand stronger forces.

2.6.3. Types

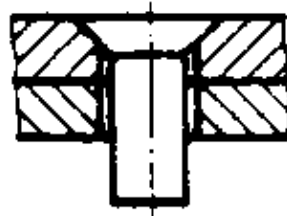
Riveted joints are distinguished by:

- The purpose of the riveted joint.
- The manner in which the riveted joint is produced, i.e. by manual, pneumatic hammer and machine riveting.
- The condition of the rivet during riveting, i.e. cold-formed riveting up to a rivet diameter of 9 mm, and hot-formed riveting from a rivet diameter of 10 mm upwards.
- The shape of the rivet (fig. 2/41).
- The arrangement of the rivet and the kind of joint (table 2/12).

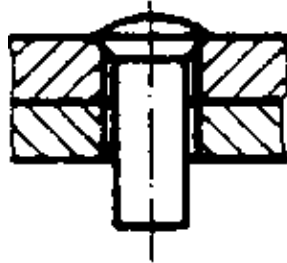
Figure 2/41 Types of rivets



a) round head;



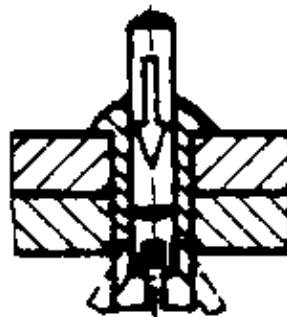
b) countersunk head;



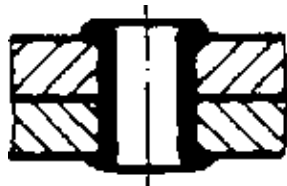
c) round countersunk head;



d) mushroom head;

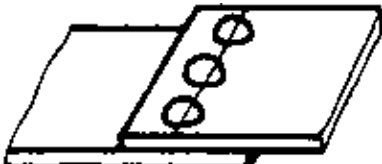




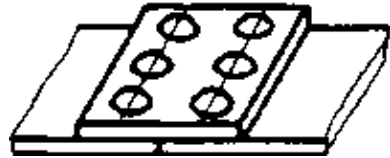



e) split rivet;



f) hollow rivet

Table 2/12: Arrangement of rivets and kinds of riveted joints

Arrangement of the rivets	
 <p>Single row</p>	 <p>Several rows</p>

	 Zig-zag	
	 Parallel	
Kinds of joints		
 Lap joint	 Butt joint	 Butt joint with double cover straps

2.6.4. Mounting Technology

Preparatory Jobs

The following preparatory jobs have to be completed to produce a riveted joint:

- The rivet hole is drilled through both parts jointly or it is punched with a corresponding cutting tool.
- Deburr the rivet holes.
- Countersink the hole for countersunk rivet heads.
- Secure the parts that are to be joined by a clamp dog or vice.
- Ream non-aligned holes with the rivet hole reamer; cut the rivet to the required length.

Rivet Head Shapes

Countersunk rivet head: The following operations are required to produce countersunk rivet heads:

- Insert rivet in the hole through both parts.
- Place countersunk head on matching head rest.

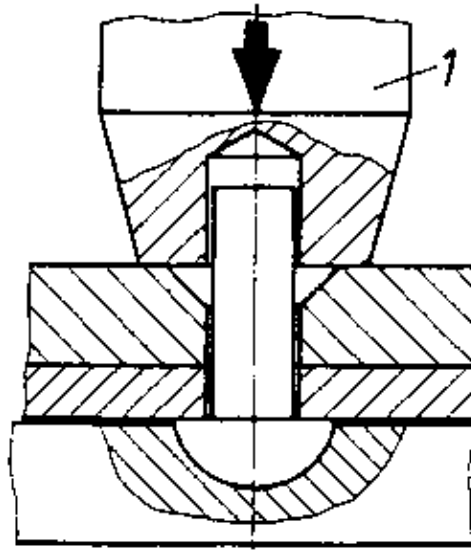


Figure 2/42 Setting

a rivet with a 'rivet set'
1 rivet set

- Compress the sheets with rivet set and by powerful blows with a hammer (fig. 2/42).
- Compress the rivet shank in its longitudinal axis by strong blows with a hammer (fig. 2/43).
- Continue compressing until the countersink is entirely filled in by the end of the rivet shank.

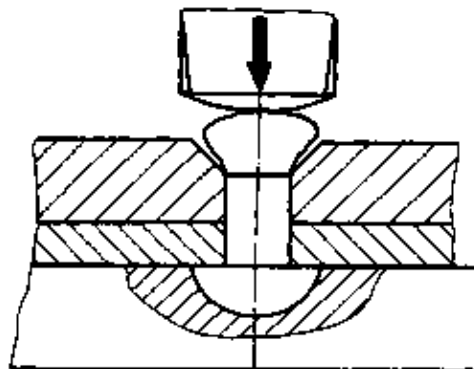


Figure 2/43 Upsetting the rivet shank 1 hammer

Button rivet head: The first stages are the same as for the countersunk head. After the shank has been compressed the head is preformed with the hammer face (fig. 2/44); its final shape is produced with a rivet header (figs. 2/45 and 2/46).

Riveting Methods

On account of its low productivity, manual riveting has all but been replaced by the far more productive method of riveting with pneumatic, electric and electromagnetic riveting hammers. Operating noise, however, is considerable.

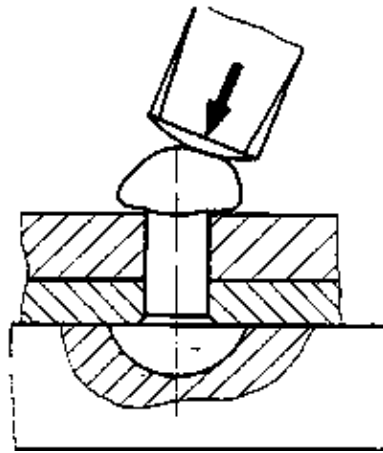


Figure 2/44 Preforming the rivet head

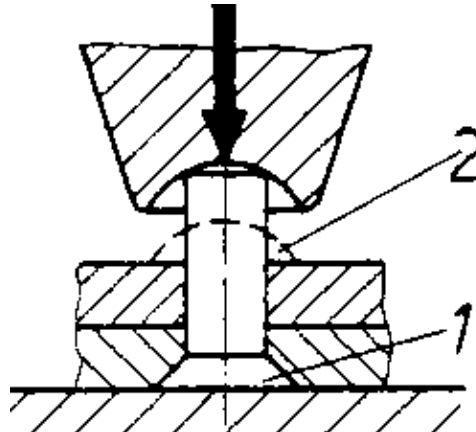


Figure 2/45 Final forming of the rivet head with the rivet header (direct riveting)

- 1 set head;
- 2 closing head

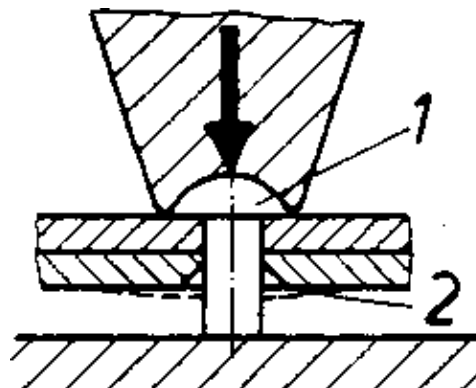


Figure 2/46 Final forming of the rivet head with the rivet header (indirect riveting)

- 1 set head;
- 2 closing head

Riveting presses, on the other hand, are nearly silent. They form the rivet heads slowly in a single continuous operation. The structure of the rivet material is more favourable for the durability of the rivet.

Questions:

1. Name the different kinds of rivets and forms of joints.
2. Describe the production of a countersunk riveted joint.
3. Which processes are superseding riveting?
4. How can riveted joints be disconnected?

2.7. Pressed Fits

The inner rings of anti-friction bearings are pressed on to shafts, while the outer rings are pressed into bearing housings. Wheel rims made of high-grade manganese steel for rolling stock are joined by pressure with the steel-cast wheel body, thus reducing the consumption of costly steel to a minimum.

To unite the leaves of laminated leaf springs into a package, the collar is heated so that a pressed fit is established by contraction of the material as it cools.

2.7.1. Design

Pressed fits are produced when two parts that are oversized in relation to each other are joined.

Pressed fits are force-closed joints.

Uniformly distributed forces arise at the fitting surface when the two parts are joined (fig. 2/47). A perfect pressed fit presupposes a material of adequate elastic behaviour. The hub is expanded while the material of the shaft is compressed in order to join shaft and hub. This produces a tensile stress in the hub and a compressive stress in the shaft. Compression levels out the negligible irregularities of surface roughness at the fit to about 6/10th of its original height (fig. 2/48).

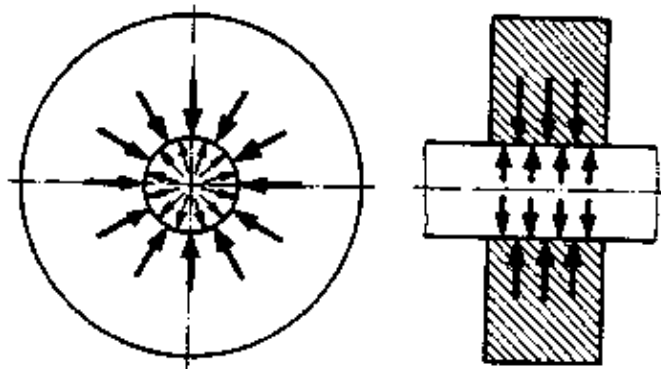


Figure 2/47 Distribution of forces at the fitted joint

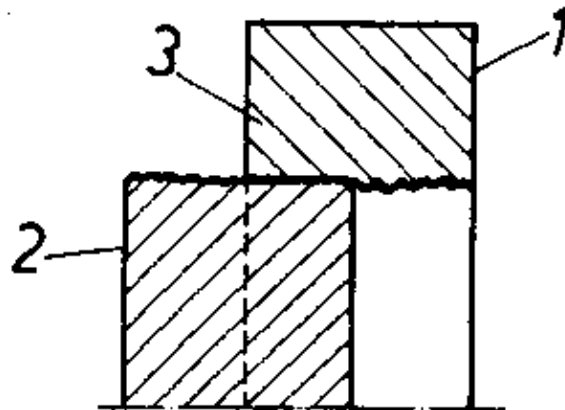


Figure 2/48 Surface smoothing by press fitting

1 hub; 2 shaft; 3 smoothing effect

Pressed fits create stresses in the joined parts which produce a frictional resistance in the fit that is so large that the two parts are firmly held together.

Pressed fits offer the following advantages:

- Costly materials are saved.
- Machining work is reduced.
- Connecting elements are saved and mounting work is reduced.
- Hub and shaft are not weakened by grooves.
- The notch effect is diminished.

2.7.2. Stresses

The magnitude of the pressing force and frictional resistance between the joined parts determines the forces that can be withstood by the pressed fit. Furthermore, it is also necessary to consider the kind of stress. For changing directions of rotation and shock loads the arising forces should be only half as much as otherwise possible.

A certain amount of force must be exerted to press a part into a hole. The necessary force will rise with increasing oversize allowance of the part in relation to the hole, and with the length of the part that has to be driven into the hole.

2.7.3. Types

A distinction is made between the shapes of the parts that are to be joined together.

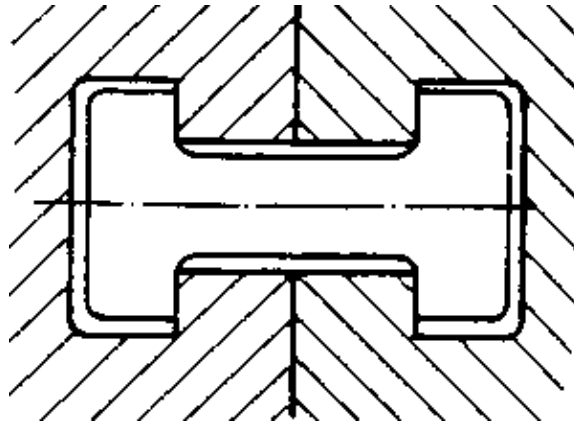


Figure 2/49 Anchor-shaped pressed fit

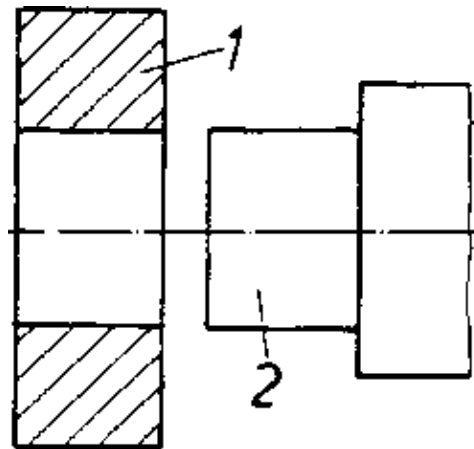


Figure 2/50 Circular-shaped pressed fit 1 ring or hub; 2 shaft

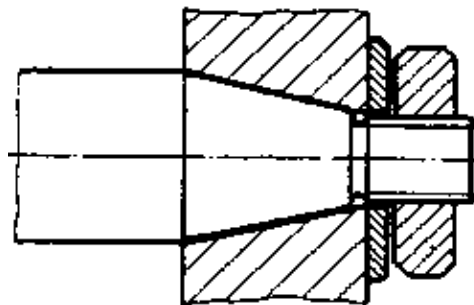


Figure 2/51 Conically -shaped pressed fit

Hence:

- Anchor-shaped pressed fits (fig. 2/49).
- Circular-shaped pressed fits (fig. 2/50).

- Conically-shaped pressed fits (fig. 2/51)

It is also possible to distinguish pressed fits by the manner in which they are produced (table 2/13).

Longitudinally Pressed Fits

The parts are joined by the action of axial forces at room temperature. Allowance is already present with cylindrical parts, or it is created with tapered parts by axial displacement.

Full adhesion strength is reached after about two days. This kind of fit includes also journals that have a profiled surface created by knurling and that is harder than the soft material around the hole into which they are forced (fig. 2/52).

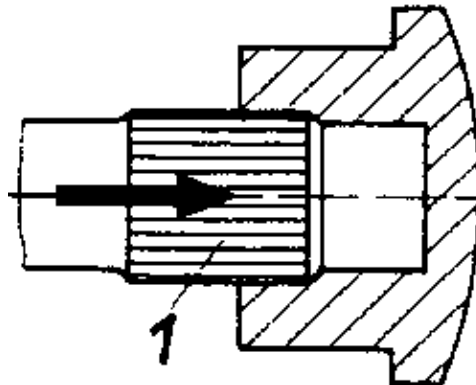


Figure 2/52 Pressed fit with knurled journal

1 knurling

Such a fit is advantageous because the hole is relatively easy to produce with a rough tolerance by a twist drill.

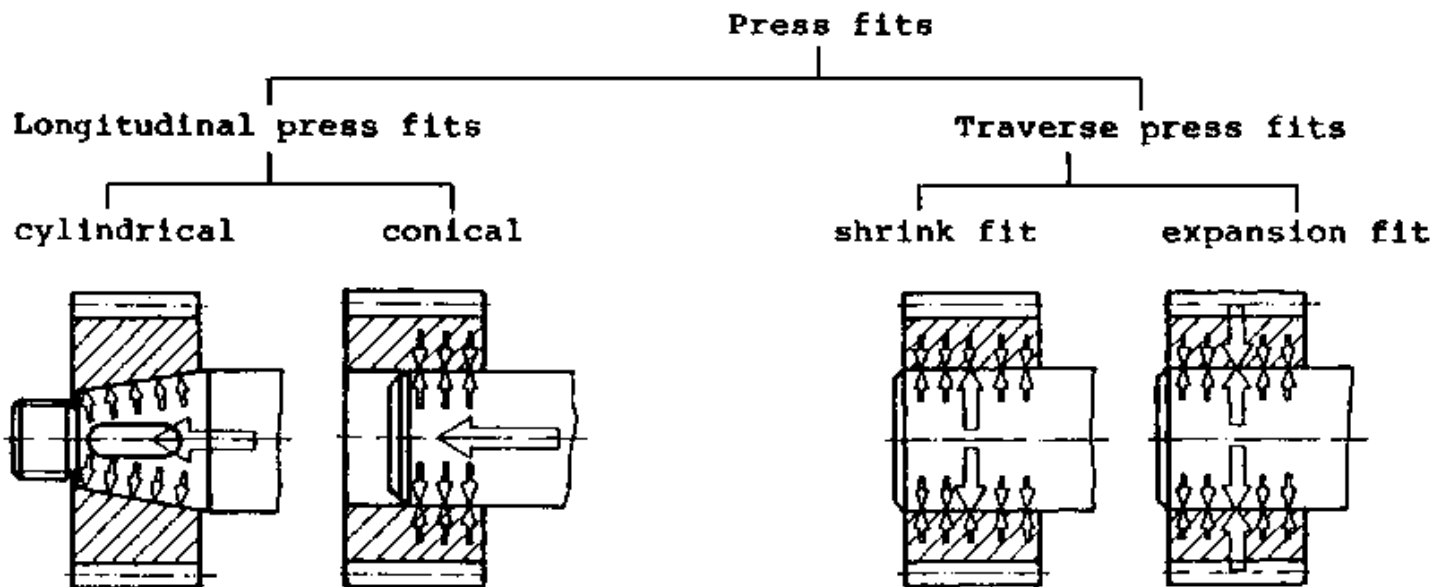


Table 2/13: Distinguishing Press Fits by Pressing Force

Transversely Pressed Joints

The allowance of transversely pressed fits is created during the actual process of joining. The oversize and transverse pressing forces are created by:

- Contraction of the previously heated outer part.
- Expansion of the previously under-cooled inner part (e.g. for hardened parts).

- Contraction and expansion to change the diameter of both parts as a result of heating and under-cooling.

Shrinkage fit: The transverse pressing action is the result of joint transformation. The hole of the part that is to be shrunk on is made with a small undersize; the part is hardened and brought to the final dimension by grinding. This dimension is selected in such a manner that the parts can be joined with only little pressure. The hub is then tempered, thus causing it to shrink by structure transformation.

The advantage of this joint is the possibility to adjust the parts with great accuracy before the fit is produced.

2.7.4. Mounting Technology

Producing Longitudinally Pressed Fits

The choice of tools to drive the parts in depends upon the amount of pressing force required and upon the size of the parts that are to be joined.

The following points must be observed in connection with longitudinally pressed fits:

- Inner and outer part must each have a chamfer of 5° or the inner part must have a chamfer of 10.
- The fitting surfaces must be cleaned with the utmost care.
- The driving force must be centrally and axially applied.
- Slow driving speed.

The driving forces can be generated by the following tools:

Hammer: Centric application of the force is hardly possible; the driving rate is not constant and cannot be controlled; only applicable for small parts and for a small number of pieces.

Presses or screws: The driving force can be generated manually, by an electric motor or hydraulically; portable tools for very large parts; the direction in which the force is applied and the driving speed can be controlled; the equipment can also be used for dismantling jobs.

Conically-shaped pressed fits: Similar to their longitudinal counterpart, they are produced by axial fitting. The allowance depends upon the extent to which the parts have to be axially shifted in relation to each other (fig. 2/53). Consequently, the force of adhesion of a conically-shaped pressed fit can be influenced by the size of the slip-over dimension. This dimension can be specified in the mounting drawing.

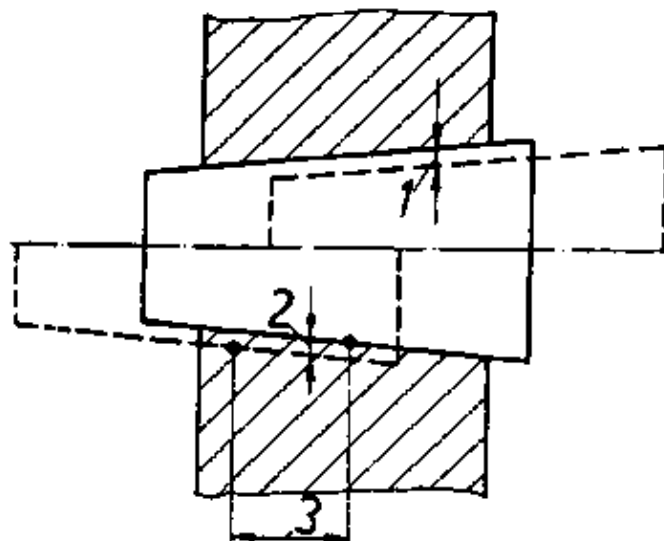


Figure 2/53 Producing a conical pressed fit

1 clearance; 2 oversize; 3 slip-over dimension

The most important criterion for adhesion force, however, is complete conformity of the taper angle and the accuracy of the shape of the fitting surfaces. Deviations will result in axial misalignment.

Producing Transversely Pressed Fits

Shrink fit: The outer part is heated, causing it to expand. This eliminates the allowance that existed when the part was cold so that the two can be easily joined. The outer part contracts as it cools, thereby shrinking on to the inner part. The two parts are then held together by the magnitude of initial allowance.

The forge fire, a circular burner, oil and salt baths, and a muffle furnace, can be used to heat the outer part.

The greater the oversize (allowance) of the shaft, the higher the temperature to which the outer part has to be heated, the greater the shrink tension, and the firmer the fit of the outer part.

After the parts have been mounted and aligned, the outer part has to be cooled rapidly by a current of cold air as otherwise the inserted inner part will also become heated. This will cause the outer part to remain expanded so that the fit will no longer be secure.

Table 2/14: Chilling Facilities and Chilling Media

Medium	Temperature
Deep-freezer	– 40 °C
Liquid carbon dioxide	– 78.5 °C
Liquid oxygen	– 183 °C
Liquid air	– 194.5 °C
Liquid nitrogen	– 195.8 °C

Expansion fit: This is preferred for smaller parts and only in exceptional cases for large workpieces. The chilling facilities must be selected according to the amount of allowance (table 2/14).

Due to the acute fire hazard resulting from the contact of oil with liquid air or liquid oxygen, special precautionary measures are necessary when working with these media.

Asbestos gloves must be worn when working with dry ice or liquid air.

Questions:

1. Explain why expansion fits and not shrink fits are employed for hardened parts.
2. Why are pressed fits only conditionally suited for parts that are subject to shock loads?

2.8. Adhesive-bonded Joints

Materials can be bonded together by adhesives. The parts that are to be joined can be made of any kind of material, even of differing materials. Metal parts can be joined by adhesives, but also metal with plastics, glass, porcelain, textile fabrics, etc. Proper execution of other joints and fits, such as riveting, welding, soldering, etc., requires extensive preparations and extra after-treatment operations. All this work can be eliminated by adhesive bonding. Adhesive bonding does not weaken the cross-section of the joined parts, as is the case with riveting, and it does not subject them to thermal influences as with welding and soldering.

Adhesive bonding is an economical method of joining light-weight components. In electrical engineering components made of widely differing materials are bonded with adhesives. Appropriate bridging can be employed if the insulating effect of the adhesive-bonded joint is not desirable. Adhesive bonding is ideally suited for thin materials and for differing materials.

2.8.1. Principle

The adhesive coated on the surfaces of the parts that are to be bonded solidifies in the bond after the parts have been joined, thereby establishing the joint.

Usually, the strength of the adhesive is lower than that of the bonded parts.

Whenever possible, only a thin coating of adhesive should be applied to the parts to keep the adhesive-bonded joint as thin as possible.

The effect of an adhesive-bonded joint depends upon the adhesion forces prevailing between two bodies. A distinction is made between two forms of adhesion.

Mechanical Adhesion

Mechanical adhesion prevails when the adhesive penetrates into the pores and irregularities of the surface of the material, thereby producing a mechanical anchor. The rougher the surface of the material, the better the mechanical adhesion (fig. 2/54).



Figure 2/54 Mechanical changes of the adhesive on the workplace surface

Specific Adhesion

The strength of adhesion between adhesive and base material is created by surface forces, i.e. by the forces prevailing between the adhesive and the material (fig. 2/55). The adhesiveness between the particles of the adhesive is effective within the adhesive-bonded joint. The adherent forces, however, should dominate. This is achieved by thin adhesive-bonded joints.



Figure 2/55 Specific adhesion of the adhesive

2.8.2. Stresses

The forces that can be transmitted by an adhesive-bonded joint depend upon the following main factors:

- The tensile strength of the adhesive
- The area of the bonding surface
- The direction of force application
- The plastic and elastic properties of the materials that are to be joined by adhesive bonding

Since the tensile strength of an adhesive is usually much lower than that of the bonded parts, adhesive-bonded joints should not be subjected to tension.

The forces acting upon the adhesive-bonded joint should be transmitted by the largest possible bonding surface to take the low strength of the adhesive into account. A large bonding surface is obtained by overlapping joints.

Shearing or peeling forces are particularly detrimental to the durability of an adhesive-bonded joint with thin materials (fig. 2/56). The forces become effective along a line having a relatively small surface. These shearing forces successively overcome the strength of the adhesive over the entire surface.

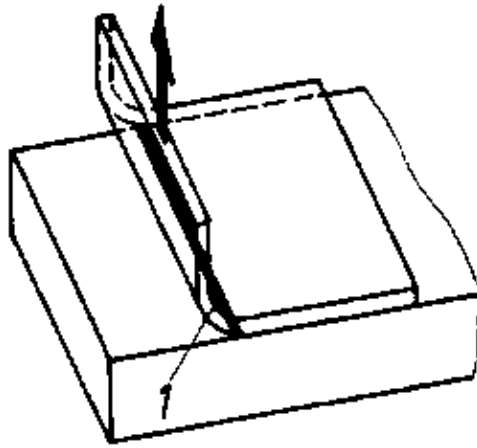


Figure 2/56 Linear stressing of the adhesive by peeling forces

1 line of attack of the peeling forces

Adhesive-bonded joints must be designed in such a manner that they are not exposed to shearing forces.

2.8.3. Types




Adhesive-bonded joints are usually classified by the manner in which the parts are joined together (table 2/15).



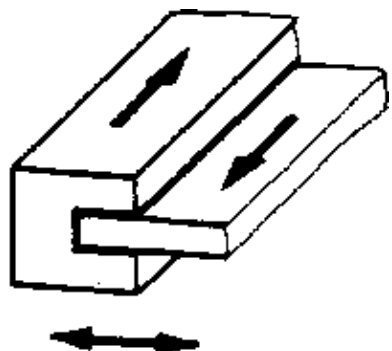
2.8.4. Bonding Technology

Epoxy resins are the most important adhesives for metal bonding. They are characterized by:

- High specific adhesion on metal and ceramic surfaces
- Resistant to water and solvents
- Resistant to corrosion and aging
- Good mechanical and elastic properties

Table 2/15: Common Adhesive Joints

Kind	Remarks
 <p>Butt joint</p>	Will only absorb pressure and thrust forces; simple to produce; for small forces.
 <p>Simple overlap joint</p>	Suitable for thrust forces in a single plane; simple to produce; eccentric action of force.
 <p>Stepped overlap joint</p>	Produces mainly shearing stresses, but only negligible tension stresses; work-intensive to produce, but it excludes eccentric distribution of forces; danger of peeling is negligible.

 <p>Oblique overlap joint</p>	<p>The forces that can be transmitted depend upon the length–height ratio; favourable ratio 8 in 1; work–intensive to produce.</p>
 <p>Butt joint with double covers</p>	<p>For shearing stresses in a single plane; simple to produce.</p>
 <p>Slot joint</p>	<p>Withstands tension, compression and thrust forces; work–intensive to produce.</p>

Many different kinds of materials can be adhesive bonded. It is of little consequence whether the parts that are to be joined are made of the same or differing materials provided that the suitable adhesive is employed for the given job.

A difference is made between hot–setting and cold–setting epoxy resins. The shearing strength of epoxy resins depends upon their setting temperature. The diagram shown in figure 2/57 gives a survey of the interdependencies.

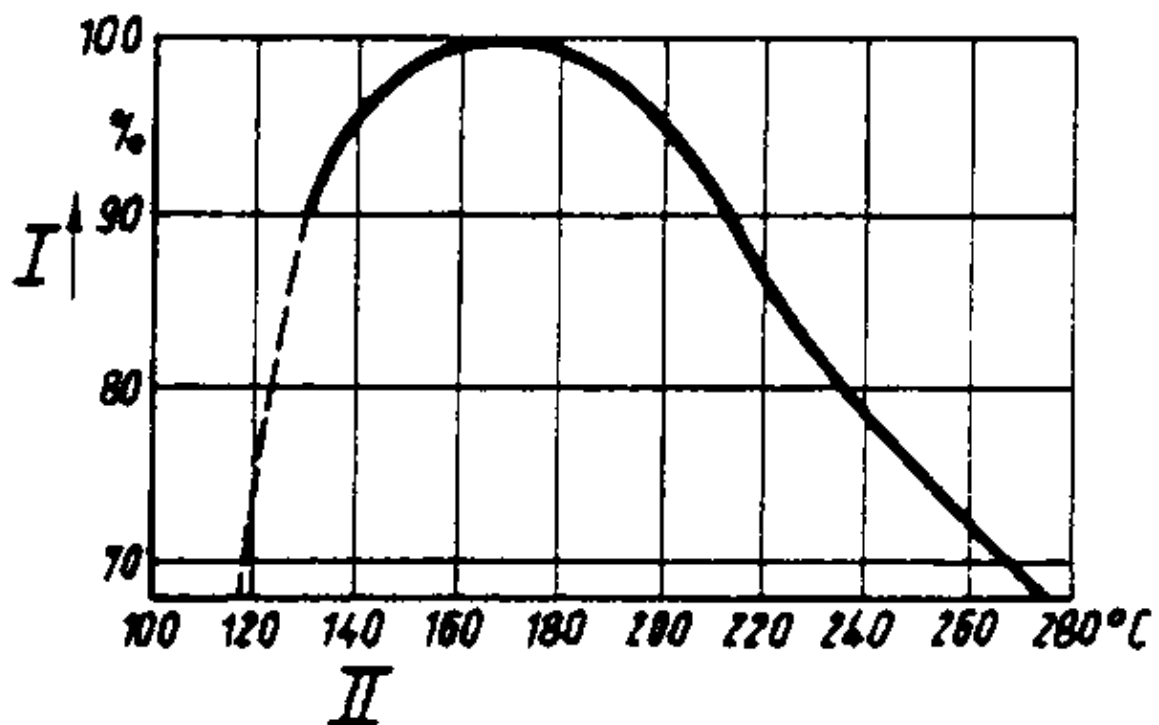


Figure 2/57 Dependency between shearing strength and setting temperature

I shearing strength in %; II setting temperature in C

Epoxy resins should be stored in a cool and dry place. The specified shelf life and instructions for use of the individual types of resin must be carefully observed.

The strength of the adhesive, and thus of the bond, is also influenced by the operating temperature.

The production of an adhesive–bonded joint entails the following jobs:

- Preparing the surfaces of the joint
- Preparing and applying the adhesive
- Joining the parts
- Adhesive setting

Preparing the Bonding Surfaces

Perfect durability of the bond is only achieved if the surfaces of the joint are well covered with adhesive. Impurities such as loose oxide layers, dirt, grease, oil and moisture will prevent complete coverage of the surface by the adhesive. Adhesive coverage is only active if its surface tension is low. The adhesive coating must not have any blank areas. That is why the following demand must be fulfilled:

The surfaces of the joint must be cleaned with a fat solvent. Provisions must be made for corresponding labour protection facilities (health hazard due to evaporating solvent!).

Furthermore, the bonding surfaces can be activated, i.e. the surface can be roughened chemically by pickling or mechanically by sand blasting. This process of surface roughening promotes adhesion.

The parts must be immediately adhesive–bonded after the parts have been prepared, The possibility of renewed contamination of the surface is thus avoided.

Preparing and Applying the Adhesive

The processing instructions for the given type of resin must be closely observed.

The shares of resin and hardener must be precisely matched and thoroughly mixed.

Heat is liberated when some types of resin are mixed. This means that cooling is essential when larger quantities of resins are being handled.

The adhesives are applied in differing forms – liquid, pasty, powdered or in the form of a film. These forms determine the manner in which they are applied.

Next to application with a brush or spatula, mechanical facilities are also available to apply adhesives (fig. 2/58 to 2/61).

Plane surfaces should be joined by a roll–down motion to prevent pockets of air from becoming trapped in the joint. After the parts have been brought together they should be held in the desired position by clamping facilities or presses.

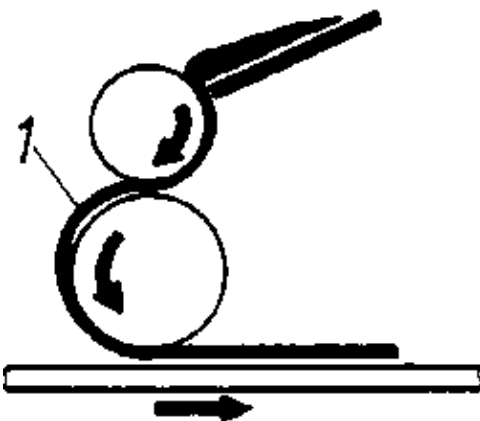


Figure 2/58 Roller application of adhesive

1 adhesive

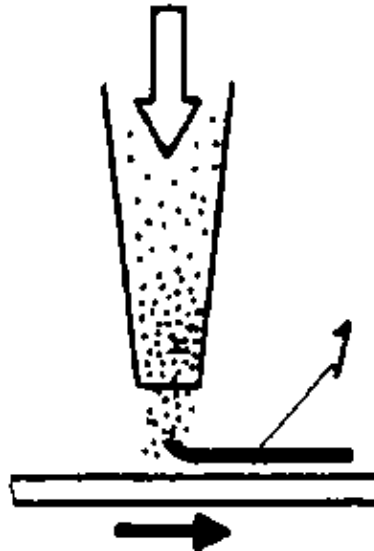


Figure 2/59 Spray application of adhesive

1 adhesive

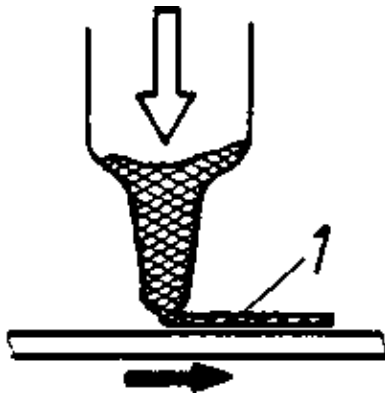


Figure 2/60 Nozzle application of adhesive

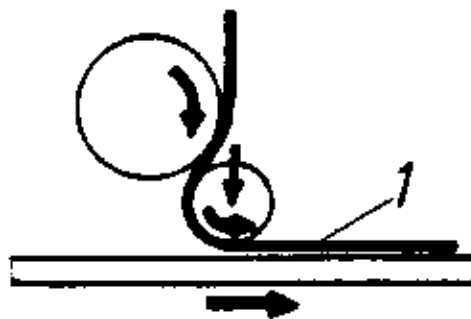


Figure 2/61 Foil application of adhesive

1 adhesive foil

1 adhesive

Adhesive Setting

Adhesives set in different ways:

- Setting by mechanical reaction, i.e. cold-setting and hot-setting
- Setting by evaporation of solvent

Cold-setting adhesives: These set at temperatures between 20 and 100 °C. Often, they achieve maximum strength only after six days. This means that suitable storage facilities must be available to shelve the newly bonded parts until the adhesive is fully set, and the parts must be held in the bonded position by suitable clamping devices.

Hot-setting adhesives: These set at temperatures between 100 and 200 °C. The clamping devices that keep the parts in the bonded position are often heatable so that they will supply the necessary heat. The setting time is shortened to between 20 minutes and a few hours.

Adhesives that set by the evaporation of solvents: They are coated on the two surfaces that are to be joined. The coated parts are then left open for a while until most of the solvent has evaporated. The parts are then pressed together in the desired position. Care must be taken to ensure that the bonding position is immediately achieved because subsequent corrections after the two parts have been brought together are practically impossible due to the adhesion of the bond.

Labour Safety

The following code of practice must be observed when handling adhesives:

When working with epoxy or polyester resins one should always wear rubber gloves, and an ointment that protects the skin should be previously applied to the hands. This is necessary to protect the skin from harm. The vapours of solvents and chemical reactions are a health hazard. Rooms in which adhesives are applied must be well ventilated.

Questions:

1. Describe the jobs that have to be completed to produce an adhesive–bonded joint.
2. List the advantages and disadvantages of cold–setting and hot–setting adhesives.
3. Which labour protective measures must be taken when handling epoxy resin and polyester resin adhesives?

3. Elements to Transmit Motions and Forces

3.1. Axles

Axles have the purpose of supporting rotating or oscillating machine parts. They are either rigidly fixed to other constructional assemblies (body, frame, enclosure, etc.), or they run in bearings.

Fixed axles are used, among others, on road vehicles, motorcycles or lifting gear. Rotating axles are fitted to rolling stock (see fig. 3/1).

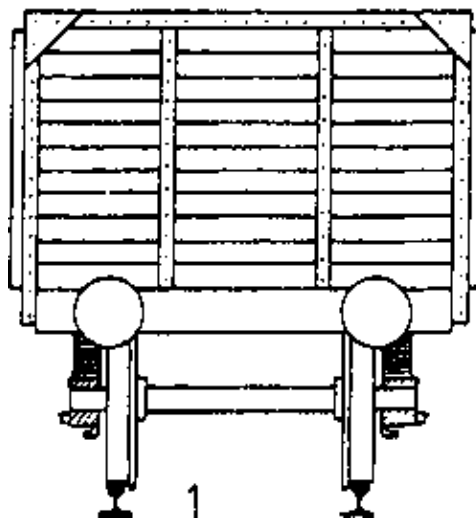


Figure 3/1 Axle of a railway waggon

1 rotating axle

Axles do not transmit torque. They are subject to bend and twist.

Stubs are short non–rotating axles. They are used to support intermediary wheels and levers at their fulcrums.

Axles are components that support machine parts and that are provided with appropriate bearing points to allow the rotation or oscillation of these machine parts. An axles does not transmit torque.

3.1.1. Design

A diversity of cross–sections are employed for axles. Usually, they are only circular at the points of bearing to enable the supported part to rotate or oscillate. This part is known as the axle journal (fig. 3/2).

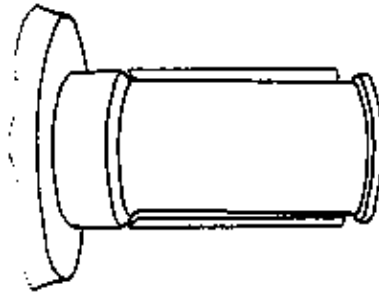


Figure 3/2 Axle journal with bearing shells of a plain bearing

Stubs are employed on many machines and devices. They are required in widely differing forms and in large numbers. Stubs are either smooth or they are provided with a collar.

They can have a threaded or a cotter-pin hole (fig. 3/3).

Axles are usually made of structural steel (ST 42 to St 70). They are often forged, while the running surfaces are refined by heat treatment to diminish wear because they run as journals in sliding bearings.

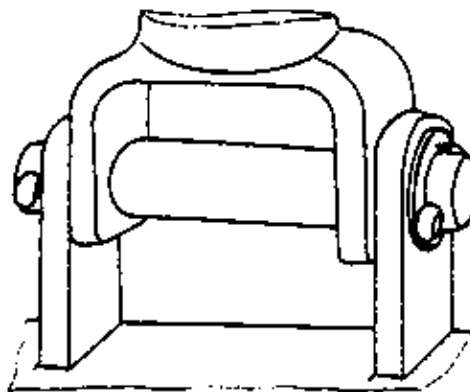


Figure 3/3 Cotter pin

3.1.2. Stresses

Axles exposed to flexural stress can be mounted at one end or both ends.

An axle journal can often be calculated as a beam mounted at one end (fig. 3/4). It withstands the flexural moment:

$$M_b = F \cdot l$$

where:

M_b = flexural moment

F = applied force

l = length of the lever arm

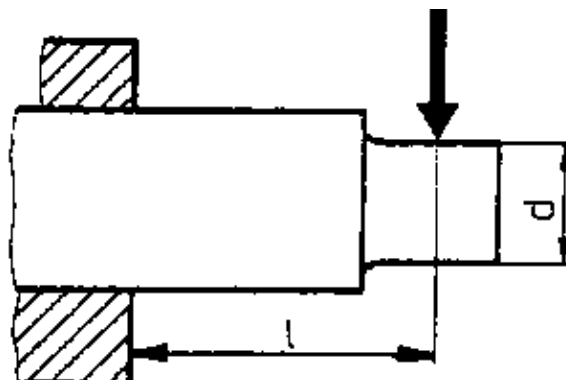


Figure 3/4 Flexural stress on an axle mounted at one end

F applied force; 1 length of lever arm; d diameter of journal

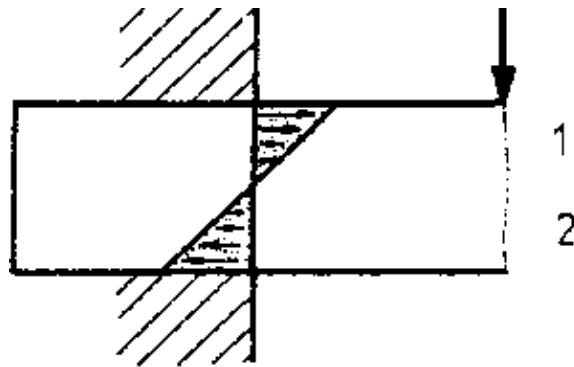


Figure 3/5 Distribution of stresses in the **axle** cross-section in the presence of flexural stress

1 tensile stress; 2 compression stress; F applied force.

The material of the journal cross-section must absorb the applied flexural moment without suffering permanent deformation. The stresses are distributed in the manner shown in figure 3/5, but not uniformly over the entire cross-section as with tensile and pressure loads.

Instead, the stresses are highest at the surface layers of the cross-section and null in the neutral plane. Consequently, the prevailing flexural stress does not only depend upon the absolute size of the cross-section, but also upon its shape and position. The journal is bent already by small loads. That is why journals are made as short and strong as possible. The ratio between length and diameter is between 0.4 and 2.0 The centre of the journal is considered to be in the point of force application.

3.1.3. Types

Axles are distinguished by their shape and load. A compilation of axles by shape is given in table 3/1. Load is differentiated by concentrated load and circumferential load (figs. 3/6 and 3/7).

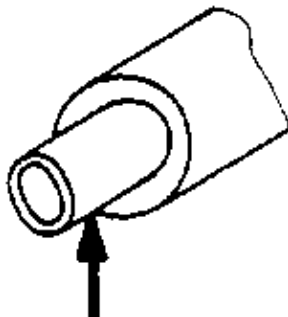


Figure 3/6 Fixed axle with concentrated load

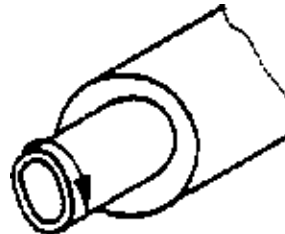
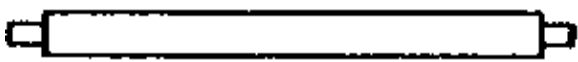
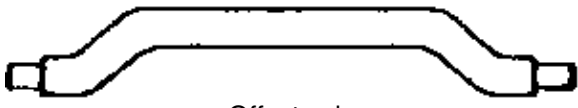





Figure 3/7 Rotating axle with circumferential load

Table 3/1: Distinguishing Axles by their Shape

Designation (illus.)	Remarks
Longitudinal shape	
 <p>Straight axle</p>	Simple to manufacture; high point of gravity for vehicles; good ground clearance.
 <p>Offset axle</p>	Space-saving installation for low vehicle height; low point of gravity; low ground clearance.
Cross-section	

 <p>I-section</p>	<p>Same resistance moment as rectangular cross-section, but much lower weight because the outer layers can take up higher loads due to cross-section enlargement.</p>
 <p>Round section</p>	<p>Simple to produce; the commonest shape for machine building, lifting equipment, etc.</p>
 <p>Hollow section</p>	<p>In light-weight construction because the material surfaces of the cross-section are shifted from a non-bearing neutral layer to the mostly bearing outer layers.</p>

Fixed Axle with Concentrated Load

Exposed to bending:

No change of stress in the cross-section

Rotating Axles with Circumferential Load

Exposed to circumferential flexure:

The stress in the cross-section changes with every half revolution from tensile stress to pressure stress.

3.1.4. Mounting Technology

Generally speaking, axle and stub fitting and dismantling depend upon the constructional peculiarities of the assembly involved.

When several axles are incorporated in a gearbox casing it will be necessary to check the parallelity of the axle, and to align them if this should prove to be necessary. The axle spacing must be checked and adjusted if the axles support gearwheels.

Installation

Depending upon the kind of fit and type of bearing, axles or stubs are either pushed in, inserted or driven in. If the holes for axle bearings are provided with casing elements, then these are heated in an oil bath or electric furnace to achieve a closer fit. The cold axle can then be easily pushed into the hole. This procedure is often adopted when installing piston pins in motor vehicles. If, on account of size, it is not possible to heat the casing sections, then the axles or stubs are chilled in deep-freezing cabinets or dry ice (CO₂). Auxiliary pins with a conical end simplify installation and prevent the supported parts from being damaged (figs. 3/8 and 3/9).

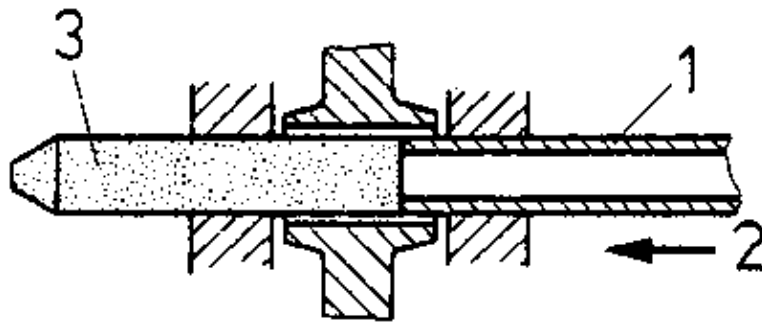


Figure 3/8 Correct installation of an axle with auxiliary pin

1 axle; 2 direction of joint; 3 auxiliary pin

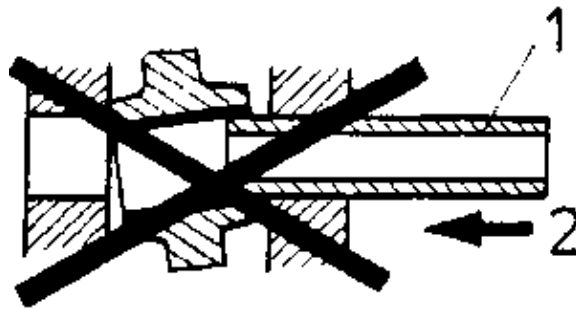


Figure 3/9 Incorrect installation of an axle without aids

1 axle; 2 direction of joint

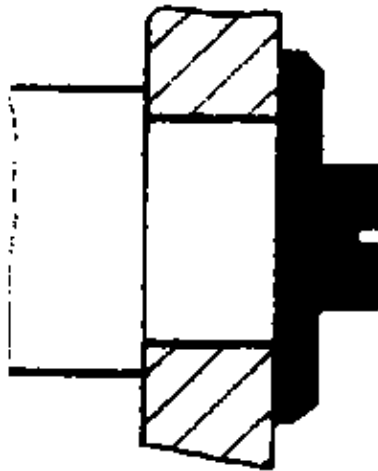


Figure 3/10 Axle fixed with screw and collar

Figure 3/11 Locking elements to fix the position of axles



a) locking ring for shafts and axles



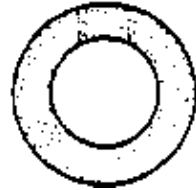
b) locking ring for bores



c) locking ring for shafts and axles



d) circlip



e) set collar and threaded pin

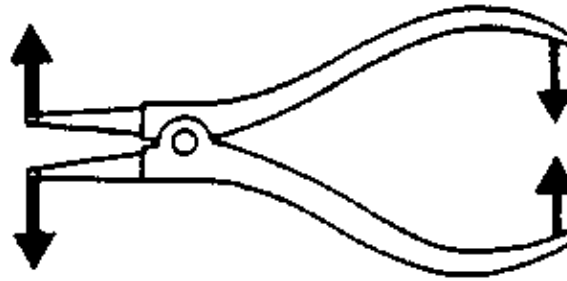


Figure 3/12 Lock-ring pliers

Axles can be fixed in axial direction by shoulders or collars (fig. 3/10) in combination with corresponding locking elements (fig. 3/11). Special pliers are used to expand locking rings. The action of these pliers is reversed, i.e. the jaws are opened when the handles are pressed together (fig. 3/12).

Checking the Axle Position

The axle spacing has to be checked when axles support gearwheels. Vernier calipers, micrometers or slip gauges are used for this job, depending upon the degree of accuracy required. Half the sum of both axle diameters has to be subtracted from the measured value when using vernier calipers and micrometers, whereas the same amount has to be added when using slip gauges.

$$\text{Axle spacing} = \text{indicated dimension} - \frac{\text{sum of axle diameter}}{2}$$

The largest possible spacing between two measuring points must be selected to obtain an accurate result when checking the parallelity of axles (figs. 3/13 and 3/14).

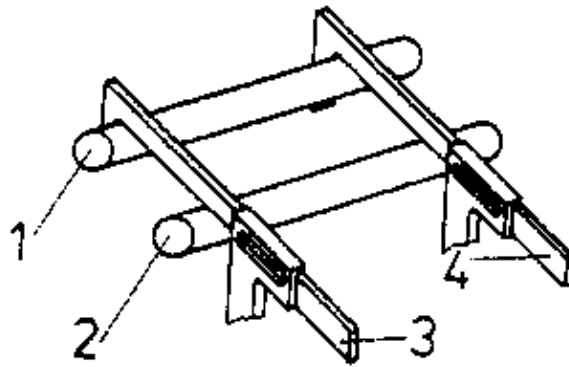


Figure 3/13 Checking the parallelity of axles with a vernier caliper

1, 2 axles; 3, 4 vernier caliper

Figure 3/15 shows the checking method adopted with a depth gauge, dial gauge or end measure, proceeding from a reference plane (e.g. making-out plate). This method is suitable for mounting assemblies. It is also possible to complete the checks with a spirit level and, if necessary, with rulers and end measures (fig. 3/16).

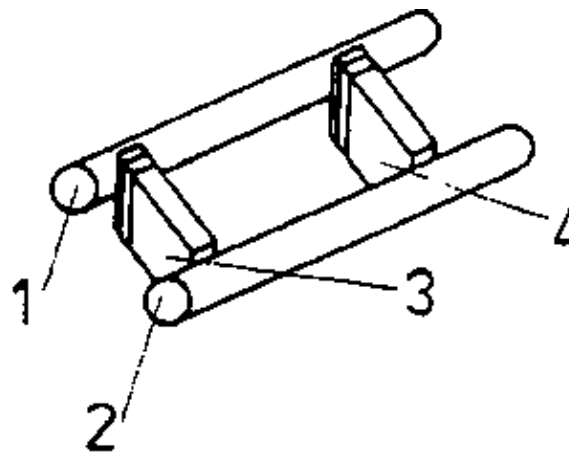


Figure 3/14 Checking the parallelity of axles with an end measure

1, 2 axles; 3, 4 end measure

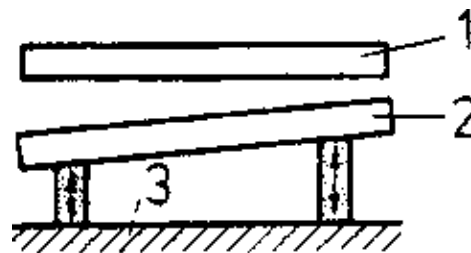


Figure 3/15 Checking the parallelity of axles from a reference plane

1, 2 axles; 3 reference plane

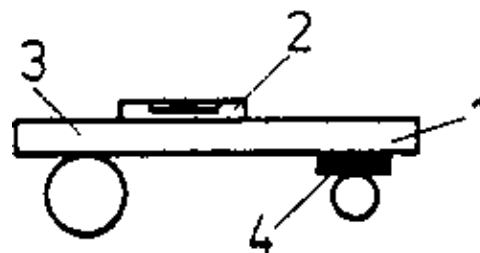


Figure 3/16 Checking the parallelity of axles with spirit level, ruler and end measure

1 axle; 2 spirit level; 3 ruler; 4 end measure

Precise alignment of the holes must be assured in the stage of fabrication.

In some cases axle bearings are provided with flanges to allow adjustments during installation.

Parallelity checks are essential for assemblies after they have been reconditioned during maintenance work. Vernier calipers and end measures only establish the parallelity of axles, but not whether they are misaligned in relation to each other in other planes.

Questions:

1. How should the centre lines of the holes of two bearings of an axle be related to each other?
2. What is the effect of non-parallelity of axles if these bear gearwheels or belt pulleys?

3.2. Shafts

Shafts, as opposed to axles, are subject to torsional stress. They bear rotary components (gearwheels, pulleys, drum cams, coupling sections, impellers, etc). which are mounted on the shafts in a fixed position or are free to slide along the shaft. The listed parts, and the forces exerted by the pull of belts, ropes or chains, subject the shafts to torsional flexure. The torsional stress of the shafts results from the transmission of the torque imparted to them by the rotary or oscillating parts mounted on the shafts.

Shafts bear machine parts which rotate on or with the shaft. They transmit torque and they are stressed by flexure and torsion.

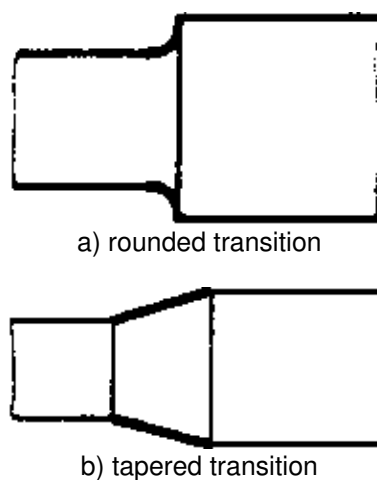
3.2.1. Design

Basically, shafts must fulfil the following demands:

- Adequate rigidity so that the shafts will withstand the applied forces with a minimum of flexure and without becoming twisted.
- All sliding surfaces must be resistant to wear.
- They should not vibrate under operating load.

Shafts in gearboxes have a cylindrical form and they are subdivided by collars and shoulders. Shoulders are used as a back stop for wheels, disks and other components.

Figure 3/17 Examples of cross-section transitions on shafts



To increase the form strength, and to reduce the danger of fatigue failure due to the notch effect, all changes of the cross-section are provided with transitions (fig. 3/17). The range of special locking elements for shafts includes locking rings, retaining washers, circlips and setting collars (see fig. 3/11). The latter are mounted with threaded or plain pins. The pins should not protrude from the setting collar because of the resulting accident hazard.

The diameter of the shaft depends upon the forces applied to it. The shafts incorporated in watches are minute, whilst the shafts used for hydro-turbines of several thousand kilowatts output can have a diameter of more than one meter. Shafts upon which tools or workpieces are mounted, as in metalworking and woodworking machines, are frequently referred to as spindles.

Steel is mostly employed for the manufacture of shafts. The bearing journals are often tempered and hardened or case-hardened to withstand high wearing stresses. Shafts with longitudinal flutes have to be finish-turned or ground after fluting because they become warped during milling.

Journals

Journals are the cylindrical ends of axles and shafts. They form the point of bearing for the machine element concerned.

A journal can also be a separate part that is fixed with other parts (e.g. crank-pin). A difference is made between supporting journals and pivot journals (fig. 3/18), depending upon the direction of the main forces in relation to the journal axis.

Figure 3/18 Kinds of journals

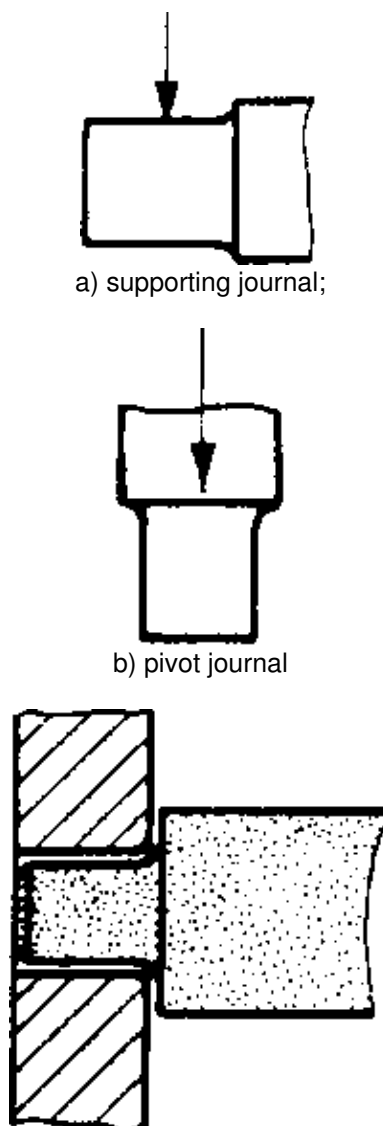


Figure 3/19 End journal

Supporting journals: These take up loads transversely to the journal axis. End journals (fig. 3/19) are supporting journals located at the ends of axles or shafts. They are produced with and without collar. Sometimes they are tapered to accept fixed or rotary bearings. They are simple, cheap to produce, and easy to mount.

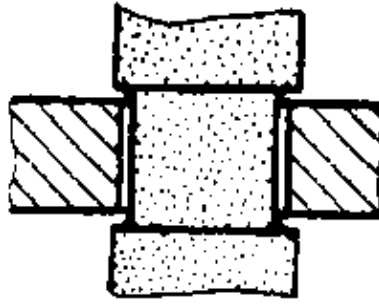


Figure 3/20 Shouldered neck journal

Neck journals are never at the ends of a shaft or axle. The bearing for a shouldered neck journal has to be divided into two parts (fig. 3/20). Neck journals that are not shouldered require a collar ring (fig. 3/21).

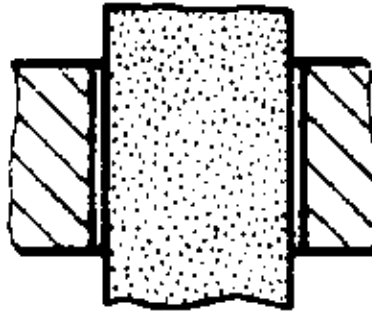


Figure 3/21 Neck journal without shoulder

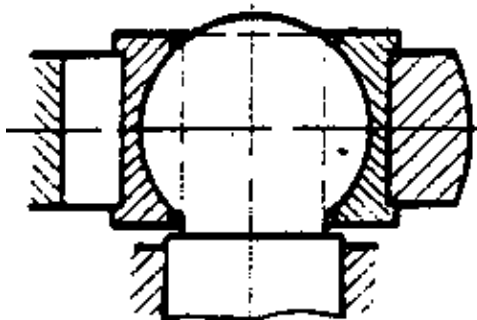


Figure 3/22 Using a ball journal as supporting journal

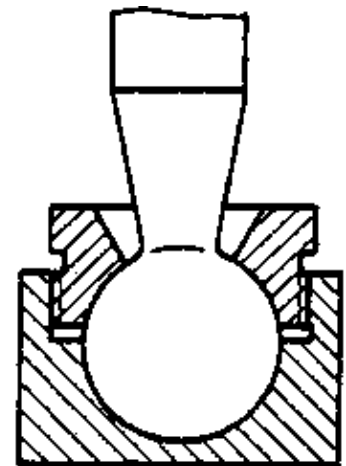


Figure 3/23 Using a ball journal as a pivot journal

Pivot journals: These take up forces acting in the direction of the shaft axis. They are manufactured as smooth, ring-shaped or ball-shaped journals. The ball journal (figs. 3/22 and 3/23) can be used as a supporting journal and as a pivot journal. Their biggest advantage is that they can be used also in those cases where the position of the axle or shaft cannot be accurately maintained (angular movement). Ring-shaped rack journals with differing profiles are used to take up strong axial forces at alternating directions of pressure (fig. 3/24).

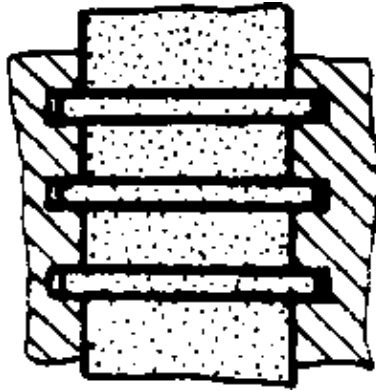


Figure 3/24 Rack journal

3.2.2. Stresses

A torsional stress is produced in the cross-section of a shaft when it transmits torque. The resulting stresses should not exceed the elasticity limit of the material of which the shaft is made of. Furthermore, shafts are subject to bending stress due to pulleys, belt tension, and gearwheels, and due to their own weight.

Torsional Stress

The shaft and its neighbouring cross-sections are twisted in relation to each other in the presence of a turning effort. The motor shaft shown in figure 3/25 drives the belt pulley with a given torque. The inertia of masses, and the friction in the bearings, act against the rotary effort of the shaft. This counteracting momentum tries to twist the shaft.

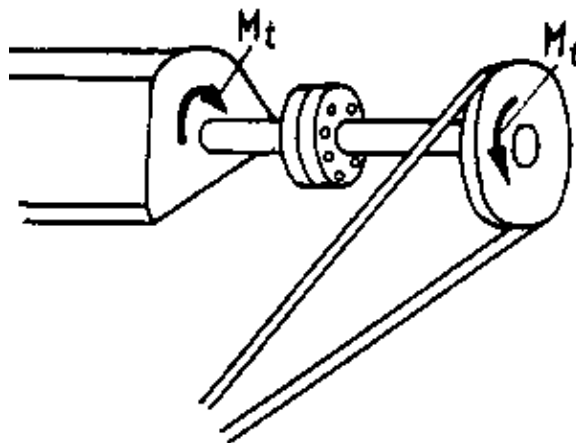


Figure 3/25 The torque of a motor shaft

Resistance momentum: The externally applied torque produces tensions in the cross-section of the shaft. Similar to the flexural stress of axles, the stresses are highest in the outer layers of the cross-section. These stresses decline from the cross-section centre to nill in proportion to the distance (fig. 3/26) because this is also the point where deformation equals nill. The resistance against deformation is therefore highest in the edge fibres.

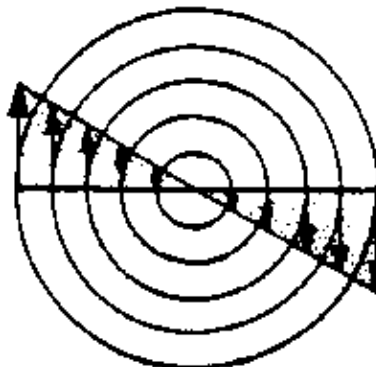


Figure 3/26 Distribution of stresses in a shaft cross-section by torsional forces

The forces acting on each surface particle in the cross-section are applied at a certain distance from the point of rotation. The sum of their momentum forms the resistance momentum.

Flexural stress: Next to the torsional stress resulting from the applied torque, the load is also subjected to flexural stresses resulting from belt pull, the load of pulleys and wheels, etc.

The applied force F is distributed to the two bearings (fig. 3/27). The highest flexural momentum is generated at the point of application of the force F .

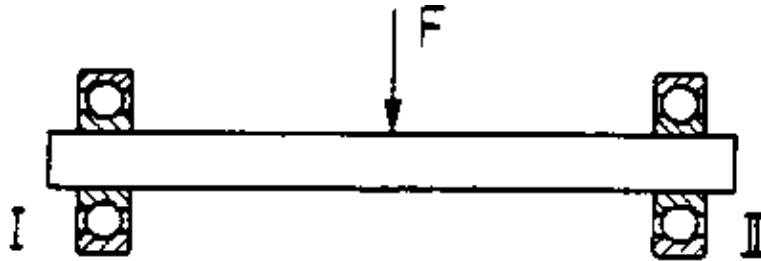


Figure 3/27 Shaft mounted in two bearings; centric force application

F applied force; I, II bearings

A shaft will bend under the action of the applied forces. The amount of flexure cannot be reduced by selecting steel of a higher strength. Flexure is only diminished by larger cross-section dimensions, and thus a higher resistance momentum.

3.2.3. Types

Just as axles, shafts can be distinguished by their shape. The classifying criterion is either their longitudinal shape or their cross-section (fig. 3/28 and 3/29).

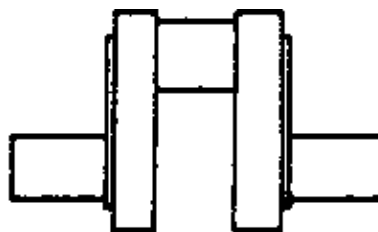
Figure 3/28 Shafts classified by their longitudinal shape



a) smooth shaft;



b) shouldered shaft;

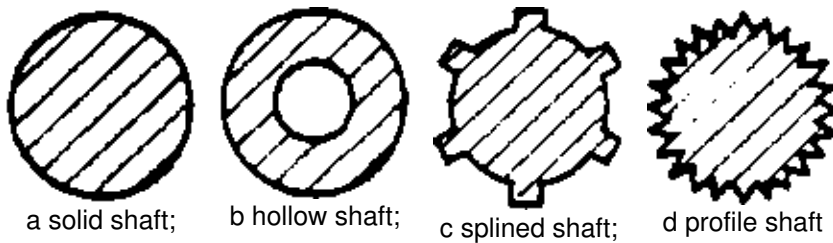


c) cranked shaft;



d) flexible shaft

Figure 3/29 Shafts classified by their cross-section



Straight shafts consist of round steel, with or without shoulder (solid shafts), thick-walled pipes (hollow shafts for lightweight construction), and round steel with milled flutes or teeth (profile shafts). They are all used for simple transmission of rotary motions in machines and vehicles.

Cranked shafts are forged from a single piece or they are assembled from single parts. In conjunction with the connecting rod and piston, they convert a rotary motion into a straight motion, or vice versa (combustion engine).

Flexible shafts are used to transmit torque between two sections that are adversely positioned in relation to each other, or between two sections where one of them has to be mobile (hand-held grinder).

3.2.4. Mounting Technology

The same code of practice to mount and check axles is also applicable to shafts. But there are certain additional specific constructional and installation problems.

The following jobs must be completed before a shaft is installed:

- Inspect all edges to make sure that they are free of burrs; deburr the edges if necessary.
- Remove all shavings and dirt out of the holes, oil channels and grooves; if necessary, use compressed air for this purpose.

Checking the Shafts for Shape and Dimensional Accuracy

Shafts are provided with differing mating and bearing surfaces in conformity with their intended functions. The mating surfaces can have clearance, transition and press fits. The bearing accuracy of the parts mounted by clearance fits depends solely upon the accuracy of shape and position of the fitting and bearing surfaces of the parts.

The following demands expected of positional accuracy of fitting surfaces on shafts and accessories must be fulfilled:

- Cylindrical shaft fitting surfaces must run centrally towards each other (fig. 3/30).
- The bearing fitting surfaces and the bearing surfaces must run at a right angle to each other (fig. 3/31).

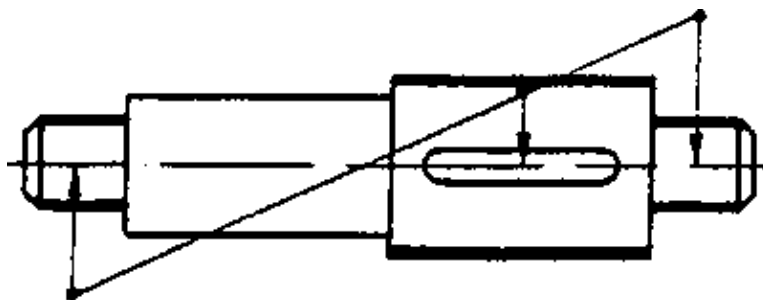


Figure 3/30 Cylindrical shaft fitting surfaces

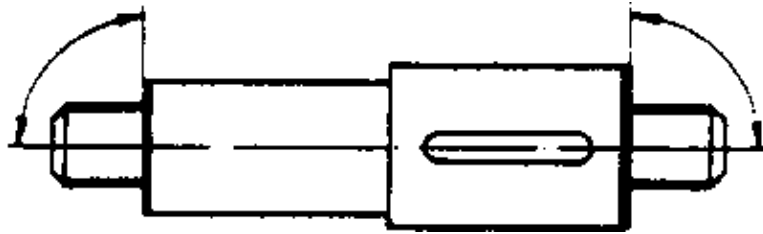


Figure 3/31 Bearing fitting surfaces and bearing surfaces on shafts

- Fluted shaft fitting surfaces or splined shaft fitting surfaces must be positioned in the centre of, and parallel to, the longitudinal axis of the shaft (fig. 3/32).

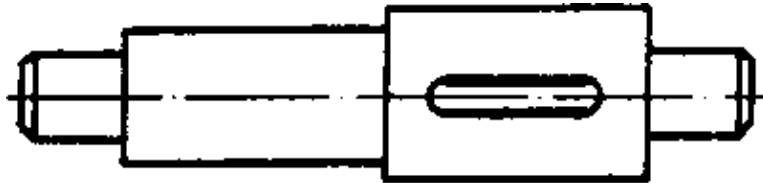


Figure 3/32 Fluted shaft fitting surfaces

- Threaded surfaces and face surfaces of mounting facilities for wheels, disks or levers must not run untrue (fig. 3/33).

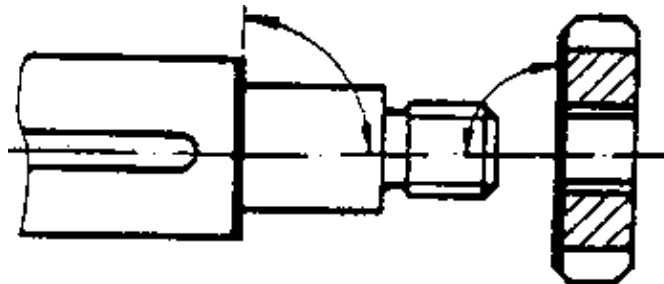


Figure 3/33 Threaded surfaces and face surfaces on shafts

Installing Shafts

The surfaces of the shafts can be grease-drawn, machine-finished, precision-finished, ground, fine-ground, polished or lapped. On no account should the surfaces be damaged. The notch effect of scratches and blow marks lead to fine hair cracks which may result in fatigue failure. Hair cracks can only be established by special testing methods during maintenance work.

To achieve the desired clearance of seat, the shaft diameter has a certain allowance to give the journal ends the necessary fit in the bearing holes. The more critical the tolerance, the higher the manufacturing costs, but also the lower the expenses for fitting work during installation.

Shafts are often nitride hardened to make them very resistant to corrosion. Small scratches will impair the corrosion resistance of the nitride case, leading to rust spots at the impaired points. This will adversely influence the strength of the shaft cross-section.

Damaged journals increase friction during operation, resulting in intense heating and premature failure of the bearing as a result of higher wear.

The alignment of two shafts in relation to each other is usually guaranteed during fabrication when the holes for the bearings and journals are produced. Proper alignment of two shafts can also be achieved during installation by adjusting parts of the casings or bearings.

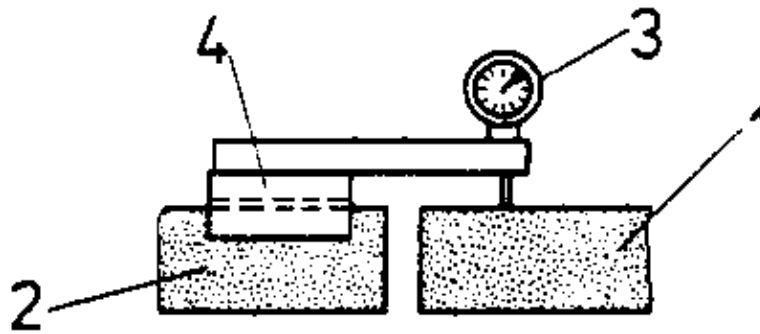


Figure 3/34 Establishing misalignment of shafts

1, 2 shaft; 3 dial gauge; 4 prism with dial-gauge bracket

Figure 3/34 shows a method to establish shaft misalignment. Rotation of the left-hand shaft produces a corresponding change of the display. The feeler of the dial gauge has to be lifted off during rotation.

Impermissible shaft misalignment results in premature wear of the bearings. The proper performance of gearings is also considerably impaired because the teeth cannot mesh uniformly over their entire width. The consequence of this is localized pressure at the tooth surface which exceeds by far the permissible limits so that the service life of the gearwheels is greatly reduced.

Misfits are also possible due to tilting or off-centre loads. Figure 3/35a shows the faults that arise as a result of tilted fitting or mounting. The shaft is then obliquely fitted in the hub. Figure 3/35b shows the faults arising from oblique-acting press-fit forces. The parts become tilted when they are pressed in and are obliquely seated after assembly.

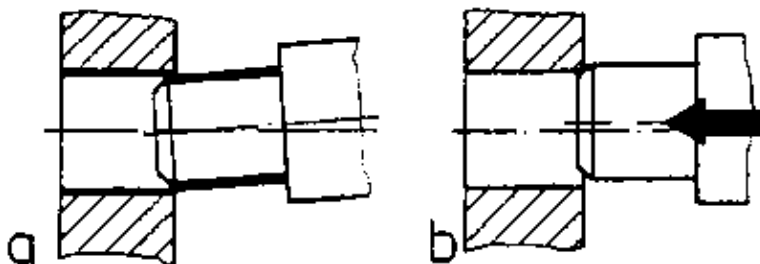


Figure 3/35 Misfits when mounting shafts

Mounted Shaft Packings

Shaft packings must fulfil the following functions:

- Prevent lubricants or gases from leaking out between the shaft and the casing, or the penetration of dust and other foreign particles into the spaces between the shaft and the casing.
- Separation of the different media with which the casing spaces are filled.

Packings protect the bearings from abrasion by foreign particles. Studies have revealed that about 75 per cent of all bearing failures are caused by the abraiding effect of dust and dirt.

A difference is made between slip packings and non-slip seals. The purpose of these packings is:

- Good sealing effect
- Low frictional resistance
- Low wear

Mounting Slip Packings

Felt and radial packing rings are extensively used in machine building for shaft packing.

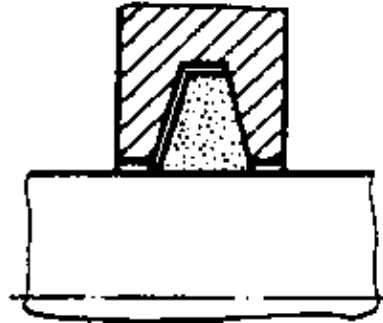


Figure 3/36 Felt packing ring

Felt packing rings: (fig. 3/36) These are only suited for grease lubrication and for slow to medium rotating speeds. This is because of unrestricted leakage of lubricant as soon as the felt has become saturated with oil.

Rules for mounting:

- Immerse the felt rings in warm oil to reduce friction during the running-in period.
- Rings must be carefully inserted in the grooves provided for this purpose.
- The shaft is carefully pushed through the rings; press on the cover plates whenever this may be necessary.

Felt is not suited for temperatures exceeding 100 C because it then becomes hard and encrusted.

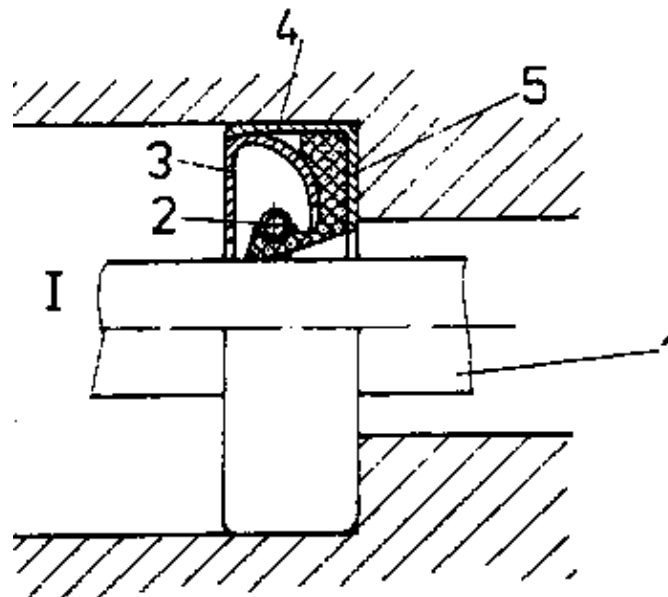


Figure 3/37 Radial packing ring I space that is to be sealed off

1 shaft; 2 spring ring; 3 inner ring; 4 casing; 5 packing ring

Radial packing rings: (fig. 3/37) These are based on the principle of the lip-type packing. The sealing effect is the result of the initial stress of the packing lips. The sealing collar of the radial packing ring has a flexible sealing lip made of oil-resistant synthetic rubber. The sealing edge of the lip must not be damaged because the packing ring will then become useless. The initial stress of the radial packing ring is the result of the undersize allowance of the sealing edge compared with the diameter of the shaft. The sealing edge is thus pressed against the shaft with the extra force generated by a spring. Packing rings must be compressed into the bearing hole with oversize allowance so that they do not revolve with the shaft as a result of frictional forces, and to make sure that there is no leakage of the sealed off medium at the periphery of the ring. Packing rings in the bearing hole have a tolerance of H 8 to achieve a firm and tight seal. A tolerance of h 11 is sufficient for the shaft.

There are two basic forms of mounting:

– The packing ring is pushed on to the shaft. The shaft and the packing ring are then jointly pressed into the casing. A mounting sleeve (fig. 3/38) with transition zone is used to push the ring on to the shaft. The external diameter of the mounting sleeve is about 0.4 mm larger than the diameter of the shaft shoulder. This makes sure that the sealing lip is not damaged, provided that the mounting sleeve and the shaft shoulder have been previously lubricated. A press-in sleeve (fig. 3/39) is employed to make sure that the packing ring is not tilted when it is mounted. This assures an axial flow of the pressing force, and that this force is uniformly distributed over the entire circumference of the ring.

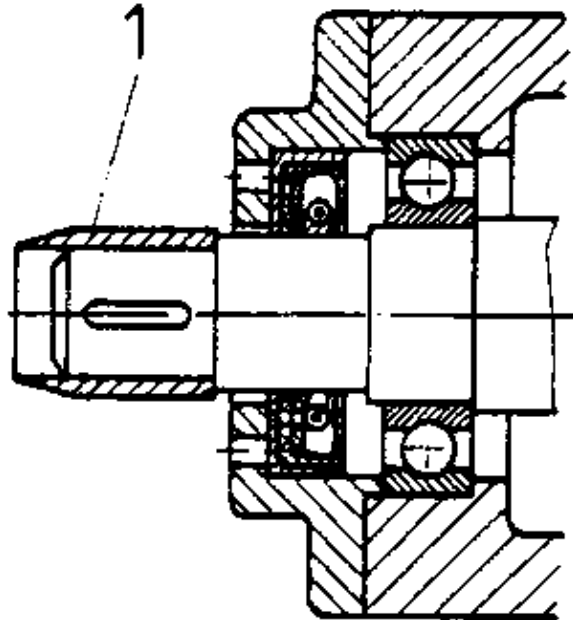


Figure 3/38 Mounting the packing ring with the mounting sleeve

1 mounting sleeve

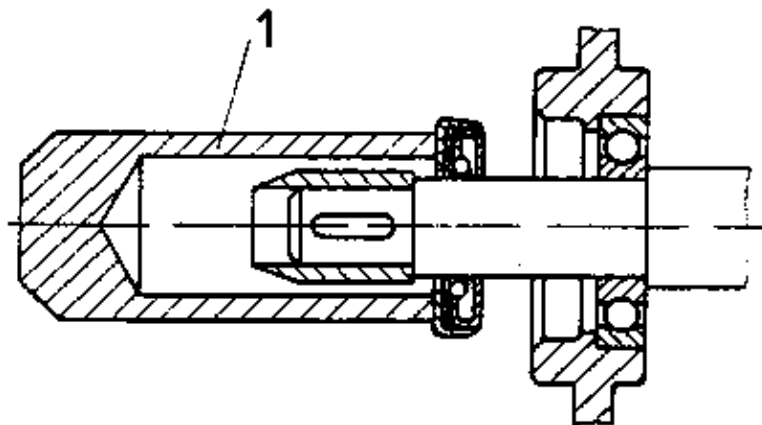


Figure 3/39 Mounting the packing ring with press-in sleeve

1 press-in sleeve

The radial packing ring must be fitted in such a manner that the sealing lip is facing towards the space that is to be sealed off.

– The packing ring is pressed into the hole of the casing. The bearing hole must be provided with a chamfer that should be lubricated to make sure that the seating surface of the ring is not damaged when it is mounted. The shaft is then fitted into the mounting case in axial direction.

Cleanliness is of primary importance when the packing ring is being installed together with the other parts. Scratches on the surface of the shaft, and foreign bodies such as chips and fluff from a cleaning rag, will adversely influence the effectiveness of the sealing ring and its durability, thereby diminishing the function of the packing ring.

Radial packing ring with diaphragm packing: It also belongs to the lip-type packing, but the profile of the lip is much smaller than the simple radial packing ring. This means that friction is reduced by between 50 and 65%.

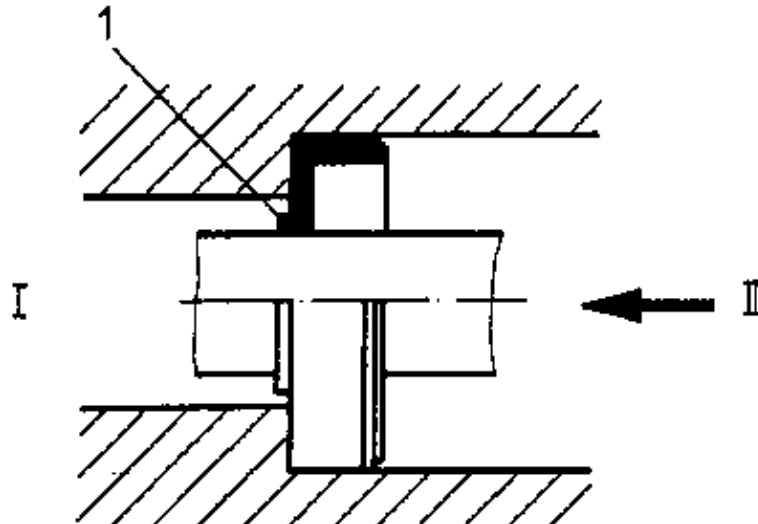


Figure 3/40 Single-lip diaphragm packing

I space that is to be sealed off;
II direction of installation, 1 sealing lip

The sealing lip of the single-lip diaphragm packing (fig. 3/40) is aligned towards the direction of installation.

Sealing with a stuffing box: The stuffing box can be used to seal shafts, i.e. rotary motions, as well as piston rods, i.e. longitudinal motions. They will withstand much higher temperatures and pressures than radial packing rings, provided that appropriate packing materials are employed. Soft packing materials, soft metallic materials and dimensionally stable packing rings are used for sealing purposes in stuffing boxes (table 3/2). The packing is deformed by axial movement of the stuffing-box gland when it is mounted, and it is this deformation that produces the sealing effect (fig. 3/41). The deformability of the packing is exhausted after longer periods of operation. It has to be removed and replaced by a new packing.

Table 3/2: Packings for Stuffing Boxes

Kind	Shape	Material	Remarks
Soft packings	Fabric cords, braided, twisted, laminated	Cotton Hemp Asbestos Glass fibres, impregnated or steeped	up to 10 MPa pressure for temperatures up to 500 °C
Soft-metal packings	Formable gaskets pressed to size and shape in mating part	Lead Aluminium	up to 30 MPa pressure for temperatures up to 280 °C
Permanently shaped packing rings	Gaskets must fit in corresponding mating parts	Carbon Synthetic carbon Grey-cast iron	for highest pressures and temperatures

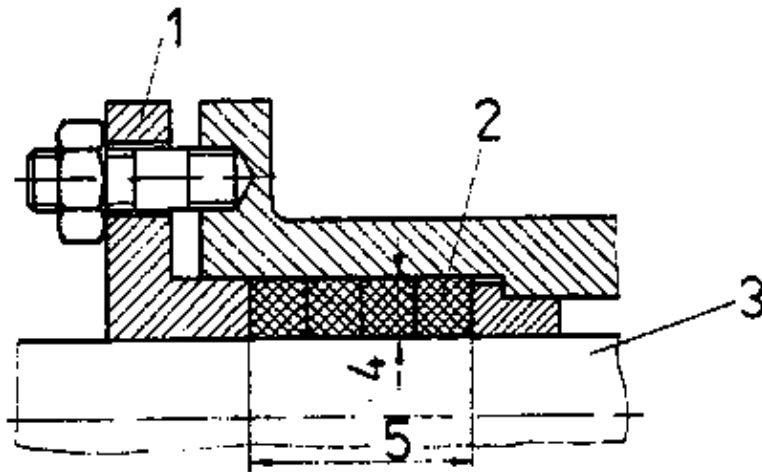


Figure 3/41 Sealing with stuffing box

1 stuffing box gland; 2 stuffing box packing; 3 shaft; 4 packing thickness; 5 packing length

The following jobs are required to install stuffing-box packings:

- The packing wicker is cut into rings in the required number of packings (fig. 3/42).,

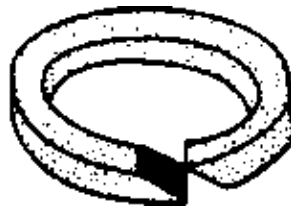


Figure 3/42 Obliquely cut ring of soft packing

The packing rings are pushed in, one after the other, with an inserting sleeve – a tube that pushes the rings together (fig. 3/43).

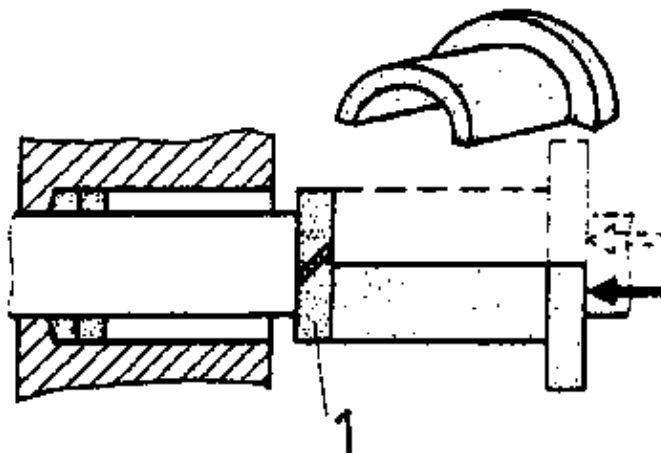


Figure 3/43 Pressing in the stuffing box packing with a longitudinally divided pipe and mounting sleeve.

1 packing ring

- The joints of the packing rings are inserted at a displacement of 90° in relation to each other.
- Smooth running of the shaft or rod is checked step by step.
- The stuffing-box packing is tensioned by careful tightening of the stuffing-box gland. The free running properties and guide clearance of the shaft are repeatedly checked throughout the mounting procedure.

If the packing wicker is to be inserted in the stuffing box as a single piece, then its ends must be obliquely cut off. The winding direction of the wicker must always oppose the direction of shaft rotation so that it cannot tighten itself during operation and thus increase its braking effect.

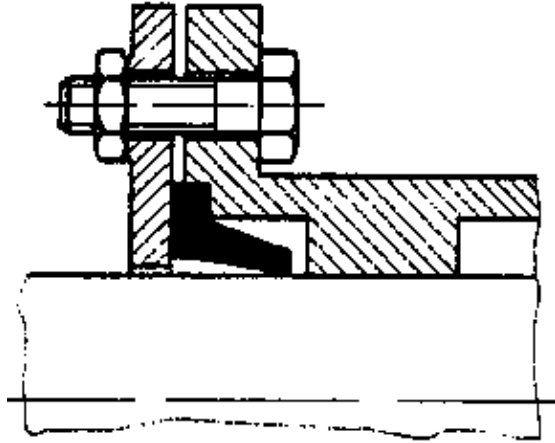


Figure 3/44 Internal packing with a hard collar

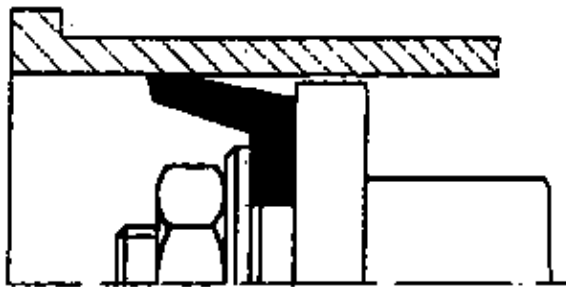


Figure 3/45 External packing with a pot packing

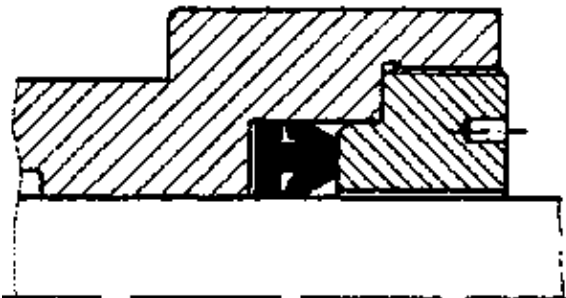


Figure 3/46 Internal and external packing with a groove ring and thrust ring

Lip ring and groove ring packings: Packing rings are defined by which part of the ring produces the seal. Hence, internal packings and external packings (figs. 3/44 to 3/46). They are standardized. The sealing lip must not be damaged during installation. Packing rings are usually employed to seal pistons and piston rods, i.e. they produce a sealing effect on axially moving machine parts. Similar to radial packing rings, mounting sleeves should be used whenever they have to be fitted over shaft shoulders, and the piston rods should be previously lubricated.

Spring rings: These are usually made of grey-cast iron. Their elasticity of deformation during mounting ensures that they press up closely against the parts that are to be sealed. Complete sealing requires several rings (piston rings on piston engines and compressors).

The rings must fulfil the following demands to produce a perfect seal:

- The rings should be transversely movable within the groove of the piston.
- The joint of the ring must have a certain measure of play.
- The ring joints must be located in a displaced position in relation to each other.
- The sliding surfaces of the ring and cylinder must be absolutely round.
- The sliding surfaces of the ring and cylinder must be running in the same direction.

The following points must be observed when fitting the rings and pistons:

- The grooves must be cleaned.
- The grooves are then oiled.
- Check the play of the ring joints.
- Mount the rings on the piston with a collet.
- Press the pistons into the cylinders, taking care to ensure that the edges of the ring are not damaged.

Mounting Non-slip Seals

A difference is made between seals for grease lubrication and seals for oil lubrication.

Usually, these seals are not separate elements, They are machined into the bore of the casing or machined on to the shafts. The grooves of seals that have collecting grooves (fig. 3/47) are filled with grease prior to mounting. This represents a simple seal. The labyrinth seal (fig. 3/48) seals by its longer path and by the repetition of spaces of higher and lower pressure.

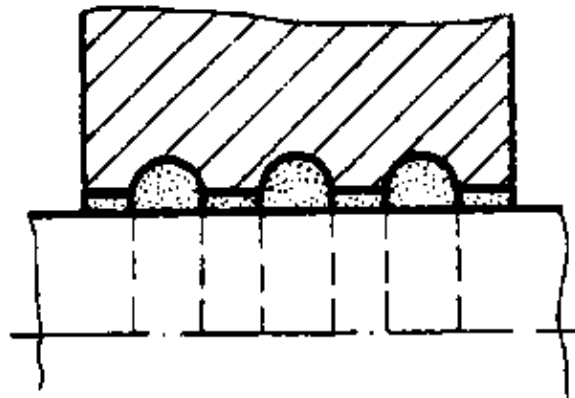


Figure 3/47 Sealing by collecting grooves

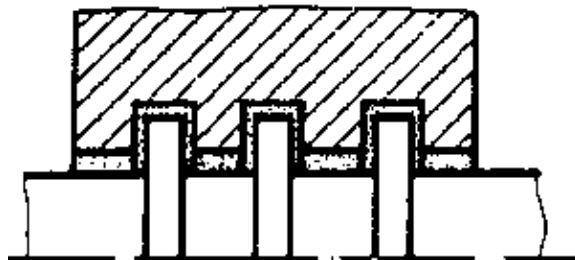


Figure 3/48 Labyrinth seal

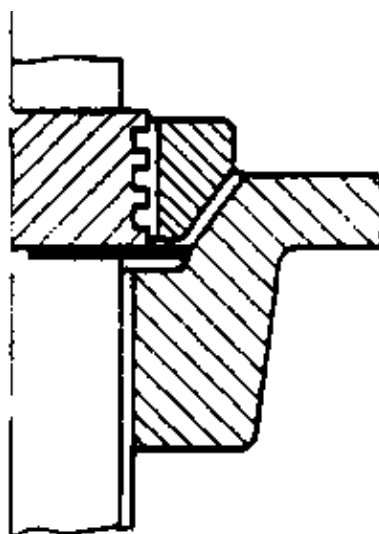


Figure 3/49 Flinger ring seal

Flinger rings with oil lubrication (fig. 3/49) produce a good seal on the shaft on account of their centrifugal action. The oil migrates along the shaft and is discharged by the centrifugal action of the oil-flinger ring. Care must be taken to ensure that the drainage holes are not clogged up so that the oil can drain freely out of the

oil splash space. These holes should be blown out with compressed air, and they should be inspected to make sure that they are absolutely free. Return threads are often applied to the outside in front of the flinger ring so that the oil can be continuously returned. Such a return–flow thread, however, will only fulfil its purpose if shaft rotation harmonizes with the direction of the thread. Otherwise the seal will have the reverse effect, i.e. it will conduct the oil out of the lubricating area.

Questions:

1. What is the purpose of journals on shafts and axles?
2. What happens when the shafts for belt, chain or gearwheel transmissions are not absolutely parallel?
3. What damage can be caused if shaft packings are not properly mounted?
4. Explain why radial packing rings with diaphragm collar have a lower frictional resistance than simple radial packing rings, and why a better sealing effect is achieved.

3.3. Plain Bearings

Bearings act as supports for rotating or oscillating machine parts (shafts, stubs). When the surface of the shaft is in direct contact with the supporting surface of the bearing, it is known as a plain or sleeve–type bearing. When the shaft is running in a raceway provided with a set of balls or rollers, then this type is known as a rolling–contact or anti–friction bearing. Bearings transmit the arising forces to the machine frame and determine the possibilities of radial and axial movement of the machine parts.

Plain bearings are employed for shock loads because they are much better suited to absorb these loads than their rolling–contact counterpart. Plain–bearings are available for lateral and longitudinal forces. They offer a number of advantages over rolling–contact bearings. These are less sensitive to dirt (building machinery), practically silent, and they have a vibration–damping effect on account of lubrication.

Plain bearings of large diameter can be economically fabricated by simple machining processes. On account of their smaller external diameter, plain bearings take up less space than rolling–contact bearings. Plain bearings can be produced right down to the smallest of diameters, and they have a very high running accuracy (main bearing on machine tools).

Plain bearings are components that permit rotary or oscillating motions of axles, shafts, levers and wheels in machines and on vehicles. The forces arising from operation are transmitted to the frame of the machine or to the chassis of a vehicle. The individual bearing parts run on a film of lubricant. The plan bearing produces a rubbing friction.

3.3.1. Design

A plain bearing generally consists of the bearing housing, the bearing sleeve or bush shells, and of the lubricating device (fig. 3/50) The cylindrical journals of the axle or shaft run in the bore of the bush shells or bearing sleeve, thereby transmitting the radial forces to the housing of the radial bearings.

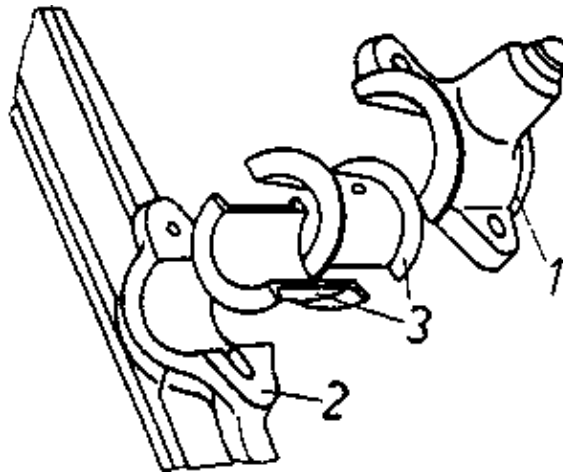


Figure 3/50 Sleeve bearing

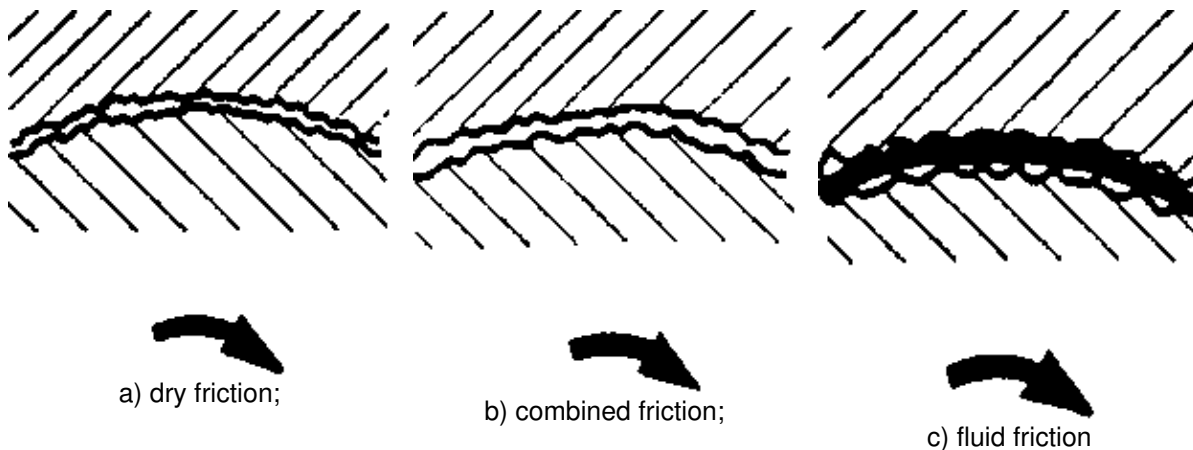
1 bearing housing (cover); 2 bearing housing (lower section); 3 bearing shells

In other types, the face surface of the shaft stub runs on level pressure plates to transmit the axial forces to the frame.

Lubricating Facilities

Plain bearings require a constant supply of adequate quantities of lubricant. If this is not assured, the bearing will be destroyed by dry running resulting from metallic contact between the surface of the shaft (journal) and the bearing sleeve. Inadequate quantities of lubricant cause semi-fluid or mixed friction which, in turn, can lead to pronounced wear of the rubbing surfaces. Fluid friction is the form of rubbing that has to be achieved by plain bearings. This is obtained when the surface irregularities of shaft and bearing are separated by a film of lubricant so that they cannot come into contact with each other. Fluid friction is only obtained if the shaft is slightly lifted off the surface of the sleeve. This means that there must be a small amount of clearance between these two parts (fig. 3/51).

Figure 3/51 Forms of friction



To ensure that the lubricant is uniformly distributed over the entire bearing surface, the non-supporting part of the bearing is usually provided with diagonal oil-distributing grooves and axial lubricating pockets.

The lubricant can be supplied to the bearing by different methods (table 3/3).

Bearing Materials


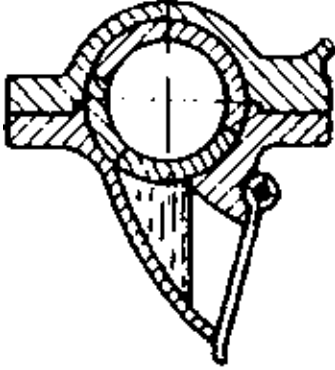
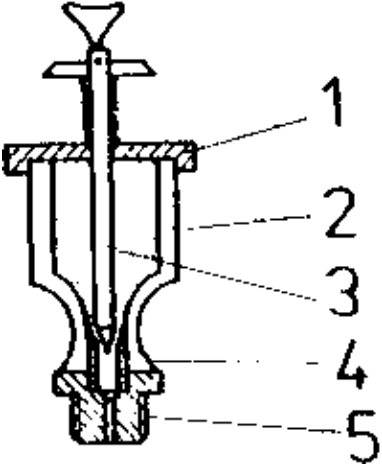
Bearing materials should have the following properties (ideally):

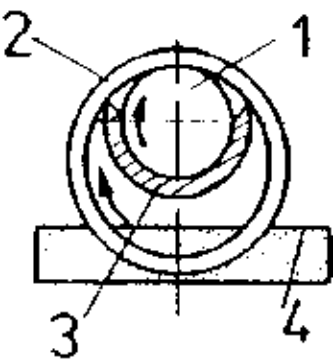
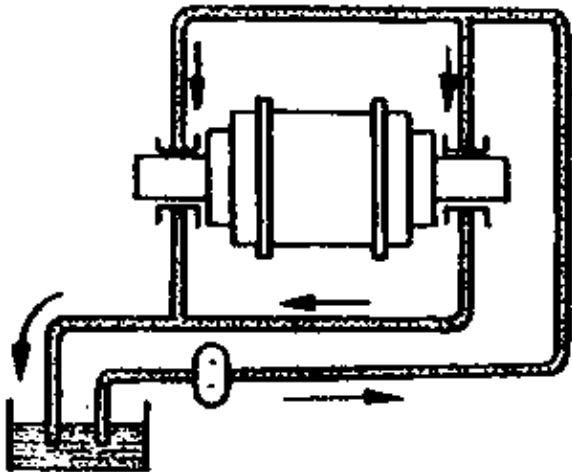
- Resistant to pressure
- Tough and elastic

- Good sliding properties
- Resistant to heat and negligible thermal expansion
- Good anti-friction properties, i.e. inadequate lubricant supplies should not cause rapid seizure
- Good running-in performance and machinability
- Corrosion resistant
- Wettable by lubricants and absorptive to lubricants

Since all these properties cannot be covered by a single material, a compromise has to be found. Consequently, the material is selected according to the application in hand. The material of the shaft journal should be three to five times harder than the bearing material. Softer materials can be made harder by planishing, nitriding or hard-chrome plating.

Table 3/3: Lubricating Devices for Bearings

Lubricant	Lubricating device (illus.)	Kind	Remarks
Grease		Grease gun and grease nipple	Simple operation; limited grease supply; uneven lubrication; points of lubrication may be missed during maintenance work.
Grease		Grease well	Uniform supply of grease to the bearings assured over longer periods.
Oil		Drip-feed oiler	Quantity of supplied oil is controlled by the position of the needle. The oil is drip-fed to the bearing when the needle is lifted. The number of drops can be checked through inspection window. 1 oil supply, 2 inspection glass, 3 adjusting needle, 4 inspection window, 5 screw-in sockets

Oil	 A cross-sectional diagram of a shaft (1) inside a bearing shell (3). A lubricating ring (2) is positioned around the shaft, and an oil filling level (4) is indicated at the bottom of the shell. Arrows show the rotation of the shaft and the ring.	Ring oiling	Simple and economical lubrication; uniform supply of oil to the bearing is assured (a single ring will feed up to 8 ltrs. of oil per hour; speed-dependent oil supply); oil has to be changed at the prescribed intervals. 1 shaft, 2 lubricating ring, 3 bearing shell, 4 oil filling level
Oil	 A schematic diagram of a circulating lubrication system. It shows a central pump connected to a network of pipes that supply oil to multiple bearings. The oil is then collected and returned to the pump. Arrows indicate the flow direction.	Circulating lubrication	Several bearings can be lubricated by a central pump; the oil is cooled and cleaned; separate pump drive will secure full lubricating condition before a machine is set into operation.

Plastics are often employed as material for plain bearings (fig. 3/52). They offer the following advantages over metallic materials:

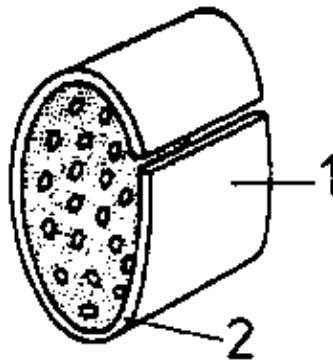


Figure 3/52 Plain bearing with plastic sliding surface

1 rolled supporting steel shell, 2 perforated plastic coating

- They are very hard wearing, giving them a service life that is 10 to 70 times longer than that of metallic bearings, depending upon the prevailing operating conditions.
- In many cases water lubrication achieves favourable sliding properties.
- Oil lubricants penetrate into the sliding surface of the plain bearing to ensure good running performance even when longer periods elapse before the lubricant is renewed by fresh supplies (good anti-seizure properties).
- Dust and dirt entering the bearing are pressed into the soft bearing material so that they cannot harm the journal.

- The material has a vibration–damping effect to assure smooth journal running.

The following disadvantages over metallic sleeves limit the use of plastics as a bearing material:

- Plastics are more sensitive to higher temperatures.
- The thermal expansion of plastics is much higher than that of metals.
- Many plastics swell through the absorption of water and oil so that more bearing clearance is required.

3.3.2. Stresses

Bearings can be stressed by a single force or by several forces acting in different directions.

Edge Pressure

Journals are easily bent in the bearing as a result of the applied forces. This leads to higher pressing forces at the edge of the bearing. This is known as edge pressure (fig. 3/53).

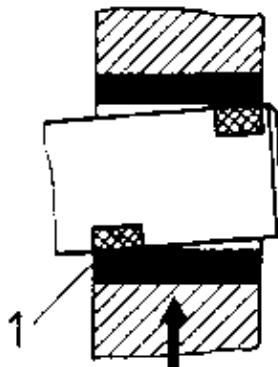


Figure 3/53 Edge pressure resulting from axle or shaft flexure

1 edge pressure

Surface Pressure

The forces are distributed over the surface of the bearing. The ratio of the forces acting on the bearing in relation to the bearing surface is known as surface pressure.

Frictional Stress

Three forms of friction can arise in plain bearings:

1. Dry friction
2. Mixed friction
3. Fluid friction (see Section 3.3.1., Lubricating Facilities, and fig. 3/51)

3.3.3. Types

Plain bearings are classified by the kind of bearing load:

- Radial bearings (journal bearings) (fig. 3/54)

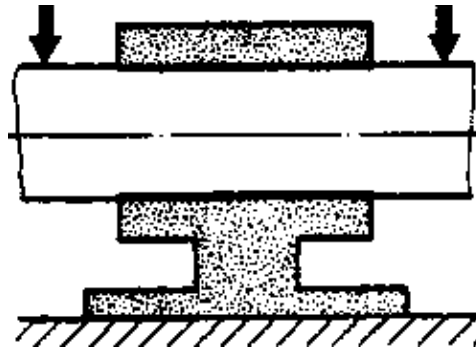


Figure 3/54 Radial or journal bearing

- Axial bearings (thrust bearings) (fig. 3/55)
- Radial–axial bearings (fig. 3/56)

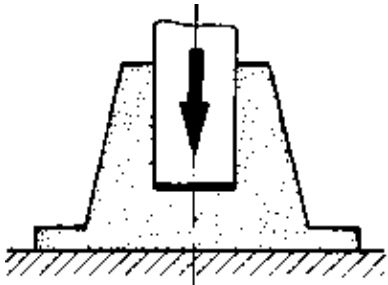


Figure 3/55 Axial or thrust bearing

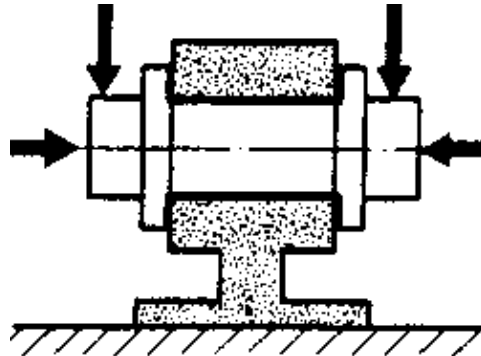


Figure 3/56 Radial–axial bearing

Radial bearings are used as supporting bearings; axial bearings as steady or step bearings.

The bearing forces arising with radial bearings act transversely to the bearing axis. With axial bearings, on the other hand, the bearing forces act in the direction of the bearing axis. Both directions of force application arise in radial–axial bearings. Lead–bronze composite bearings are extensively employed. They require little non–ferrous metal. Such composite bearings are employed for high–speed steam turbines, transmission gearings, blowers, presses and in the locomotive and rolling stock industry. This kind of bearing increases the machining accuracy in the machine tool building industry because the thermal expansion of the running layer is of no consequence since it is so thin. Furthermore, the shaft and the housing have the same coefficient of expansion. The lead bronze is applied by dipping, chill casting or by centrifugal casting.

Next to considerable savings in non–ferrous metal, lead–bronze composite bearings are extensively employed on account of the superior sliding properties of bearing metal in conjunction with good strength properties of the steel used for the reinforcing shell.

3.3.4. Mounting Technology

The impeccable performance of a plain bearing, irrespective of whether it incorporates bushes or shells, presupposes strict observance of the following conditions for their installation:

The geometric dimensions of the bearing must be accurately maintained.

The surfaces of the bearing should not be deformed, scratched, notched or cracked during installation. Such faults will cause dry running, leading to premature failure of the bearing.

The radial and axial clearance of the bearing must be maintained.

The bearing clearance is influenced by the quality of the bearing and journal surfaces. A clearance of 0.3 to 0.4%, related to the journal diameter, is generally selected for a plastic bearing. The amount of bearing clearance for tin–bronze bearings is selected in conformity with the sliding speed and the bearing load. The axial clearance of radial bearings should be in the order of 2 to 6% of the length of the bearing; the higher values for shorter bearings and the smaller values for longer bearings. The amount of clearance is measured with the feeler gauge.

The clearance can be changed with spacing rings or by turning off the bushes.

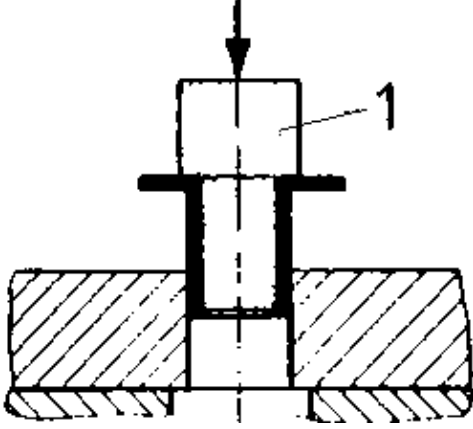
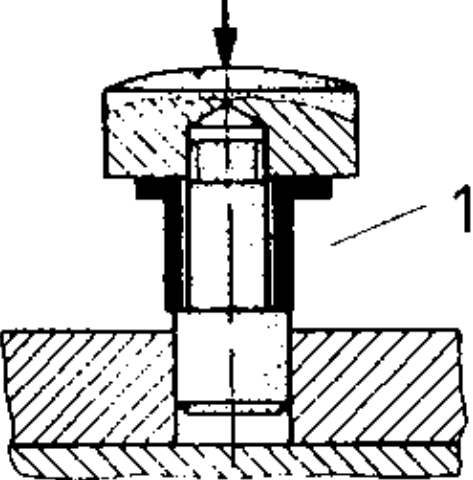
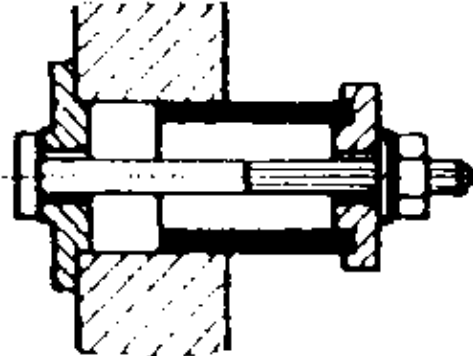
Opposing bearings must be precisely aligned.

Misaligned bearings cause edge pressure in the individual bearings, thereby leading to premature wear. The mounting surfaces are marked to align the bearings when highest demands are expected of accuracy.

Bushes should be pressed in with the utmost concentric accuracy.

Bushes must be pressed in with the fit H 7/r6. This can only be accomplished impeccably with a press or a drawing-in device (table 3/4). The bore with the fit dimension E 6 or F 7 is diminished to H 6. To make it easier to press in the bush, the face side of the bush has a chamfer of 5° or a cylindrical lead-in lug of the tolerance h 6.

Table 3/4: Pressing in Undivided Bearing Bushes

Illus.	Tools, machines and fixtures	Explanations
	<p>Guide plug, seating sections, press</p>	<p>Bushes are driven in by tapping with a hammer for single-piece fabrication; a press is employed for the same job in mass manufacture; suitable for bushes of differing wall thickness. Each bush bore requires a matching plug; the bush must be perfectly aligned in relation to the bore as otherwise it will become deformed.</p> <p>1 plug</p>
		<p>Aligned guidance of the bush assured by the plug seat; clearance between plug seat and bore must be small. Plug and pressure section are screwed together; suited for long and thin-walled bushes.</p> <p>1 bush</p>
	<p>Fixtures with screw spindle</p>	<p>Universally applicable for bushes of differing diameter; particularly suited for several bushes arranged behind each other.</p>

The bearing bush must be pressed in with the lubricating groove in the right position.

An incorrectly positioned lubricating groove in the supporting section of the bearing interrupts the supporting film of lubricant. This causes dry friction, and thus premature failure of the bearing.

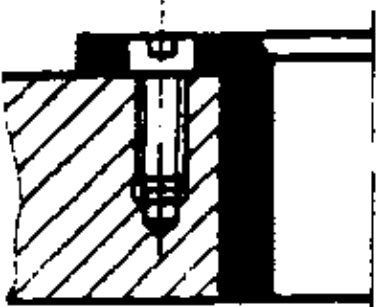
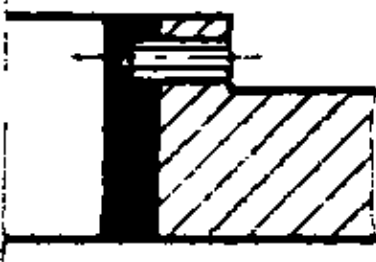
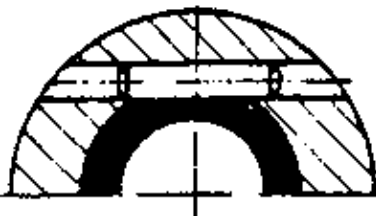
The bush should be greased before it is pressed in. Greased bushes are easier to press in. Clean lubricating holes and check free passage of oil through the hole.

Clean lubricating holes are essential for the free flow of lubricant. Furthermore, any dirt that may be in the lubricating holes is fed into the bearing.

Lock the bushes against axial and radial shift. (table 3/5). If necessary, pressed-in and locked bushes should be finished-rearred to final size.

Bushes intended for finish reaming are given an extra reaming allowance of 0.15 to 0.30 mm.

Table 3/5: Locking Bearing Bushes

Illus.	Locking device	Explanations
	Cylindrical screw	The bore through bush collar and casing is jointly drilled after the bush has been driven in; cut the thread and then tighten the screw.
	Threaded pin	Drill the casing and then cut the thread; spot-drill the bush after it has been driven in; tighten the screw.
	Notched pin	Tangential spot drilling of the bush after it has been driven in; the pin is then driven in.

When split bearings are mounted, care must be taken to ensure that the bearing shells fit entirely with their outer fitting surface in the bearing housing.

The two bearing halves are held together by bolts. These bolts must be tightened with the same initial stress when the bore fit is produced as when the bolts will be tightened for final installation.

Make sure that the locking lug is properly seated when the bearing shells are inserted in the housing. The bearing cover should be opened only by light tapping with a rubber mallet. The shells must not be shifted when the bolts of the bearing cover are tightened. To ensure a uniform distribution of tension, the cover bolts should be tightened with a limited torque with a torque spanner.

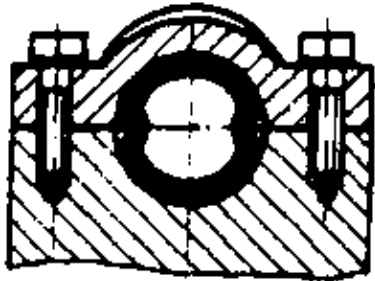
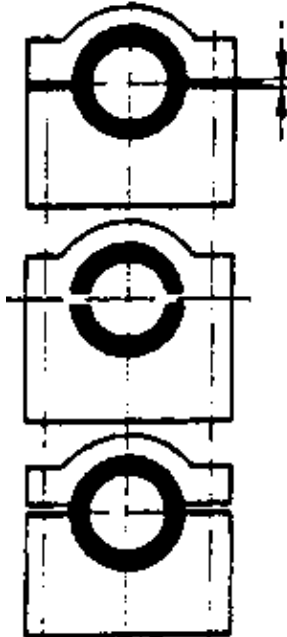
The bolts must be tightened in pairs –first the middle ones and then the outer ones.

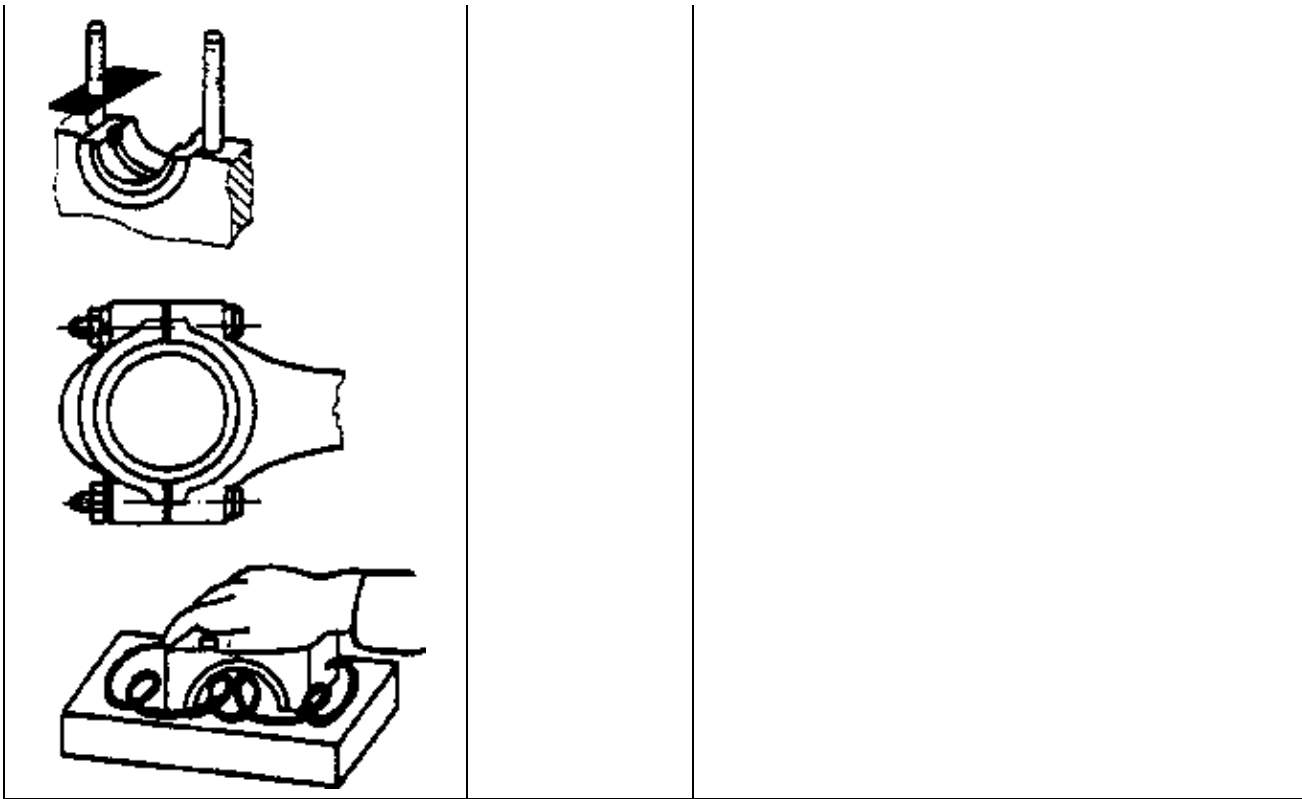
The mounting jobs associated with divided bearings are listed in table 3/6.

Questions:

1. List practical examples of application of plain bearings from your own area of activity.
2. Which properties are expected of materials for plain bearings?

Table 3/6: Mounting Split Bearings

Illus.	Mounting job	Explanations
	Fitting the bearing shells in the casing	Attention must be paid to the height of the two shell halves when they are pressed in. Excessive height will deform the shells when they are tightened. The lubricating oils of the shells must coincide with the lubricating channels in the casing; the channels must not be clogged.
	Adjusting the initial stress	<p>The bearing cover must be matched to the journal in such a manner that an initial stress is produced, i.e. the cover must be pressed against its seating surface when it is tightened. The initial stress ensures that the shells are firmly seated and held together at the dividing joint. A light gap should be formed when one side of the cover is loosened; the gap is checked with a feeler gauge. The dividing joint should be ground down if the prescribed initial stress is not achieved. The surfaces of the shells must be ground down if the initial stress is too high.</p> <p>Always identify upper and lower bearing shells! Identification must clearly define the position of the bearing shells in relation to each other, and it must be assured that the shells are not shifted by 180° in relation to each other.</p>
	Setting the bearing clearance	<p>The clearance between journal and bearing is checked with a feeler gauge. A feeler gauge matching the specified clearance is inserted between journal and shell; the cover is then tightened. The prescribed clearance is obtained if the shaft is easily rotated. The clearance is too large if the shaft rotates too freely. In this case bearing case and bearing shell must be ground off. The same procedure must be pursued to check all bearings if a shaft runs in several bearings. Bearing clearance can be corrected with packings. Packings of equal thickness are placed on either side of the bearing and safeguarded against displacement. The thicker layer of packing is placed on the bearing casing, followed by the tinner layer on top. This makes it possible to correct play while the bearings are being mounted.</p>



3.4. Rolling-Contact Bearings

Rolling contact bearings, just as plain bearings, support shafts and enable them to rotate. The advantages of rolling-contact bearings are: low friction, shorter in width (space saving), non-ferrous metals are saved, and little maintenance.

The starting friction of a rolling-contact bearing is only one tenth of that of a plain bearing.

The shorter length of the rolling-contact bearing means that the journals can be shorter and, hence, shorter spanning widths than for plain bearings. Consequently, the overall length of axles and shafts can be diminished accordingly. Due to their shorter length and constructional peculiarities (self-aligning bearings), rolling-contact bearings match shaft flexure more easily than plain bearings. The fitting dimensions of rolling-contact bearings are standardized so that they can be exchanged at any time.

Plain bearings that are subjected to high stresses are usually made of non-ferrous metal.

Rolling-contact bearings do not have to be lubricated as often as plain bearings.

Consequently, lubricant consumption is lower. Low-maintenance and maintenance-free rolling-contact bearings are now also available.

The standardized rolling-contact bearing is an economical machine element in mass manufacture because it can be produced in large numbers, and it is supplied ready for installation without requiring any refinishing.

The application of rolling-contact bearings covers a very wide latitude from all kinds of instruments and machines, even the very smallest employed in fine-limit engineering, to the largest for heavy machine building. Rolling-contact bearings are therefore extensively employed in motor vehicles, fans and blowers, compressors, conveyors, farm machinery, machine tools, household appliances, electric motors and other items of equipment.

<p>Rolling-contact bearings permit rotary or oscillating motions of shafts, axles and wheels, and they transmit the supporting forces to the machine frame.</p>

3.4.1. Design

The counter-rotation of two raceways is possible as a result of the rolling members (balls or rollers) located between them. A rolling-contact bearing consists of two raceways, the rolling members, and of a cage that keeps the rolling members at the proper distance from each other (fig. 3/57). Some needle bearings rotate without a cage.

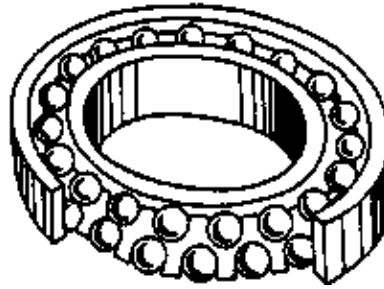
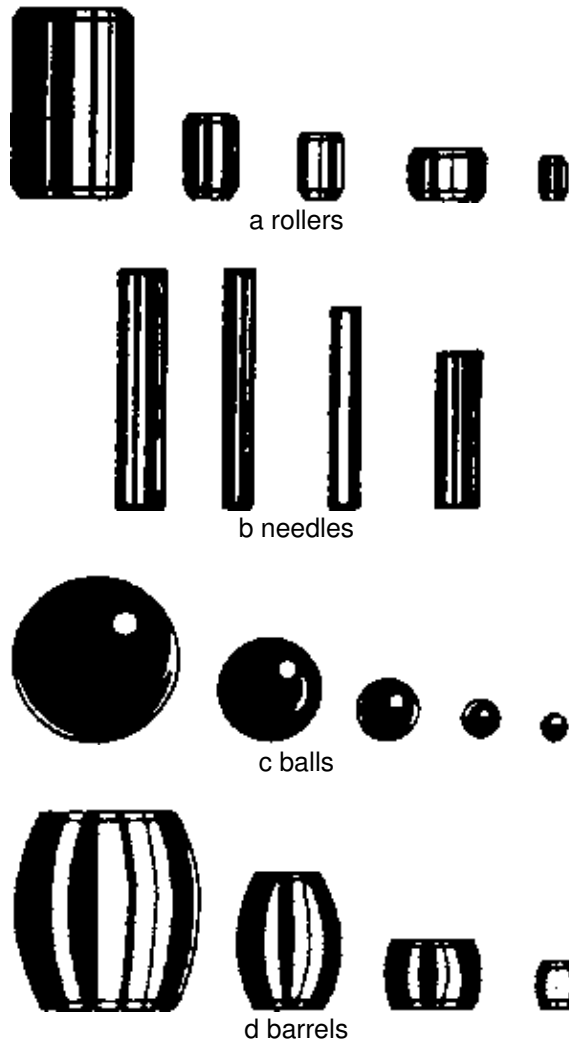


Figure 3/57 Parts of a rolling-contact bearing

1 outer raceway; 2 inner raceway; 3 rolling members; 4 cage

Figure 3/58 Different types of rolling members



Raceways

Figure 3/58 shows some of the different shapes that raceways may have. Raceways of bearings that take up radial forces are sometimes referred to as the inner ring and the outer ring, or the shaft ring and the housing ring. The same parts of bearings taking up axial forces are sometimes referred to as housing disk and shaft disk.

Cage

The cage is usually punched out of sheets. It sets the spacing between the rolling members of the bearing. The cages for heavy-duty bearings are machined from solid metal by drilling or milling. Cages made of plastics have the advantage of good sliding properties and low weight, and they produce little centrifugal and out-of-balance forces at high rotating speeds. Plastics also have soundproofing and vibration-damping properties.

Materials

Rolling-contact bearings are made of a material that can take up considerable stresses. High-grade chromium steel is used for this purpose. Rolling members and raceways are also made of steel (100Cr6 or 100CrMn6). Recent years has seen the rise of rolling-contact bearings made of plastics.

A rolling-contact bearing is composed of raceways and rolling members in the form of balls or rollers of cylindrical, tapered or barrel shape. The cage interposed between the two raceways separates the rolling members and keeps them at a defined distance from each other.

3.4.2. Stresses

The proper use of rolling-contact bearings presupposes careful analysis of the forces that will be acting upon the bearing.

Friction

The laws of mechanics apply to the movements of all bodies. Knowledge of these laws makes it possible to exploit them for one's own purpose. Hence, the friction of rolling-contact bearings is much lower than that of the rubbing friction of plain bearings. This phenomenon is exploited for the movement of heavy loads. These are placed on rollers so that they can be moved with less effort. The higher rubbing friction is replaced by the much lower rolling-contact friction, i.e. the resistance to movement is diminished.

Hardened rolling bodies roll on hardened and polished raceways, giving rise to rolling friction. The amount of rolling friction depends upon the condition of the base, upon the force applied vertically on the base, and upon the diameter of the rollers.

Static Load

The permissible load of a rolling-contact bearing (fig. 3/59) is known as the static bearing capacity. Bearings that are only completing slow oscillating motions during operation, or that are standing still, must not be subjected to loads that exceed their specified static bearing capacity because this will lead to premanent deformation of the parts of the bearing.

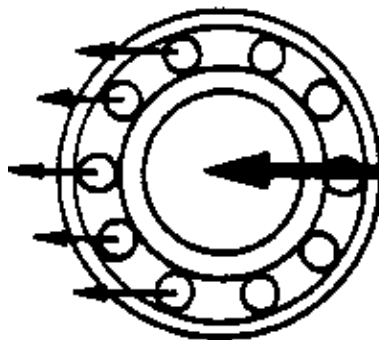


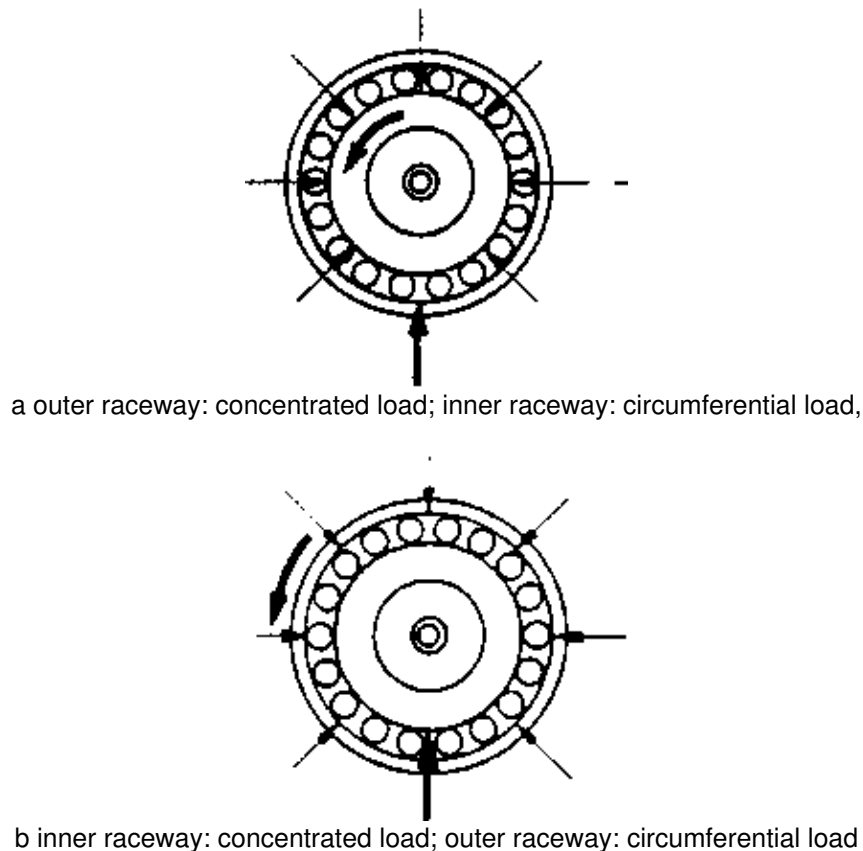
Figure 3/59 Raceway loads caused by the rolling members

Dynamic Load

Repeated permanent loading of the raceway material by the rolling bodies causes material fatigue in the form of peeling. This material stress to which rolling-contact bearings are subjected is known as roller pressing. The service life until material fatigue arises under operating load is known as the dynamic bearing capacity.

One of the rings of a rolling–contact bearing is subjected to a concentrated load, while the other ring is subjected to a circumferential load (fig. 3/60). With concentrated load, the operating stresses are always applied to the same point of the raceway ring. With circumferential load, the stress rotates or oscillated with the raceway ring.

Figure 3/60 Dynamic loading by the rolling members



Service Life

Prolonged operation results in raceway peeling. The removed material particles damage the remaining bearing. The period of operation until the first damage arises is known as the rated service life. 90 per cent of the bearings must last for 10^6 revolutions under a given load during testing. The practical service life must proceed from this rated service life under consideration of the factors that extend or shorten the service life. These factors are:

- The material, quality, size and internal design
- Loads, lubrication, mounting and temperature (external influences)

Dirt, inadequate lubrication, the flow of electricity (electro–corrosion), shock loads, incorrect direction of loading, and misfits, are all causes of premature bearing failure. Rolling–contact bearings are designed for differing service lives in keeping with their intended application. The designer aims at giving the bearing a service life that is equivalent to that of the machine into which it is incorporated.

3.4.3. Types

Rolling–contact bearings are distinguished by constructional features. Hence:

- By the shape of the rolling members (balls, rollers, needles)
- By the seating of the rolling members (groove, shoulder, inclined and self–aligning)

A difference is also made by the direction of the applied load:

- Radial bearing – load acts vertically in relation to the longitudinal axis (fig. 3/61).
- Axial bearing – load acts in the direction of the longitudinal **axis** (fig. 3/62).

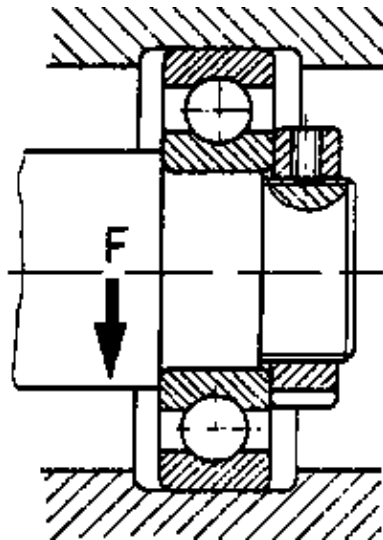


Figure 3/61 Radial ball bearing

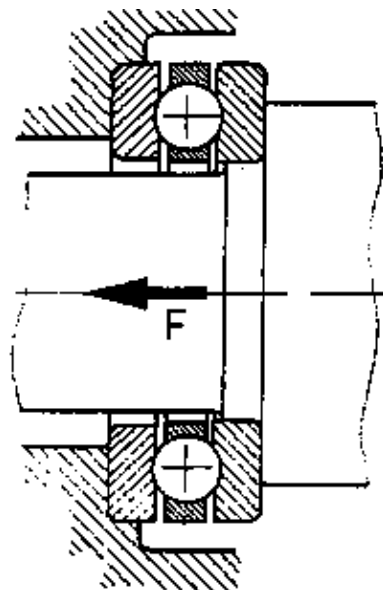


Figure 3/62 Axial ball bearing

Differentiation by the manner of mounting covers:

- Fixed bearing (inner and outer rings are secured against lateral shift) (fig. 3/63).
- Floating bearing (only the ring running relative to the direction of load is safeguarded against lateral shift, while the other ring is laterally shafttable within certain limits) (fig. 3/64).

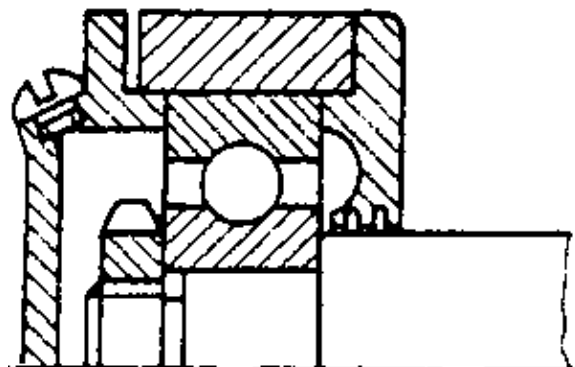


Figure 3/63 Fixed bearing

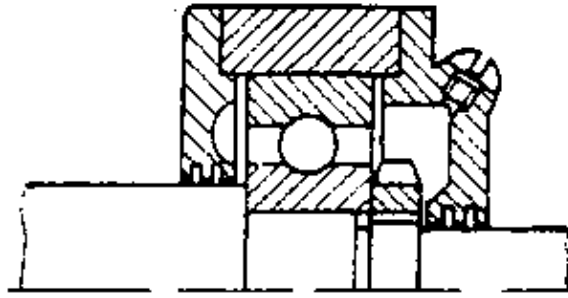


Figure 3/64 Floating bearing

Grooved radial ball bearings are the most frequently employed kind of rolling–contact bearing. Their standardized abbreviated code of designation specifies their form, dimensional series and bore characteristics. Outer and inner diameter are internationally fixed.

Bearing Code

Example: grooved ball bearing 6204

- The first digit defines the kind of bearing (6 = grooved ball bearing)
- The second digit (2) specifies the width series
- The third digit (0) stands for the diameter series
- The last digit (4) gives the diameter of the bore when it is multiplied by the factor 5 ($4 \times 5 = 20$ mm diam.)

3.4.4. Mounting Technology

Certain important mounting rules must be observed, irrespective of the shape of the rolling–contact bearing:

- Housing and shaft must be impeccably cleaned prior to mounting.
- No grinding (abrasive wheel, emery, etc.) or other dustdeveloping jobs should be completed in the workshop where bearings are being mounted.
- Bearings should be removed from their packaging only just before they are to be mounted.
- Bearings that have not yet been mounted should be covered during work intervals.
- Rolling–contact bearings should not be cleaned with blast air.
- Bearings should not be handled with moist hands (corrosion!).
- The mounting sequence should be carefully considered beforehand so that one can decide in advance which ring is the first one to be mounted.
- Mounted bearings must be protected against dirt during subsequent machining work.
- Check the fitting surfaces and edges for surface quality, dimensional accuracy and freedom of burrs. The fitting surfaces should be ground (depth of roughness: 1 to 2 μ m) or precision turned (depth of roughness: 4 to 6 μ m).

Excessive depth of roughness leads to a loss of diameter as the peaks of roughness are smoothed out during operation with the result that the initial tight fit is lost. The prescribed fitting tightness cannot be maintained any longer.

- No brushes should be used to clean rolling–contact bearings. Detergents should be flushed with light pressure through the bearing.
- The bearing must be immediately greased after it has been washed.

Mounting Self-retaining Bearings

The raceways of self-retaining bearings cannot be separated. Among others, this applies to groove ball bearings and to floating roller bearings.

For reasons of convenience, the outer ring with the fixed fit should be mounted first. In the majority of cases this will be the inner raceway. The fitting surfaces of bearing and shaft should be lightly greased before mounting.

When installing the bearing, the pressing-in force or blows should not be transmitted by the rolling members from one raceway to the other. The bearing must always be driven in by the raceway that will have the fixed seat.

On no account should the blows of a hammer strike the body directly. The cage will be damaged as a result of this, and it will even break. Furthermore, the rolling bodies will be pressed into the tracks of the raceways, causing permanent deformation and rapid failure of the bearing.

Bearings must not be tilted while they are being mounted.

That is why it is inadvisable to use a copper plug to transmit the fitting forces to the ring. One-sided pressure makes tilting inevitable, even if the light blows are successively spread out over the entire circumference.

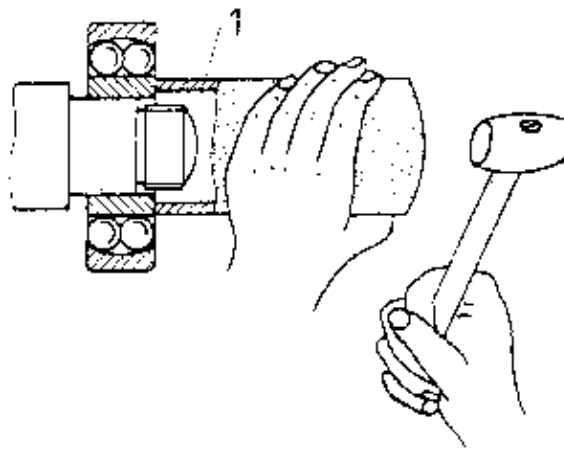


Figure 3/65 Driving a rolling-contact bearing on to a journal

1 pipe section

A sleeve made of hard wood, brass or steel with a face-turned end is used to drive a bearing on to a shaft by light blows with a hammer (fig. 3/65).

No dirt or burr particles must penetrate into the bearing from the tapping sleeve or plug because they will damage the bearing in a very short time.

Presses are used to press bearings on shafts when mounting work involves a large number of bearings. Care must be taken to ensure that both raceways of the rolling-contact bearing are resting firmly against the base plate (fig. 3/66). The raceways can become deformed by the rolling members if this is not assured.

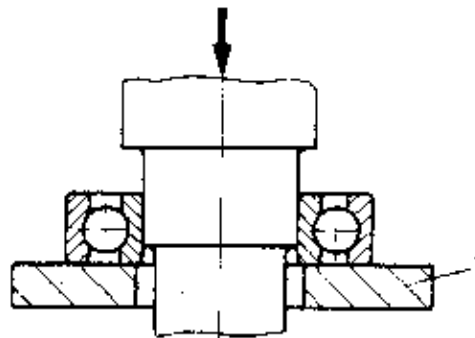


Figure 3/66 Pressing a journal into a rolling-contact bearing

1 base

Preheating of the bearings to a temperature of between 70 and 80 °C in a bath of oil has proved to be very useful for efficient mounting.

Appropriate conveying facilities (fig. 3/67) will remove the bearings from the oil bath and slip them on to the shaft without loss of time. Contraction of the bearing, as it cools down, gives it a tight fit on the shaft.

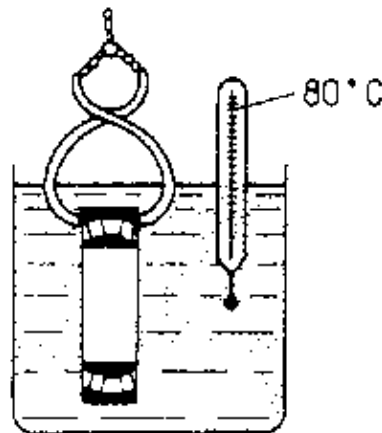


Figure 3/67 Heating a rolling-contact bearing in an oil bath

Only absolutely clean mineral oil and clean containers must be used for preheating.

Appropriate conveying facilities should be used wherever possible. This is because fibre particles can enter the bearing if it is held with a rag.

The ring should be slipped on until it rests firmly against the collar of the shaft. The radius of the transition from the fitting surface to the shaft collar is smaller than the radius of the bearing ring. There is no tilt if the ring rests perfectly against the collar. Spacer rings (fig. 3/68) are fitted when the resting surface on the shaft is not high enough or when the transition radius at the journal is too large (in the interest of added strength). Locking nuts (see Section 3.1.4.) and other facilities are employed to lock the bearing in axial direction.

Figure 3/68 Spacer rings



a) when the transition radius of the journal is too large,



b) when the resting surface is not high enough

Much lower fitting forces are used to mount the housing ring on account of its lighter fit. Appropriate bore tolerances allow any kind of fit. The rules applying to the fitting of the inner ring apply equally to the outer ring.

A disk (fig. 3/69) is placed in front of the bearing when the bearing has to be simultaneously pressed on to the shaft and into the housing. The same applies also to the self-aligning bearing so that the outer ring cannot become dislocated.

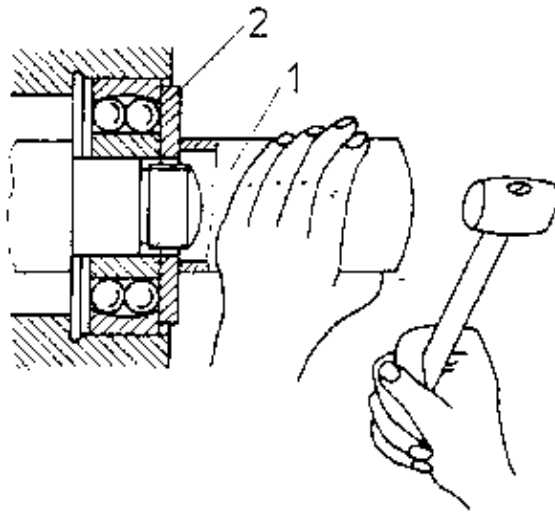


Figure 3/69 Rolling-contact bearing is simultaneously pressed on to the journal and into the housing

1 pipe section; 2 washer

Mounting work must take into account that the rings are elastic. The firm fit extends the inner ring and compresses the outer ring. Form deviations of the shaft or housing fitting surface are transmitted to the bearing. The original bearing clearance is diminished to nill when the fit is too tight so that the bearing will become jammed.

The mounted bearing must be tested for free movement.

Fixed and Floating Bearings: The temperature in transmission gears increases during operation. This heat causes expansion of the parts, eventually jamming the bearing and leading to impermissible axial loads. This can be prevented if the two rings of the fixed bearing are fixed in axial direction, while the ring with the loose fit of the floating bearing is shiftable in axial direction (fig. 3/70).

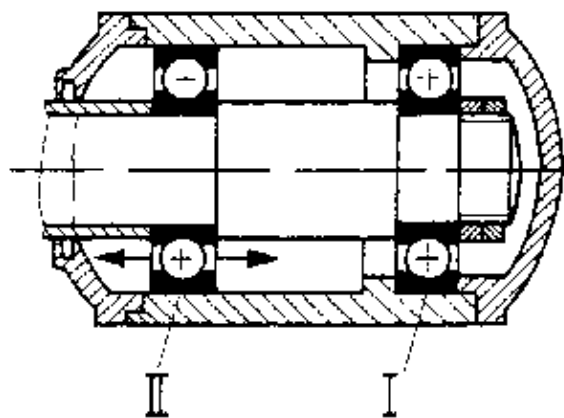


Figure 3/70 Fixed and floating bearing on a shaft

I fixed bearing; II floating bearing

Mounting Bearings that are Separately Joined

It is a definite advantage if the raceways can be separated while the bearing is being mounted. This is the case with cylinder, taper and needle bearings. Here too, the same mounting rules have to be observed, namely that the rings are not tilted, that they have the correct allowance, that they rest firmly against the stop collar, and that they are not damaged. The raceways of cylinder roller bearings (they are specifically identified) must not be exchanged with raceways of other bearings of the same type. If bearings are used once again after maintenance work, it is essential to ensure that the raceways of the individual bearings are not exchanged. The bearing point on the axle accepting a cageless needle bearing must be thickly coated with grease. Furthermore, the needles themselves must be firmly bedded in grease. The outer ring is then carefully slipped on, taking care to ensure that the needles do not fall out.

Needles should not be exchanged between bearings!

Needles must be stored in specifically identified containers when bearings are removed to make sure that the same ones are once again installed in the same bearing. This is because wear caused by operation is not uniform with each individual bearing.

After longer periods of operation it is necessary to measure the width and depth of grooved needle bearings to establish the dimensional accuracy. Worn down grooves must be reground and correspondingly larger needles must be fitted.

Adjusting the Bearing Clearance

When a shaft is supported by several groups of bearings, only one bearing (the fixed bearing) should be firmly seated in the housing. The other bearing (the floating bearing) is then checked for freedom of axial movement. This is done to ensure:

- That inaccuracies in machining and mounting can be compensated for.
- That tensions through thermal expansion are prevented (fig. 3/70).

All parts of an assembly are not heated to the same extent during operation so that expansion will not be uniform.

Axial bearings are mounted separately. The shaft washer is pushed on to the shaft. The housing washer with the somewhat larger inside diameter (which is not fine-finished) is pressed into the housing. When axial ball bearings are mounted, care must be taken to ensure that the raceways are at a right angle to the shaft, and that they run concentrically in relation to each other.

- Axial freedom with normal bearings: 0.02 mm
- Axial freedom with precision bearings: 0.01 mm

The axial bearing clearance should amount to between 0.05 and 0.1 mm. A plane-parallel ground intermediary washer must be interposed between the adjusting facility and the bearing washer (fig. 3/71).

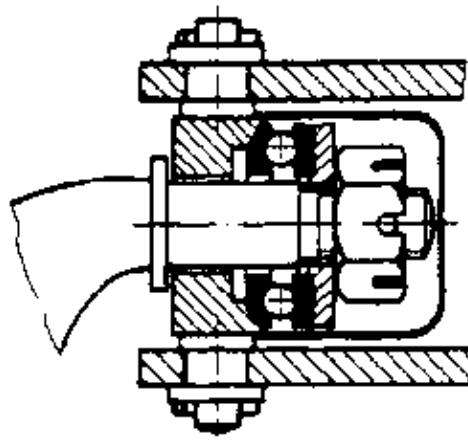


Figure 3/71 Axial bearing on a load hook

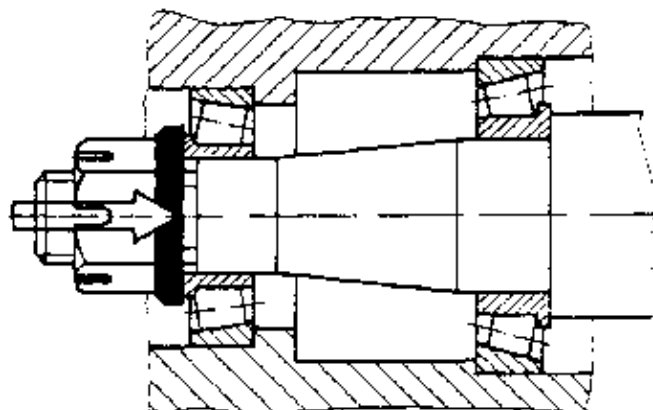


Figure 3/72 Adjusting the bearing clearance on a tapered roller bearing by axial shifting of the raceways

The clearance of shoulder and tapered roller bearings is adjusted with a setting nut (fig. 3/72). The born part must rotate freely after the setting nut has been tightened. The amount of clearance is adjusted by shifting the inner ring. The movable ring can be fixed in its correct position by fitting washers and setting rings instead of by a crown nut.

Checking the Bearing Clearance

Three courses can be adopted to check the bearing clearance:

- A feeler gauge is employed to check the clearance of larger bearings; the clearance of multi-row bearings must be the same in each row.
- Clearance can also be established by rolling over a lead wire; the flattened side is then measured.
- The clearance of smaller bearings is established by manual rotation of the shaft. The shaft must rotate freely without any noticeable play.

Bearing Lubrication

Bearings should never run dry, i.e. without lubrication, and this also applies to trial operation. Generally speaking, bearings that are grease lubricated should be half filled with grease. The higher the rotating speed, the lower the quantity of grease in the bearing. A full filling of grease is only applied to slow-running bearings where the grease simultaneously takes on a sealing function. Excessive grease filling means that rolling-contact bearings must perform an additional grease-kneading function with the result that bearing and grease become impermissibly hot. The grease drains out of the bearing, leading to premature wear. Bearings running at high speeds are lubricated with oil very high speed bearings are lubricated with dripping oil or by oil mist consisting of a mixture of cleaned compressed air and oil. The latter simultaneously has an extra cooling effect. Other common lubricating methods include immersion lubrication and circulating-oil lubrication for engines, splash lubrication for transmission gears, and forced lubrication for turbines and motors.

The oil level of the oil-bath system must be filled to the centre of the lower rolling body.

The higher the speed, the less oil and the more mobile the oil.

The maintenance of rolling-contact bearings covers constant inspection for wear because the operating reliability and efficient performance of the machine depend upon this factor. Bearing wear can cause sudden blockage of high-speed motors.

Running-in Rolling-contact Bearings

After the bearings have been mounted, manual turning of the shaft will usually reveal whether it is running properly in its bearings. The running speed is slowly increased until top speed is reached. A uniform humming noise indicates perfect running of the bearings. Noise testing should be applied during the running-in period (table 3/7). For this purpose, the ear is pressed against the handle of a screwdriver while the blade end is brought into contact with the bearing housing.

Table 3/7: Running-noise Testing of Rolling-contact Bearings

Noise	Cause
Rough knocking noise	Soiled by dust
Regular or irregular scratching noise	Soiled by shavings, sand and other foreign particles
Whistling noise	Insufficient lubrication
Regular friction, sometimes with scraping noise	Jammed foreign body, coarse shavings or cracked rolling member
Metallic ringing to howling noise	Insufficient bearing clearance

Dismantling Rolling-contact Bearings

For general overhauls the bearings are removed, cleaned and then carefully examined. Even the smallest blemishes on the raceway or rolling members make it necessary to replace the defective bearing by a new

one. This is because even the minutest faults in the raceway will quickly cause complete destruction of the bearing.

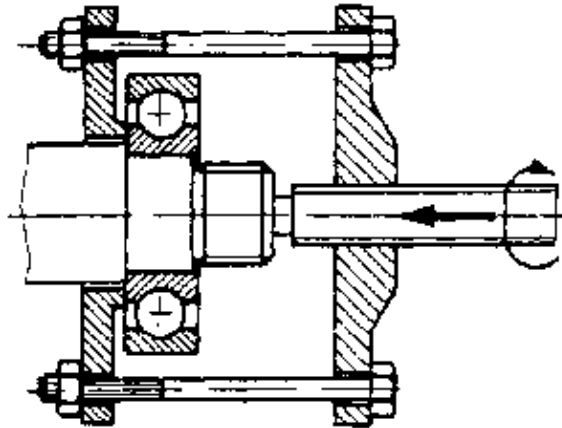


Figure 3/73 Dismantling a rolling-contact bearing with a simple drawing-off device

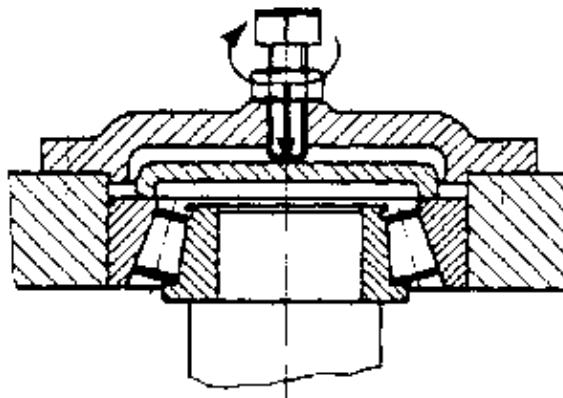


Figure 3/74 Pressing out an outer raceway with a forcing screw

Figures 3/73 and 3/74 show different possibilities to remove rolling-contact bearings. Figure 3/73 shows the removal of a bearing from a shaft with the help of a simple draw-off tool. Figure 3/74 shows how the outer ring of a tapered roller bearing is pressed out of the housing cover with a forcing screw.

3.4.5. Comparison of Plain Bearings and Rolling-contact Bearings

Table 3/8 gives a comparative survey of the plain bearing and the rolling-contact bearing.

Questions:

1. List the principal parts of a rolling-contact bearing.
2. Explain the procedure for running noise testing of rolling-contact bearings.
3. Which rolling-contact bearings are best suited for compensating axis deviations (flexure of the shafts)?

3.5. Guideways

Machine parts that complete straight motions receive positive guidance. The tool slide of a lathe, or the machine table of a milling machine, are guided by a straight slideway in the machine bed.

Guideways are machine elements that assure positive linear or other motions of machine parts.

3.5.1. Design

If the purpose of guiding machine parts along certain tracks is to be achieved, some of the diverse possibilities of movement of the guided part have to be restricted. Theoretically, every body can be rotated around each of its three axes, and it can be moved in the direction of the body axes (fig. 3/75). Disregarding the fact that every rotary and linear motion can proceed in one or the opposite direction, this means that a total of six movements are possible. This freedom of movement is generally known as the degree of freedom. Hence, every body has six degrees of freedom. A guideway usually limits five of these movements, leaving only the longitudinal motion (fig. 3/76) in one axis of the body.

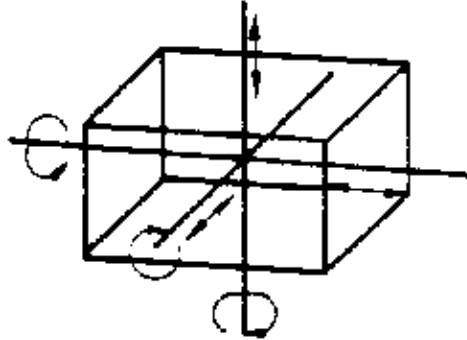


Figure 3/75 Degrees of freedom of a body in the space

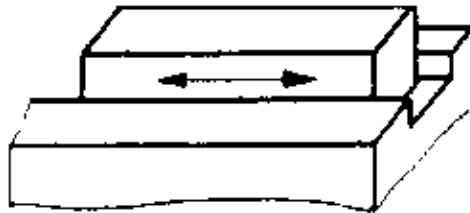


Figure 3/76 Degrees of freedom of a longitudinally guided member

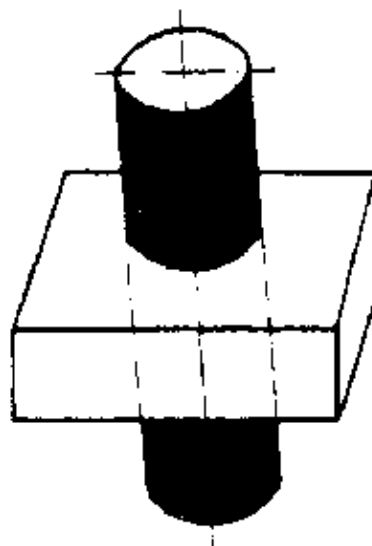
Table 3/8: Comparison of Plain and Rolling-contact Bearings

	Plain bearings	Rolling-contact bearings
Direction of load	a) Vertical in relation to axis of rotation (radial) b) Parallel in relation to axis of rotation (axial) c) Vertical and parallel in relation to axis of rotation	a) Vertical in relation to axis of rotation (radial) b) Parallel in relation to axis of rotation (axial) c) Vertical and parallel in relation to axis of rotation
Rotating speed	High speeds can be achieved with appropriate materials (e.g. white metal, lead bronze) provided that the running surfaces of the shafts and bushes are perfectly smooth, tightly sealed and properly lubricated.	Particularly suited for high speed; undemanding lubrication.
Bearing play	Less than for rolling-contact bearings	Bearing play can only be eliminated by special constructional measures.
Load-carrying capacity per cm bearing width	Small	Large
Running-in time	Considerable	None
Advantages	Silent, vibration-free running, depending upon the material; high trueness of rotation; less sensitive to jolts and brief overloading; less sensitive to dirt;	Within smaller to medium ranges, friction is independent of speed, load and temperature; low starting-up friction; develops little heat; undemanding

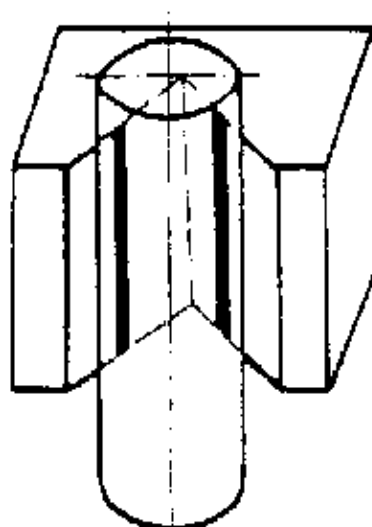
	corrosion-resistant and acid-proof bearings can be produced; can be manufactured for the smallest diameters; low-cost fabrication (self-made, i.e. workshop manufacture is possible).	maintenance; standardized dimensions for simple replacement at any time; no running-in; bearings can be easily stocked; low-cost mass manufacture by automatic machines.
Disadvantages	Lubrication must be constantly checked; friction depends upon speed, load and temperature; friction is higher than that of rolling-contact bearings; plain bearings are not so easily exchanged; stocking of plain bearings is not readily possible.	High demands expected of geometric accuracy and surface quality of seating and supporting surfaces for rolling-contact bearings; high demands expected of the quality of the rolling surfaces; sensitive to dirt and shocks; produces running noise; limitations regarding the smallest possible sizes; constructional reasons restrict the possibilities of installation; cannot be self-made, i.e. dependent on outside suppliers.

Usually, the two superimposed parts have plane, open and separated sliding surfaces. The sliding surfaces of round guideways have an enclosed part within which the other parts slide (fig. 3/77).

Figure 3/77 Closed and open guidance



a) closed guideway



b) open guideway

In order to limit five degrees of freedom, the guided part requires at least one slideway and one guideway on

the guiding assembly.

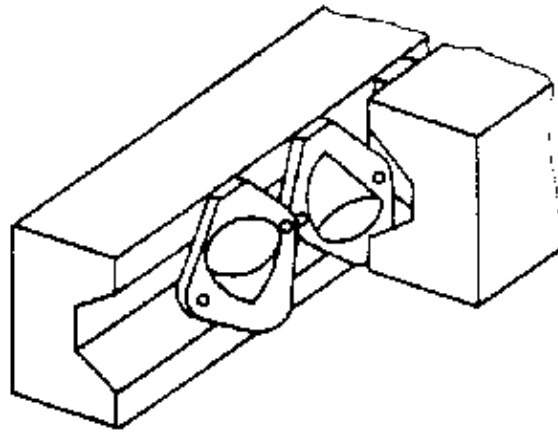


Figure 3/78 Roller guides

If the slideways are impermissible on account of frictional resistance at inching speeds or for the finest settings, then these must be replaced by roller guides (fig. 3/78).

The advantages of such roller guides are:

- Negligible wear
- Lubricating film thickness independent of loads so that the table height always remains the same
- No noticeable difference between rest resistance and roll resistance
- No jerky movements at inching speeds and for minute setting distances

3.5.2. Stresses

The slideways and guideways of machine tools usually form an integral part of the machine frame. Hence, they are often made of grey-cast iron. Wear arises when metallic surfaces slide upon each other. This means that the tracks of the guideway and of the guided part are subject to wear. This is present in the form of:

- Abrasion wear; minute particles of material are removed and are held in free suspension in the lubricant.
- Sliding wear; minute particles of material are removed, causing considerable local surface pressures at other points which become fused into the surface of the slideway track in a similar manner as cold pressure welding. In the workshop this is known as seizing.

The following characteristics are expected of materials that are used for slideways:

- Wear resistance
 - Good sliding properties
 - Good lubricating properties
- The following material combinations can be adopted for slideways:

Guideway:	soft	hard	hard
Guided part:	soft	hard	soft

The third combination has proved to be very effective, i.e. a soft slide on a hard track. The slide is made the wearing part so as to achieve good sliding properties. This is because it is easier to replace or refinish than the guiding track.

The required hardness of the guideway of the machine frame after milling or planing is secured by flame hardening or induction hardening with subsequent grinding. Planing or milling of the sliding surface of the slide

is possible if accuracy demands are not so stringent. Shaving is employed for highest standards of accuracy. The combination ground guideway and shaved surface on the slide results in particularly good lubricating properties.

Lubricating the Slideways

In order to reduce wear to an absolute minimum and achieve favourable sliding properties also with the shortest feed rates, e.g. as applied to grinding machines, the guideways have to be lubricated. At creep speeds of a few millimeters per minute, no lubricating oil wedge can be formed, as is the case with plain bearings.

Pressure lubrication can build up a load-carrying lubricating film. Its thickness, however, may depend upon the load and therefore on the cutting forces. This drawback is compensated by appropriate separate setting of the lubricating pressure for each guideway. The lubricant is supplied by:

- Hand oiler (for undemanding applications)
- Wicker lubrication (for simple demands)
- Ball-type lubricating valve (is linked with the pressure line and opens as the slideway passes over it; fig. 3/79)
- Lubricating rollers (dipped in oil for transfer to the slideway during travel; fig. 3/80)

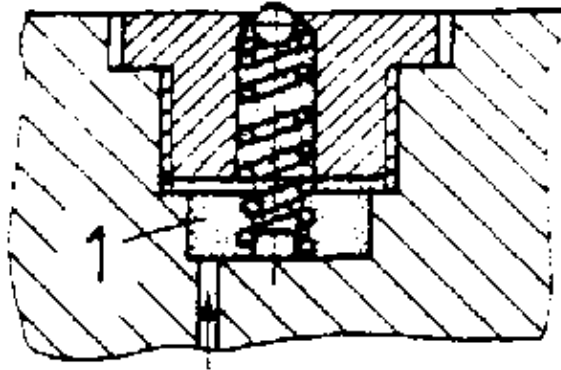


Figure 3/79 Pressure lubrication with ball-type valve

1 pressure oil

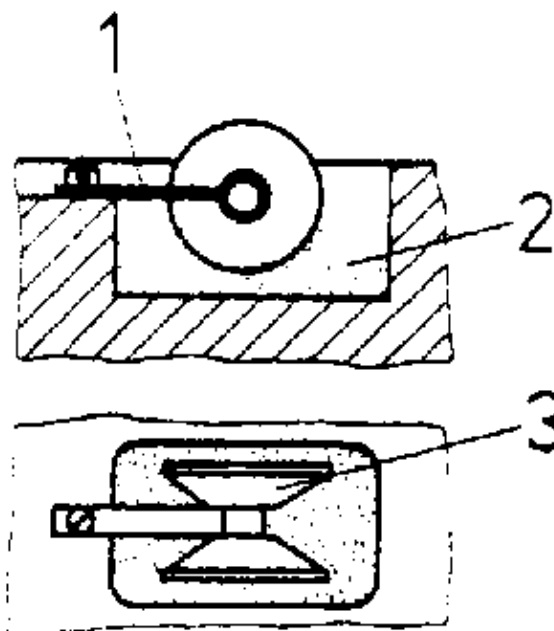


Figure 3/80 Immersion lubrication by lubricating rollers

- 1 spring;
- 2 oil supply;
- 3 lubricating roller

Lubrication of Rolling–Contact Guides

Rolling–contact guideways require much less lubricant so that efficient lubrication of the roller–contact guides should be no problem. Oil is normally applied, and it is fed to the guides by wicker or rollers.

Protection of the Guideway

The table and slide guides of cutting machine tools are particularly exposed to shavings, abrasive dust, etc. These particles mix with lubricant, forming a very effective abrasive medium. To offset the danger of wear, the guideways are often covered by plates. Felt seals to retain dirt particles are only conditionally suitable. The felt holds the particles. These become embedded in the felt, gradually giving it an abrasive action as it becomes harder. That is why the felt must be continuously supplied with oil to keep it soft.

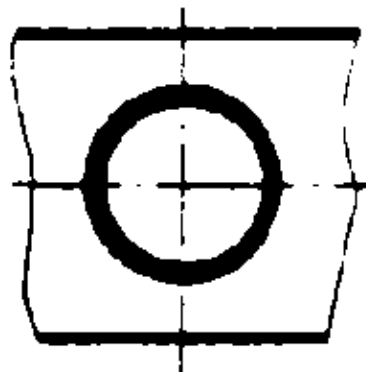
3.5.3. Types

Guideways are classified by their manner of friction. Hence:

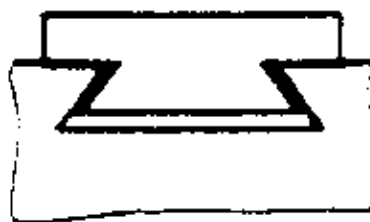
- Slideways
- Roller–contact guides

They are also distinguished by their shape (figs. 3/81 and 3/82).

Figure 3/81 Closed guideway

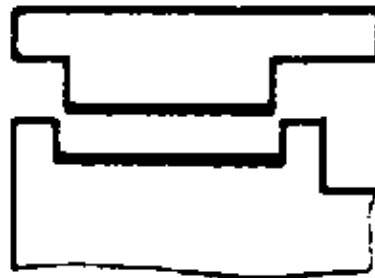


a) circular guidance

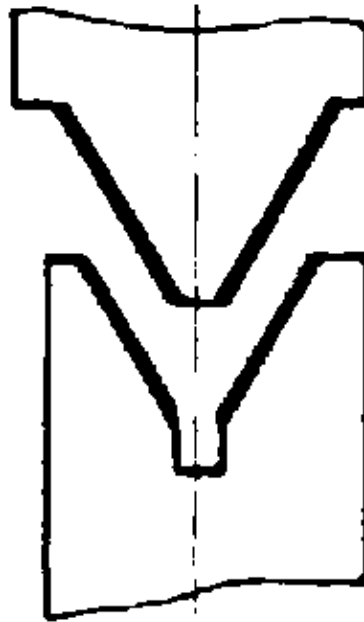


b) dovetail guidance

Figure 3/82 Open guideway



a) flat track



b) V-guideway

3.5.4. Mounting Technology

Planing or milling is sufficient when the demands expected of accuracy are not exacting, e.g. for vices.

The guides for tables and slides of machine tools demand higher standards of surface quality and closer tolerances. Guideway tracks made of steel are ground on special machines. The tracks of the guided parts, often made of grey-cast iron, are shaved in a mounted condition to achieve close tolerances and good lubricating properties.

Shaving removes minutest quantities of material to smoothen the workpiece surface, eliminate machining marks, and to remedy errors of shape.

Shaving involves several operations. The result is inspected after each operation, and the shaving direction is then changed. The shaving depth diminishes with each pass until an impeccable surface is obtained (table 3/9).

Table 3/9: Operations and Surface Quality of Shaved Surfaces

Operation	Shaving depth in mm	Number of peaks per cm ²	Number of passes
Dressing	0.03	2 to 3	about 3
Rough/shaving	0.02	3 to 5	about 5
Finish shaving	0.01	6 to 8	about 10
Fine shaving	0.005	10 to 14	about 15
Super-fine shaving	0.003	15 to 20	over 20

Plane surfaces are obtained in three operations:

- Rough shaving
- Spot shaving
- Honing shaving

Rough shaving removes machining marks by long shaving strokes set at 45° in relation to the machining direction. The result of rough shaving is checked with a master surface plate after all machining marks have been removed.

The master surface plate reveals deviations of shape (irregularities) of the workpiece surface with the help of ink.

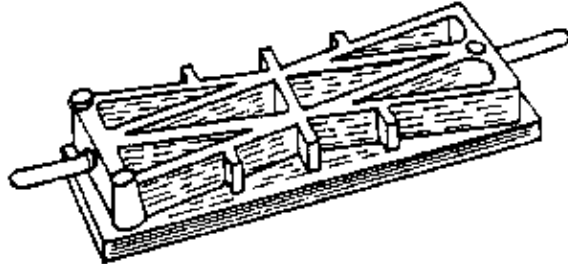


Figure 3/83 Master surface plate strengthened by ribs for dimensional stability

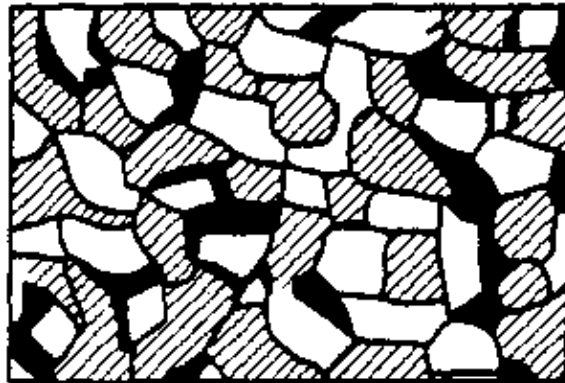


Figure 3/84 Contact pattern on a workpiece

For this purpose, the master surface plate is covered with marking ink (fig. 3/83). The master surface plate has an optically flat surface that is used as a plane of reference. The surface of the workpiece that is to be tested is moved with light pressure to and fro over the reference surface of the master plate (the procedure is reversed for large workpieces). This produces a contact pattern on the surface of the workpiece (fig. 3/84) from which the following conclusions may be drawn:

- Parts that are not marked with ink are the deepest parts (valleys), in the surface
- Parts that are weakly marked with ink indicate the highest points (peaks) on the surface
- Intensely inked points indicate the mean surface level

The marking ink must be applied as thin as possible and as uniformly as possible on the reference plane of the master surface plate.

The object of spot scraping is to increase the number of peaks. The weakly marked points of the contact pattern, i.e. the highest points on the surface, are removed by shaving (fig. 3/85). The removal of a peak produces two new lower peaks.



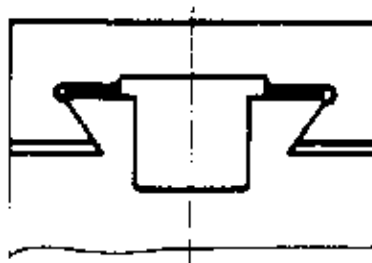
Figure 3/85 Principle of spot scraping

The final honing–shaving operation removes the remaining individual peaks, producing a contact surface in the order of 70 per cent.

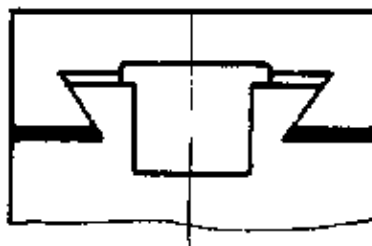
Joining Dovetail Guides

The slideway and guideway of dovetail guides are separate. The sliding surfaces can be on top or underneath (fig. 3/86a and b). The surfaces rest upon each other at an angle of 55° . Special measuring assemblies and conversions are necessary to check the spacing of the surfaces and their parallelity (fig. 3/87). Since dovetail guides are usually fitted with guide plates, guiding clearance can be adjusted with great sensitivity with the help of pressure screws.

Figure 3/86 Dovetail guides



a) with sliding surface on top



b) with sliding surface underneath

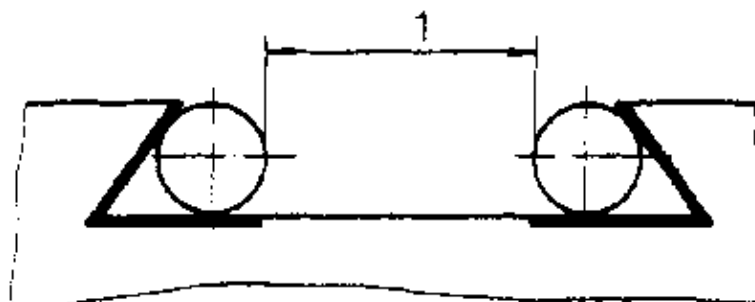


Figure 3/87 Checking the spacing of a dovetail guide

1 gauge

Testing functional accuracy: The joined parts must be tested for ease of movement and functional accuracy. For this purpose the guided parts are moved from one end position to the other on the guide. A dial gauge and straight edge (fig. 3/88) are used to measure continuously, or at certain intervals, the deviations from the ideal track. The results are entered in a test protocol. The deviations must be within the permissible allowance. The tracks of rolling–contact guides can be measured in the same manner.

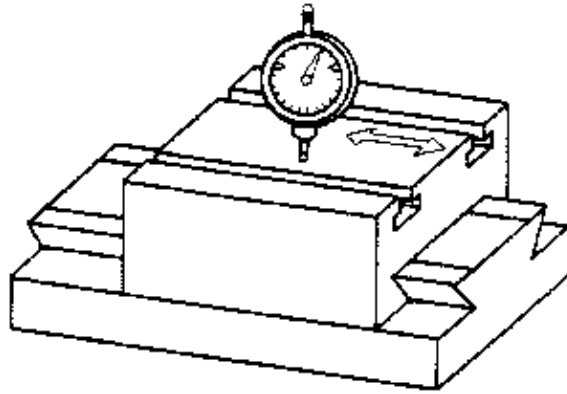


Figure 3/88 Checking for deviation from ideal track

Questions:

1. Deduct the causes of jerky movement of slideways from the differing values for adhesion and sliding friction.
2. Suggest different measuring assemblies to measure the planeness and parallelity of surfaces.

3.6. Couplings, Clutches and Brakes

Two

Two shaft ends or live parts often have to be connected to transmit power. Such links between shaft ends are common because shafts cannot be produced with an indefinite length and cannot be transported. Consequently, for reasons of convenient mounting, several shorter shafts are permanently connected by couplings.

Sometimes it is necessary to divert torque in machine tools. Special couplings make it possible to link up the two shaft ends at a certain angle to each other. On many machine tools, motor vehicles, etc., it is often necessary to connect and disconnect driving and working mechanisms at will. This is accomplished by couplings known as clutches. Furthermore, driving parts can be protected against overloads by couplings. Small deviations of parallelity or angularity of shaft ends can be compensated by couplings. Shock loads arising in machines can be damped by couplings to protect subsequent driving parts from the effects of these shocks.

Shaft couplings and clutches are elements that connect shafts and transmit torque and rotary motions.

3.6.1. Design

Clutches connect two shaft ends. Basically, they consist of flanges mounted on each shaft end and of bolts, wedges or shrink joints that establish frictional connection, or pins and springs for positive connection.

Friction Clutches

The pressing force between the two halves of friction clutches is generated by springs, bolts or magnetically (fig. 3/89). This action presses the friction surfaces together. The pressing force of transmission clutches must develop a frictional resistance that is greater than the maximum turning effort. If the turning effort is higher, the clutch will slip. A certain frictional resistance is adjusted when only a defined turning effort has to be transmitted so that subsequent driving elements are protected from overloads. Clutch slip will offset overloads only for brief periods. This is because prolonged slip generates so much heat that the coupling soon becomes useless.

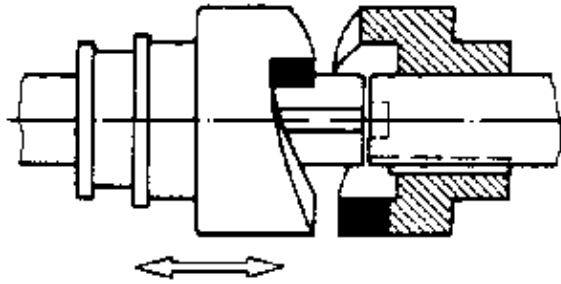


Figure 3/89 Generating the pressing force between two halves of friction clutches by screws

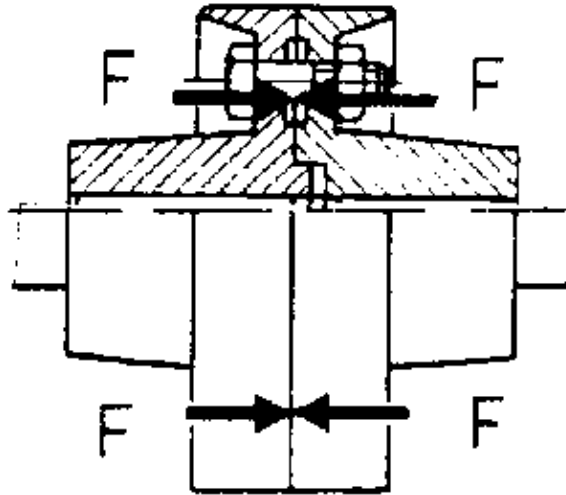


Figure 3/90 Forms of positive-action engagement of clutches

Positive-action Clutches

The positive-action clutch employs teeth or lugs that engage in grooves to transmit the turning effort (fig. 3/90). This type of clutch is not so suitable for limiting the transmitted torque.

3.6.2. Stresses

Clutches must transmit dependably a certain amount of power from the driving shaft to the driven shaft. The size of the clutch is determined by the torque that has to be transmitted. Next to possible compensation of positional deviations of shafts and shock loads, the choice of clutch depends upon the amount of power that has to be transmitted. Normally, a clutch is selected that is capable of transmitting two to three times the torque or coupling moment.

3.6.3. Types

Couplings are distinguished by the manner in which the link is established, i.e. into permanent couplings and into clutches.

Permanent Couplings

These couplings establish a permanent link between two shaft ends. They are employed under the following conditions:

- When torque transmission between the two shaft ends does not have to be disconnected.
- When the transmitting assembly is composed of several inter-linked shaft sections.
- When machines are to be permanently inter-linked.
- When vibration and shock loads are to be damped.
- When axial, radial or angular shifts at shaft ends are to be compensated or achieved.

Rigid Couplings

Rigid couplings do not allow for any relative movement between the driving half of the coupling and the driven half. Hence, they are composed of two, precisely aligned shafts that are permanently connected.

Safe, positive transmission of the turning effort is the most important consideration of a rigid coupling. The frictional resistance at the coupling must be larger than the torque that is to be transmitted (e.g. disk clutch, compression coupling).

Disk couplings: (fig. 3/91) These are preferred for medium to heavy shafts. The hubs of these pressed-on or shrunk-on clutch disks are locked against twist by fitting bolts or wedges. The two disks are pressed together by bolts for force-closed torque transmission. Shafts of differing diameter can be connected in this manner, and they are suited for high powers.

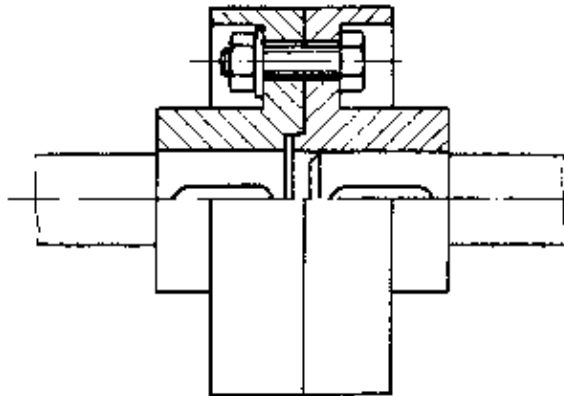


Figure 3/91 Disk clutch

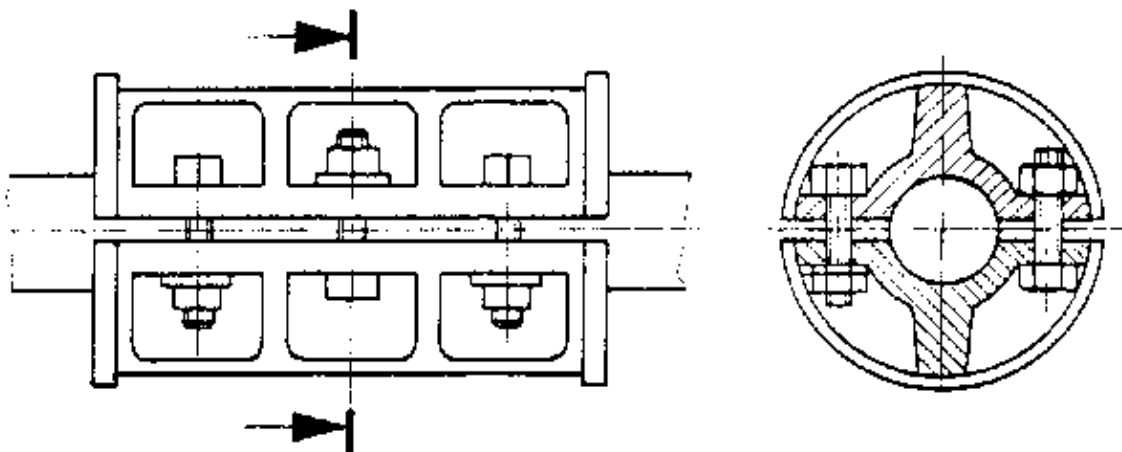


Figure 3/92 Compression coupling

Compression couplings: (fig. 3/92) They are used to link shafts of differing or identical diameter. The two shell halves are mounted on the shaft ends and are firmly pressed together by bolts. The press fit ensures that the shell halves are firmly seated on the shafts. A spline that engages in the notch of the other half of the shell prevents slip. The force-closed link of the two shaft ends is only positively engaged by the spline in the presence of overload. A sheet of metal can be wrapped around the coupling to prevent accidents.

Compensating couplings: These allow for a certain amount of relative movement between the two halves of the coupling.

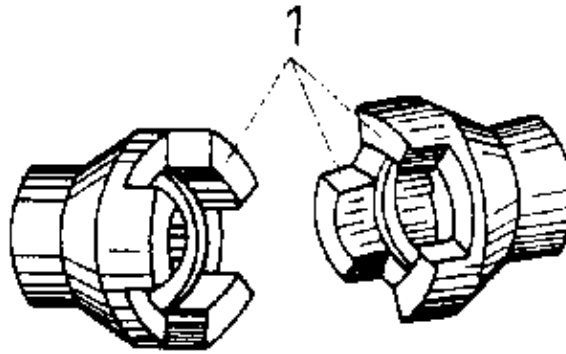


Figure 3/93 Claw coupling

1 claw

Claw couplings: (fig. 3/93) They consist of two identical coupling halves provided with claws on their face sides. They compensate axial differences in shaft length (influence of temperature, bearing clearance). Torque transmission is positive.

Clutches

These are couplings provided with elements to engage or disengage at will the driving section of the coupling with the driven section.

Clutches transmit torque by:

- Positive transmission by means of claws, teeth, bolts, etc.
- Frictional transmission

Positive clutches can only be actuated while idle or during synchronized rotation. Friction clutches, on the other hand, can be asynchronously actuated, i.e. during operation.

Positive clutches: Most of these can be disengaged during operation but, as opposed to friction clutches, can only be engaged again when idle or during synchronized operation. They are normally designed as claw or toothed clutches. If one of the clutch halves can be shifted on the shaft by splines and is provided with a corresponding mechanism to complete the shifting movement, then the teeth can be engaged or disengaged at will, provided that the two members have the same angular velocity. The engaging types of clutches are subject to surface pressure at the contact surfaces (fig. 3/94).

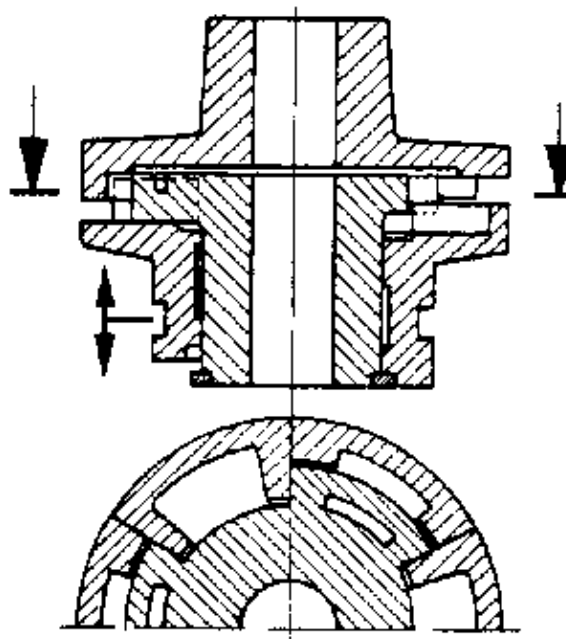


Figure 3/94 Shiftable claw coupling

Friction clutches: The torque is transmitted by friction between the two clutch surfaces as they are pressed together. They are fitted with clutch linings that can be easily replaced after wear. Clutches based exclusively on metallic frictional surfaces always require an oil bath to prevent seizure. The force required to press the two clutch members together can be generated mechanically (e.g. by springs), hydraulically, pneumatically or electro-magnetically.

A distinction is made by the arrangement of the frictional surface, i.e. jaw clutches, conical clutches and disk clutches. A coupling consisting of several thin disks is also known as a multiple-disk clutch.

The single-disk dry clutch is one of the most important types that can be actuated during operation. It is extensively employed on motor vehicles (fig. 3/95).

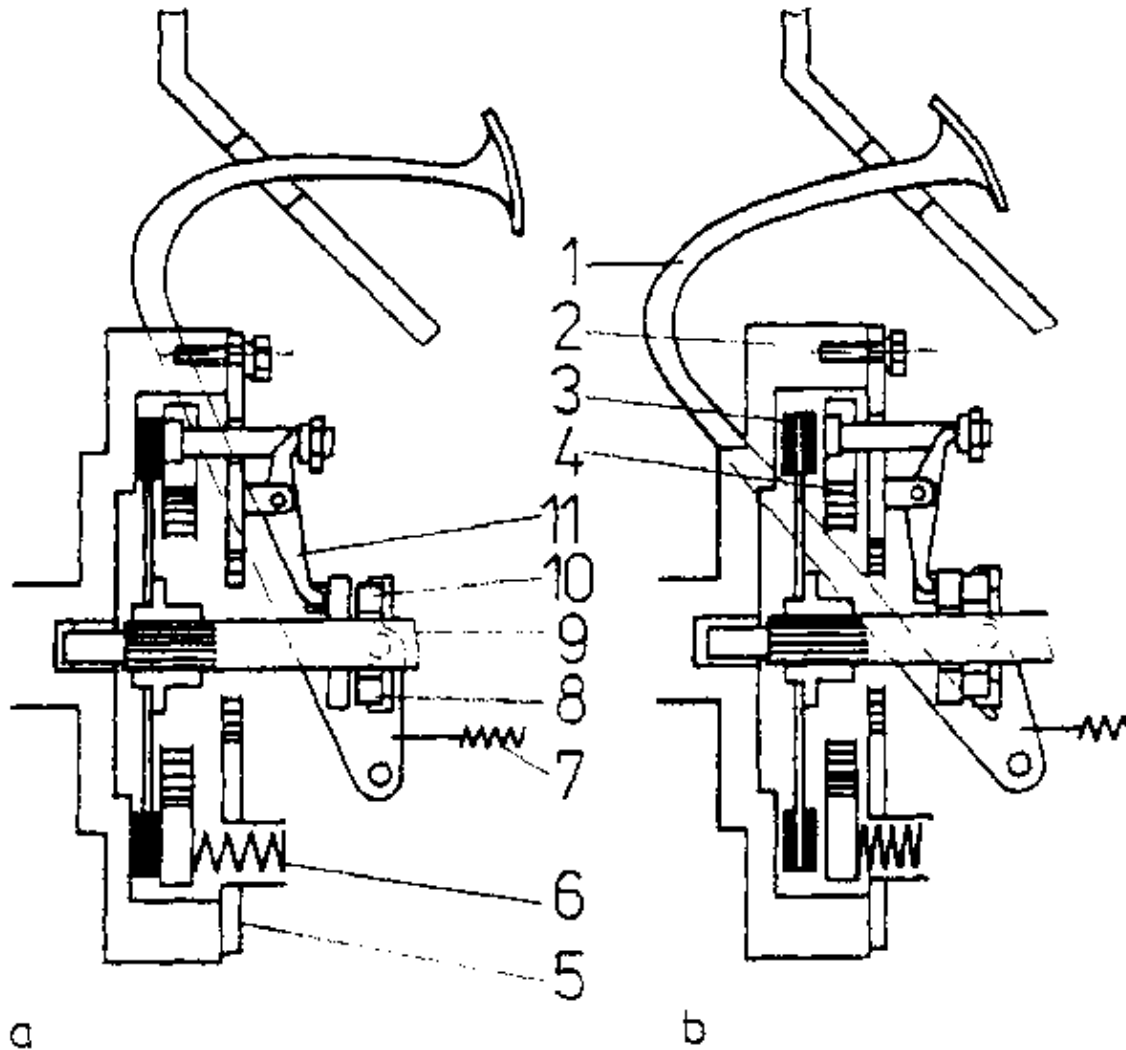


Figure 3/95 Single-disk dry clutch: a) engaged; b) disengaged

1 clutch pedal; 2 flywheel; 3 driving disk; 4 pressing spring; 5 cover plate; 6 main spring; 7 return spring; 8 declutching part; 9 coupling shaft; 10 disengaging ring; 11 engaging lever

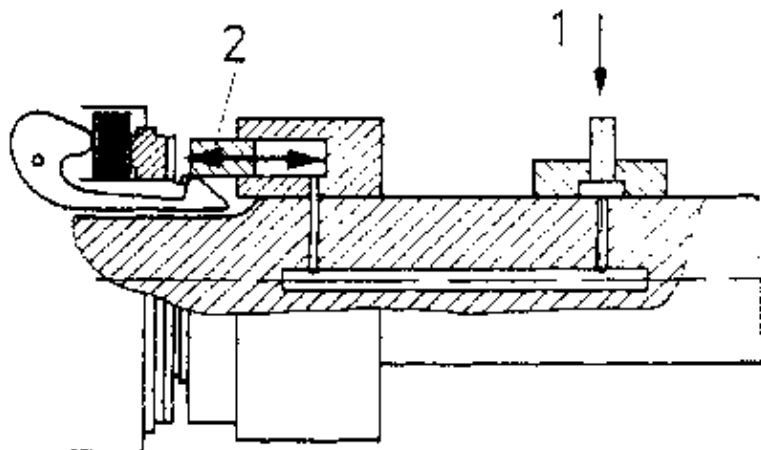
The power of the torque that can be transmitted depends upon the pressing force, the friction, and on the mean radius of the engaging surfaces. The greater the diameter of the clutch, the higher the coupling moment at the same pressing force and the same frictional value.

Due to the permissible material-dependent surface pressure, the force with which the two members are pressed together cannot be indefinitely large. The number of clutch disks in a multiple-plate clutch is increased to generate an adequate coupling moment, yet to make sure that the permissible surface pressure is not exceeded. This measure also diminishes the size of the clutch.

When the clutch is engaged, the friction surfaces are carried along with a certain amount of slip because of the inertia of the idle coupling member and of all subsequent parts connected to it that have to be moved. The bearings of clutches which have their members mounted on separate shafts are seated closely to the clutch.

The arising load diminishes somewhat the speed of the driving clutch member, while the driven clutch member is accelerated. The resulting frictional energy is converted into heat. When the two clutch members rotate at the same speed the sliding friction is transformed into adhesion friction. Both clutch members are then accelerated to the operating speed. The full coupling moment becomes effective when sliding friction ceases because the adhesion friction becomes greater than the sliding friction.

A mechanical shifting mechanism may consist of a shifting fork fitted with blocks that engage in the notch of a clutch sleeve and complete shift actuation. Often, the blocks are replaced by a shifting ring which engages in the notch of the clutch sleeve. The shifting fork then engages in the bolt of the ring. It is usually linked with a switching lever that is moved by hand or foot control, by a magnet, by oil pressure, or by compressed air (fig. 3/97).



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coupling can also be used as a safeguard against overloads.

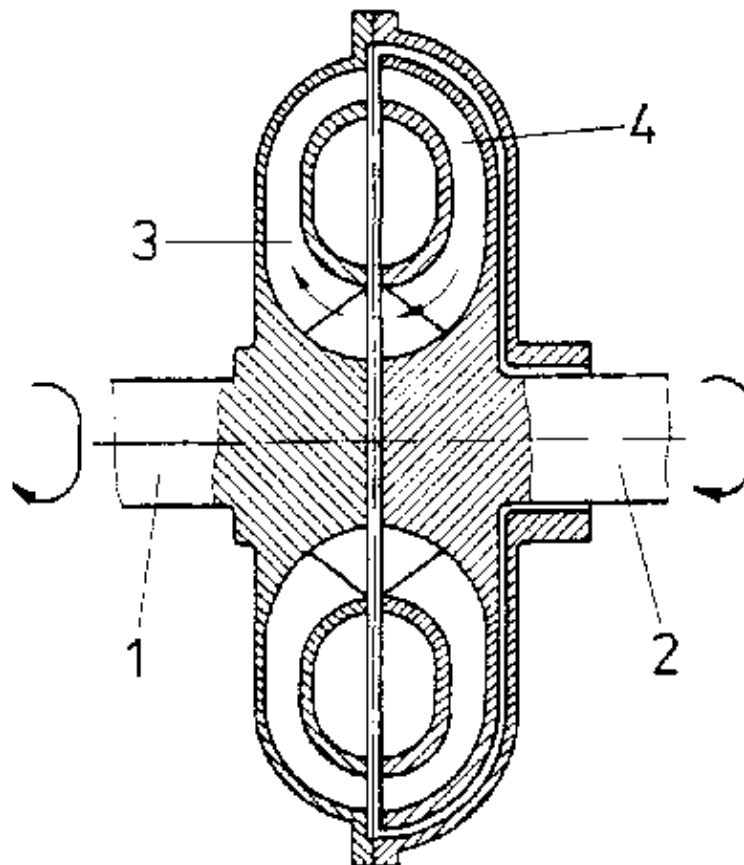


Figure 3/98 Fluid coupling

1 driving side; 2 driven side; 3 pump; 4 fluid power motor

Fluid couplings are composed of a primary section (the pump) and of a secondary section (the fluid power motor). The pump generates a pressure that is utilized by the fluid power motor. Torque is only transmitted if the pump runner and the motor impeller are rotating at different speeds. These two main sections of the fluid coupling are housed in a common enclosure (see fig. 3/98).

3.6.4. Mounting Technology

The mounting technology depends upon the design of the coupling. Many couplings form self-contained units. The installation of couplings usually involves the following jobs:

- Mounting the two coupling members on the shafts
- Installing the shifting mechanism (of clutches)
- Adjusting the coupling and the shifting mechanism
- Lubrication (only for clutches)

Mounting the Two Coupling Members on the Shafts

The two coupling members are usually fitted on the shafts with a taper fit. The kind of fit in this particular case is determined by the slip-on length. The plane and cylindrical surfaces of the coupling members can be used to check the accuracy of alignment of the shafts. Concentric tapered press fits of the two coupling members give the coupling a centric position. Deviations of the coupling members, therefore, can only be caused by positional deviations of the shafts, provided that the coupling has been concentrically machined.

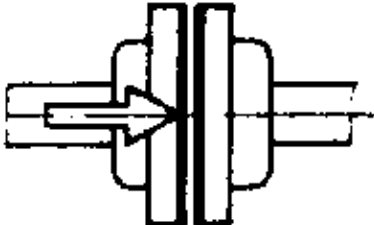
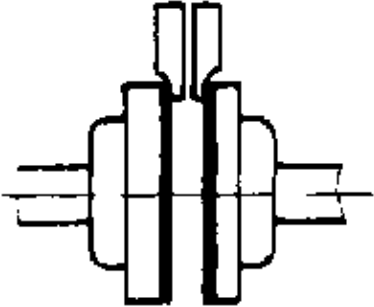
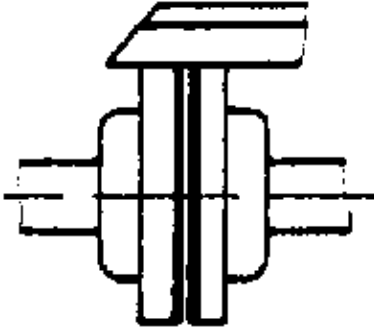
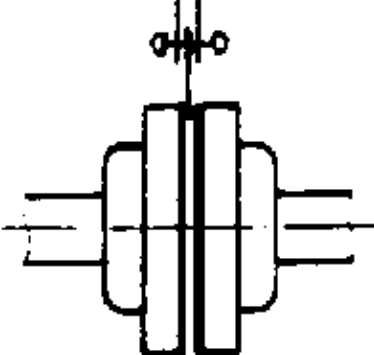
Different procedures can be adopted to check the axial position of the coupling (table 3/10).

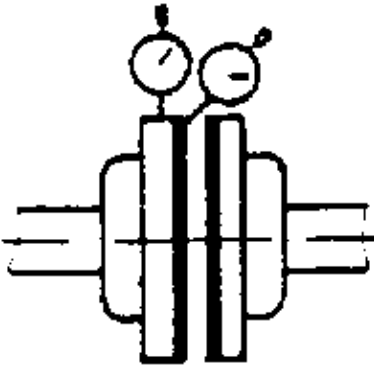
Faults in the faces of disks of clutches result in hard, shock-line engagement of the clutch. Prior to the installation of rigid couplings and clutches, the shafts must be checked for their axial position and for

true-running faults. Clutches must not have any axial play because this will cause impermissibly high bearing pressures.

If, for instance, electric motors are linked with generators or pumps by couplings, irrespective of the type of coupling, then both machines must be perfectly aligned on the foundation. A rule is used to check the position of the shafts at the coupling. The shafts are then aligned by shifting the machines accordingly.

With the exception of compression couplings, most other couplings can only be installed if one of the shafts can be shifted within its bearing or if the housing part is flanged.

Illus.	Testing method	Testing accuracy
	<p>Visual inspection; when the two members of the clutch are slowly pushed together their face surfaces should simultaneously come into contact with each other of their entire circumference.</p>	<p>Adequate when demands are not stringent, e.g. clutches with elastic links.</p>
	<p>Testing with vernier caliper; measurements at several points of the circumference must furnish the same readings (do not turn the clutch!)</p>	<p>Adequate when demands are not stringent.</p>
	<p>A ruler is aligned against several points; checking by the light-gap method (see fig. 6.18).</p>	<p>Adequate for flanges of permanent couplings.</p>
	<p>Measuring the spacing of several points around the circumference with a vernier caliper (do not turn the clutch!).</p>	<p>Adequate for flanges of permanent couplings.</p>

	<p>Checking the radial and face eccentricity while the two clutch members are slowly rotated.</p>	<p>High accuracy for concentric and face running trueness; unsuitable for alignment testing.</p>
<p>Housing parts and bearings must be concentrically adjusted as the coupling will otherwise jam. All housing and coupling bolts must be loosened and tightened cross-wise.</p>		

Balancing Couplings

Rotating parts such as coupling flanges or disks may have a displaced centre of gravity, i.e. the centre of gravity is not located in the axis of rotation (fig. 3/99). This will cause centrifugal forces that will subject the bearings of a machine to severe additional stresses. This will result in strong dynamic bearing forces, loud noise and a shortened service life due to fracture and fatigue failure. The point of gravitation of a rotating body must be within the axis of rotation of the body so that the centrifugal forces will be the same at all points.

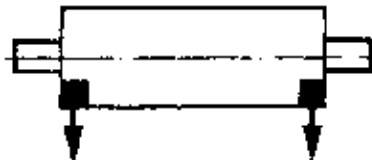


Figure 3/99 Displaced centre of gravity (unbalance) of a shaft

Every centrifugal force of a perfectly balanced rotating body will be counteracted by another centrifugal force of equal magnitude. This means that bearings will not be subjected to extra strains. Thus, a rotating body must be provided with points of compensation. Imbalance is remedied by removing weight (drilling or milling) or by adding weight (riveting, build-up welding, soldering or bolting). Such a job is known as balancing.

Balancing means the measurement and counterbalancing of a body that is running out of balance.

Two procedures may be adopted for balancing:

- Static balancing
- Dynamic balancing

Static (or standing) balancing: The body that is to be statically balanced is supported on edges or between points to minimize friction between the body and the base. If the centre of gravity is not within the axis of rotation, the unbalanced side of the rotating body will always be at the lowest point possible when this body comes to a state of rest. This is because every body endeavours to reach a state of equilibrium. In this manner the position of unbalance in relation to the axis of rotation is established (fig. 3/100).

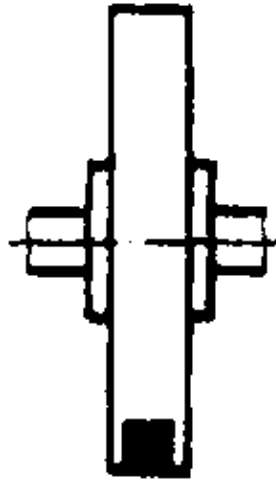


Figure 3/100 Displaced centre of gravity (unbalance) of a disk

Dynamic (or running) balancing: The points of unbalance are distributed in longitudinal direction over the body (fig. 3/101). Dynamic unbalance, also known as wobble, is established by balancing machines that indicate the magnitude and position of unbalance. The shaft is rotated at a certain speed by the machine.

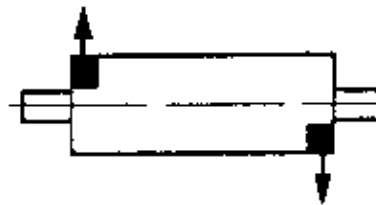


Figure 3/101 Dynamic unbalance (wobble) of a shaft

Static and dynamic unbalance can be eliminated by one of the two following methods:

- By adding counterbalancing weights opposite to the point of unbalance; the counterbalancing weight must equal the magnitude of unbalance.
- By removing weight at the point of unbalance.

For instance, unbalance of disk clutches is compensated by adding lead rivets which act as counterbalancing weights.

All balanced rotating parts must be marked when assemblies are dismantled to ensure that their relative position to each other is once again obtained when they are mounted.

Installing the Shift Mechanism of Clutches

When installing the shifting fork it is necessary to ensure that the friction ring and blocks are perfectly seated on all sides in the groove of the shift sleeve. The point of action of the shifting fork must not be one-sided. A certain amount of clearance must be present in the groove so that wear is low.

The shift mechanism is installed in the shiftable part of the clutch in such a manner as to ensure that its wear is as low as possible and that it is in its rest position when disengaged. All joints and bearings must move easily after they have been assembled. The shifting mechanism for disk and multiple-plate clutches must be adjusted in such a manner that there is a certain amount of clearance at the actuating lever. It should be adjusted in conformity with the installation rules. If this clearance is too small the clutch springs will not be fully untensioned. Consequently, the clutch disks will slip and not transmit the full torque.

Slip causes intense heating of the clutch and high clutch lining wear.

If the clearance is too large the clutch will not disengage properly in spite of the fact that the actuating lever has reached the end of its disengaging position.

A clutch that does not disengage entirely does not interrupt power transmission. This will damage the clutch and the transmission gearing.

Most shifting mechanisms are provided with adjustable levers or special setting screws with which the necessary clearance can be accurately adjusted. A friction clutch will only achieve the expected performance if the springs generate the necessary contact pressure.

After the clearance has been adjusted on the shift mechanism it is necessary to check whether the clutch is transmitting the torque properly.

If this is not the case the force of the springs will have to be testing with appropriate testing facilities. If the springs are exerting the necessary force it will be necessary to seek for alternative reasons for the slip of the clutch lining. The multiple-disk clutch has a setting ring which is turned in steps of 20° in clockwise direction until the torque is properly transmitted. The position of the ring is then secured by a catch that engages in the holes of a perforated disk.

A friction clutch is properly adjusted if power is transmitted without any slip after a brief friction period.

It must be possible to turn the two members of the clutch in opposite direction to each other with ease when it is in rest position. A small measure of idle transmission is hardly avoidable with multiple-disk clutches. A brake will have to be installed if such idle transmission is impermissible.

Lubrication

All moving parts of couplings must be well greased. If the elastic transmitting elements are made of rubber then no grease must be applied.

The shift mechanism of clutches must be lubricated with the prescribed type of grease.

Care must be taken to ensure that no grease or oil comes into contact with the friction lining.

Friction heating of multiple-disk clutches can become very high with poor heat dissipation. To prevent rapid wear, the plates must be lubricated. The diminished friction due to lubrication is still enough to assure closed force transmission. It is sufficient to wet the plates with oil. The most advantageous solution is the lubrication of the clutch with the oil mist of the gearbox or internally through the axle. These clutches should be immersed only to 1/8th of their diameter in oil. The lubricating oil for an open clutch is supplied by an oil screw fitted in the outer body.

Only the finest machine oil should be used for lubrication. It should not resinify, it must be light bodied, and free of acids. The oil must be changed regularly.

3.6.5. Brakes

The three principal areas of application of brakes are:

- To reduce speed or to keep it constant.
- To main the speed at $v = 0$.
- To load driving machines on test stands.

Brakes are assemblies that diminish the speed of rotation of machine parts and the travelling speed of vehicles, or they hold parts and vehicles at $v = 0$.

Brakes can be classified by their manner of action into three groups:

- Friction brakes
- Fluid brakes
- Electric braking

In design, manner of action and basis of calculation, all three types are similar to corresponding clutches.

Friction Brakes

The friction brake is extensively used in vehicles and lifting equipment on account of its simple design, robust construction and low maintenance costs. Its disadvantages are constant wear of the friction elements, and the changing friction moment due to dirt (oil, water, dust), temperature, pressure and speed.

The kinetic energy of the moving mass is converted into heat by the braking action. This heat has to be dissipated, a factor that is taken into account in the design of the brakes (e.g. enlarged surface, cooling, etc.). A distinction is made by the kind of braking element, namely between internal shoe brakes, block brakes, belt brakes, disk brakes and conical friction brakes (fig. 3/102 to 3/106).

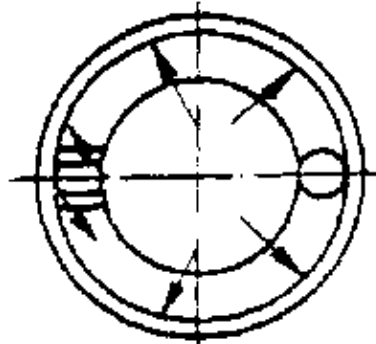


Figure 3/102 Internal shoe brake

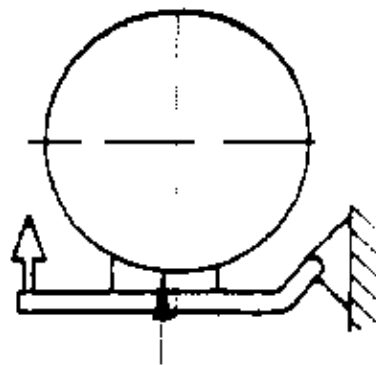


Figure 3/103 Block brake

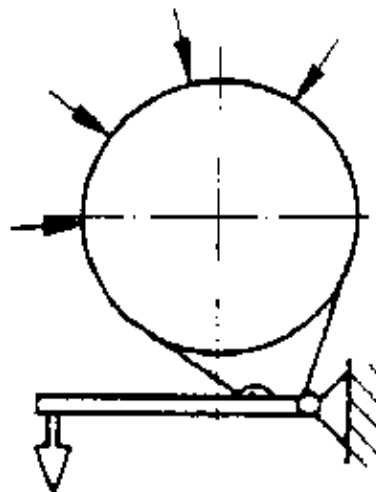


Figure 3/104 Belt brake

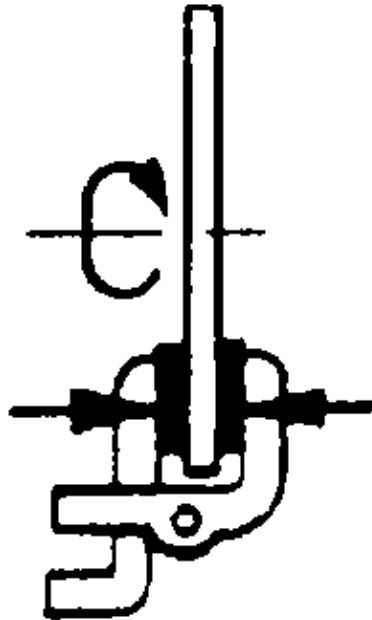


Figure 3/105 Disk brake

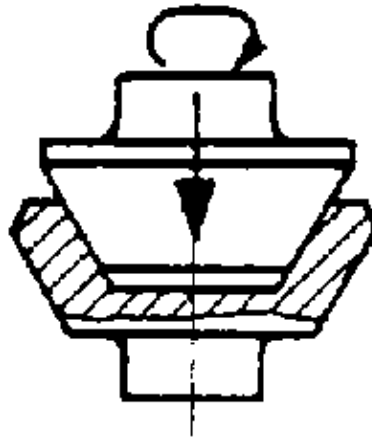


Figure 3/106 Conical friction brake

Fluid Brakes

These brakes utilize the flow resistance of water or air for braking.

Rotor rotation of the hydro-kinetic brake (fig. 3/107) forms a ring of water. The thickness of this ring depends upon the quantity, of water. Pins in the stator resist the circulating ring of water, thereby generating the counter moment. The kinetic energy is converted into heat (the temperature of the water increases). Cold water is constantly fed into the brake to keep the temperature of the water low (prevent the precipitation of minerals inside the brake), or special cooling systems are employed to assure adequate cooling. Fluid brakes are employed for powers that cannot be handled by mechanically acting brakes (lowering drill pipes in derricks), for engine test stands, etc. Braking capacities exceeding 7500 kW are being achieved by modern hydro-kinetic brakes. Air-kinetic brakes are rarely encountered and are only used for small braking powers.

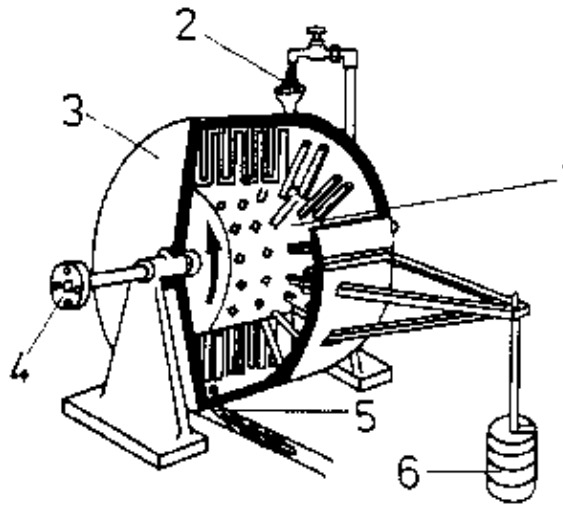


Figure 3/107 Fluid brake

1 rotor with pins; 2 water in-feed; 3 casing with pins; 4 coupling point with the driving unit; 5 water outflow; 6 weight

Electric Braking

The braking action is achieved by a magnetic field that is built up by flowing current. There are three principal ways of electric braking – regenerative, counter-current and dynamic braking.

Questions:

1. What are the advantages and disadvantages of rigid couplings?
2. Explain the difference between frictional and positive couplings.
3. Describe the manner of operation of a single-disk dry clutch.
4. What are the consequences of unbalanced rotary parts?
5. Explain the difference between friction clutches and friction brakes.

4. Power Transmission Elements

Elements that are used to transmit and convert motions are known as gearings or transmissions. They are employed when the driving motion of a machine does not correspond with the required working motion.

Thus, a rotary driving motion is often available (e.g. electric motor or combustion engine), whereas the required working motion has to be linear or curved. The situation may also arise where a rotary motion in one direction has to be reversed into the opposite direction, or that a given rotating speed has to be changed into another speed.

Transmissions are used to convert rotary motions. Such transmissions can be either directly linked with each other (as with toothed gears or friction wheels), or they can be interlinked by belts and chains (belt pulleys or sprockets). Table 4/1 gives a survey of the different types of transmissions. Coupling and crank transmissions, hydraulic transmissions and cam drives are employed to convert rotary motions into other forms of motion. A survey of such transmissions is given in table 4/2.

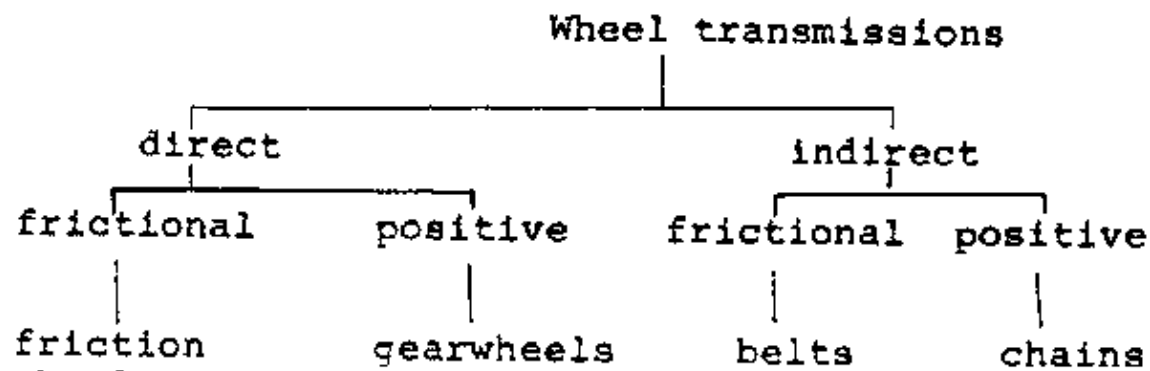


Table 4/1: Kinds of Wheel Transmissions

4.1. Friction Gearings

Friction gearings are only employed when low power-transmitting capacities are required. Consequently, friction gearings are often used in fine-limit engineering. In general machine building friction gears are employed, among others, for continuous speed control and in screw presses.

4.1.1. Design

Pressing force is used to press two wheels together so that friction is created at the circumference of the wheels as they rotate (see fig. 4/1).

Such transmissions are known as wheel friction gearings. Their disadvantage is that the transmitting friction is too small at a low pressing force. This is due to the relative movement (known as slip) that arises between the wheels in the presence of high loads.

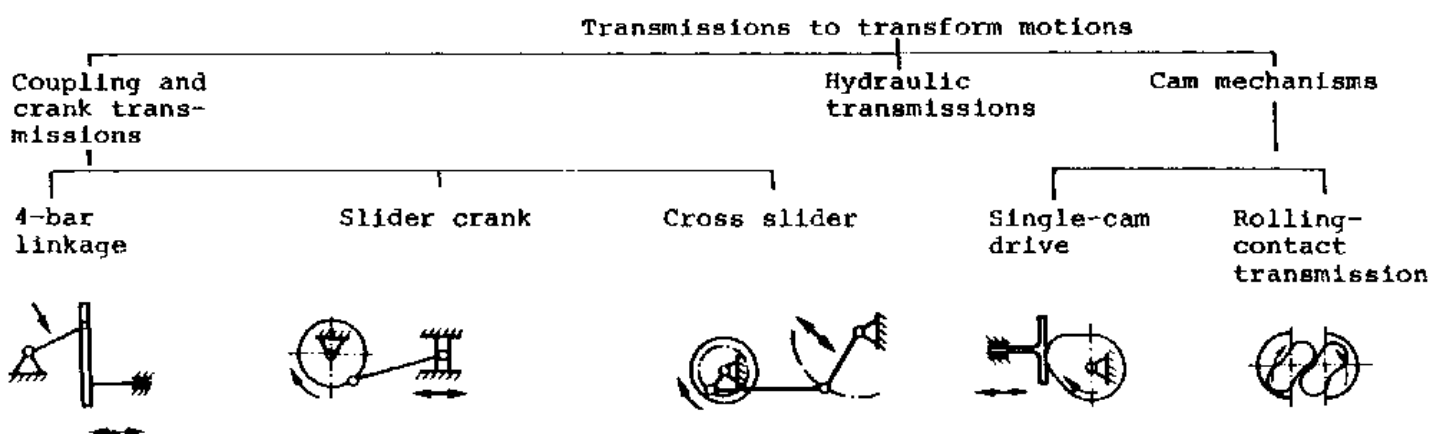


Table 4/2: Kinds of Transmissions to Transform Motions

Friction gearings involve the use of a broad conical disk, plate wheel or ball as one of the wheels, while the counter wheel is usually designed as a roll.

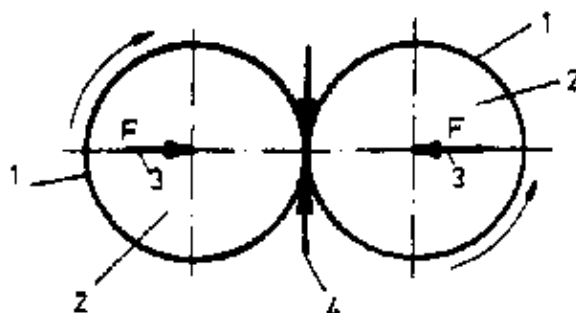


Figure 4/1 Principle of the friction-wheel transmission

4.1.2. Operating Characteristics

The coefficient of friction (μ) is a major characteristic of friction gearings. It depends primarily upon the materials used for the wheels, and upon the constitution of the surfaces. The condition of lubrication of the running surfaces (dry, greased or oiled) is also decisive. Table 4/3 lists the friction values of different friction linings. Ideally, the wheels of friction gearings should roll on each other without slip. The circumferential speed of the contacting wheels is then:

Circumferential speed $v_1 = v_2$

Table 4/3: Friction Values of Different Materials

Material	Coefficient of transmission ?
Grey-cast iron on grey-cast iron	0.10 to 0.15
Steel on steel with oil lubrication	0.08 to 0.09
Grey-cast iron on leather	0.15 to 0.30
Grey-cast iron on asbestos	0.30 to 0.50
Grey-cast iron on laminated fabric	0.15 to 0.20

The rotating speed of the wheels depends upon their diameter. It follows, therefore, that wheels of a smaller diameter rotate at a higher speed than wheels of a larger diameter.

The diameter is inversely related to the rotating speed.

$$d_1 : d_2 = n_2 : n_1$$

where:

d = wheel diameter

n = rotating speed

The ratio of the rotating speed in the direction of the flow of power is known as the transmission ratio i :

$$i = \frac{n_1}{n_2}$$

where:

i = transmission ratio

n_1 = speed of the driving wheel

n_2 = speed of the driven wheel

The transmission ratio can also be deduced from the ratio of the diameters of the wheels:

$$i = \frac{d_2}{d_1}$$

where:

d_2 = the diameter of the driven wheel

d_1 = the diameter of the driving wheel

Example:

An electric motor of a rotating speed of $n_1 = 960$ revolutions per minute (r.p.m.) and a friction wheel diameter of $d_1 = 120$ mm, will drive another wheel that should rotate at a speed of $n_2 = 300$ r.p.m.

- a) Calculate the diameter of the driven wheel d_2 .
- b) Determine the transmission ratio i .
- c) Calculate the circumferential speed v in m/s.

Solution:

a) Diameter of the driven wheel in mm
Wanted:

Given: Diameter of the driving wheel

$$d_1 = 120 \text{ mm}$$

Speed of the driving wheel

$$n_1 = 960 \text{ r.p.m.}$$

Speed of the driven wheel

$$n_2 = 300 \text{ r.p.m.}$$

$d_1 \cdot n_1 = d_2 \cdot n_2$ resolved after d_2 furnishes:

$$d_2 = \frac{d_1 \cdot n_1}{n_2}$$

$$d_2 = \frac{120 \text{ mm} \cdot 960 \text{ r.p.m.}}{300 \text{ r.p.m.}}$$

$$d_2 = 384 \text{ mm}$$

b) transmission ratio i .
Wanted:

Given: Speed of driving wheel $n_1 = 960 \text{ r.p.m.}$

Speed of driven wheel $n_2 = 300 \text{ r.p.m.}$

$$i = \frac{n_1}{n_2}$$

$$i = \frac{960 \text{ r.p.m.}}{300 \text{ r.p.m.}}$$

$$i = 16:5$$

$$i = 3.2:1$$

Circumferential speed of the friction wheels

c)

Wanted:

Given: Diameter of the driving wheel

$$d_1 = 120 \text{ mm}$$

Speed of the driving wheel

$$n_1 = 960 \text{ r.p.m.}$$

$$v = \pi \cdot d_1 \cdot n_1$$

$$v = 3.14 \cdot 0.12 \text{ m} \cdot \frac{960 \text{ s}^{-1}}{60}$$

$$v = 6 \text{ m/s}$$

4.1.3. Types

Friction transmissions are subdivided into:

- Gearings with constant transmission (crown friction gearing, spur-wheel friction gearing, conical friction gearing)
- Gearings with continuously variable transmission (crown friction gearing, conical drum gearing, Heynau friction gearing, ball friction gearing)
- Gearings to reverse the direction of rotation (crown friction reversing gearing)

Gearings with Constant Transmission

- Crown Friction Gearing with Constant Transmission Ratio

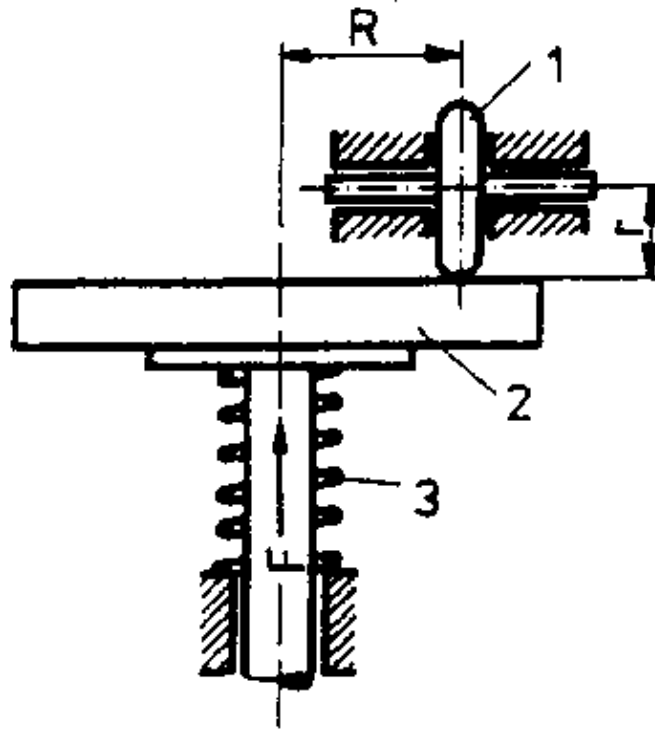


Figure 4/2 Crown friction gearing with constant transmission ratio

1 sliding wheel; 2 crown wheel; 3 spring; R effective radius at the crown wheel; r radius of the sliding wheel; F pressing force

As indicated by figure 4/2, this transmission gearing consists of a crown wheel that has a rotating axle with limited longitudinal movement. A spring generates the necessary contact pressure between the wheels. The crown wheel is located at a right angle to the sliding wheel that can be axially shifted on a splined shaft. Shifting changes the effective radius at the crown wheel, thereby producing the desired transmission ratio.

- Spur Friction Gearing

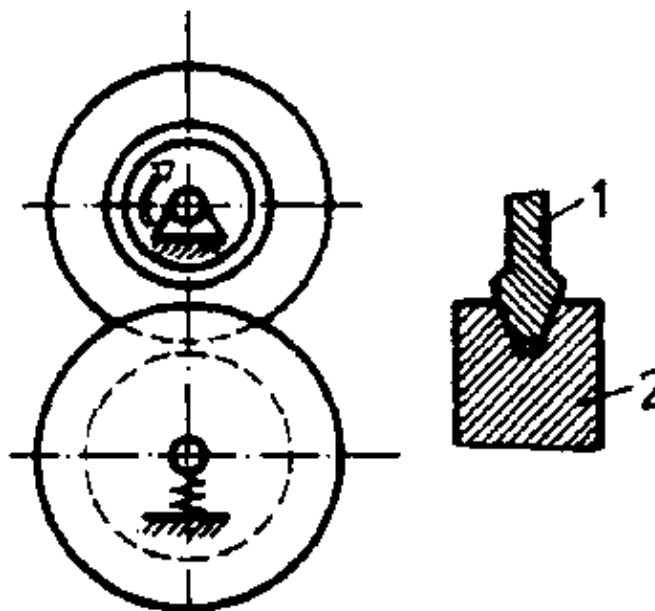


Figure 4/3 Spur friction gearing

1 conical wheel; 2 wheel with conical groove

It usually consists of two friction wheels of differing diameter (fig. 4/3). Here, too, one of the wheels is pressed against the other by spring pressure acting on the bearing. The entire normal force must be absorbed by the bearings of both wheels. To diminish the bearing forces, a gearing is selected by which a conical wheel engages in another wheel that has conical grooves.

- Conical Friction Gearing

This transmission consists of two conical friction wheels of differing size that are positioned at an angle of 90° in relation to each other, and with their axes usually crossing each other (intersecting). The left-hand wheel shown in figure 4/4 is pressed against the other wheel by a spring.

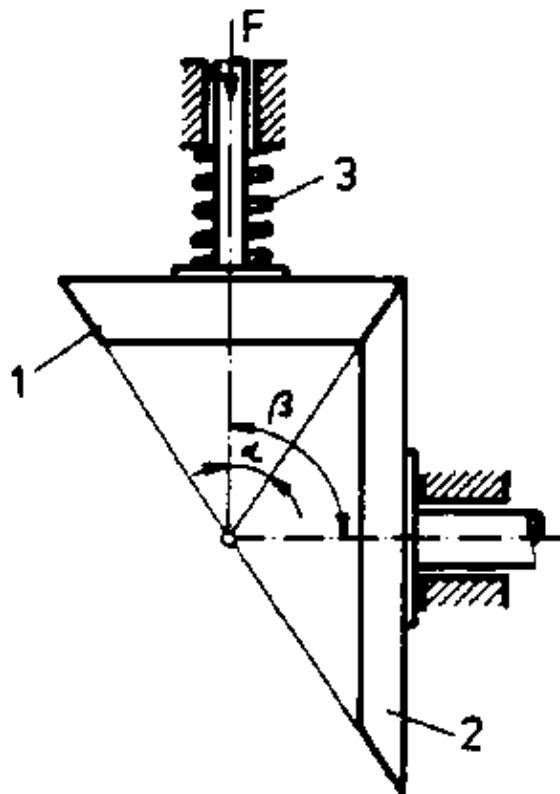


Figure 4/4 Conical friction gearing

1 small conical friction wheel; 2 large conical friction wheel; 3 spring; F pressing force; α angle of the shafts in relation to each other; β conical angle of the wheel

Gearings with Continuously Variable Transmission Ratio

- Crown Friction Gearing

It is designed in the same manner as its counterpart with constant transmission (fig. 4/5).

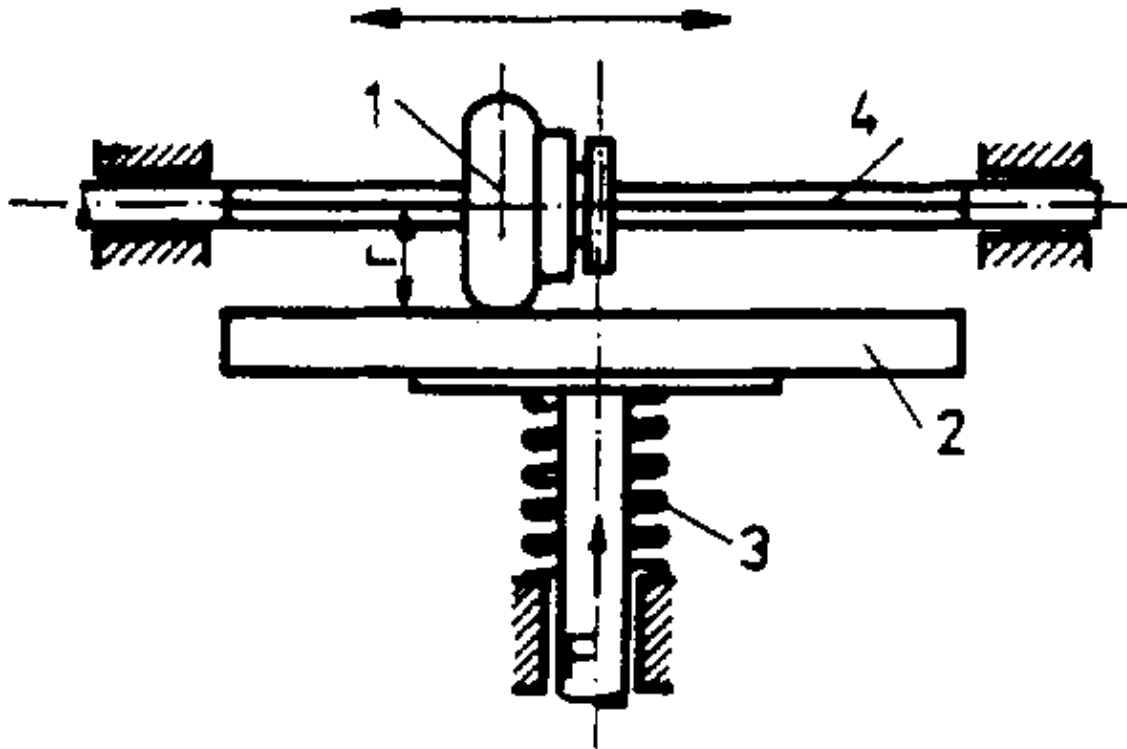


Figure 4/5 Crown friction gearing with continuously variable transmission ratio

1 sliding wheel; 2 crown wheel; 3 spring; 4 splined shaft; F pressing force; r radius of the sliding wheel

The difference in this particular case, however, is that the crown wheel runs at a constant speed around the sliding wheel which is shifted on the splined shaft to adjust the desired rotating speed. It is also possible to move the sliding wheel to the other side of the crown wheel, thereby reversing the direction of rotation.

• Conical Drum Gearing

The gearing consists of a conical drum that can be moved to a limited extent in longitudinal direction. A sliding wheel is arranged at a right angle to the circumference of the conical drum and can be shifted along this drum (fig. 4/6). The conical drum is driven at unvarying speed. The desired rotating speed is adjusted by shifting the sliding wheel up or down the conical drum.

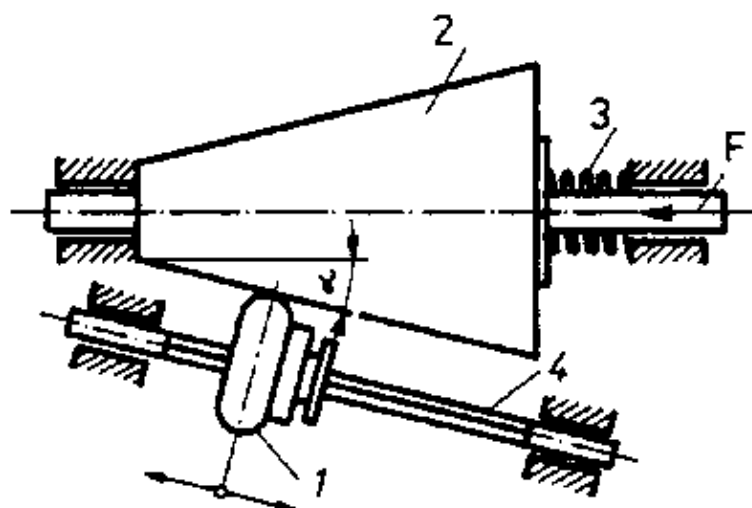


Figure 4/6 Conical drum gearing

1 sliding wheel; 2 conical drum; 3 compression spring; 4 splined shaft; F pressing force

• Heynau Friction Gearing

This transmission is composed of four pairs of friction cones arranged behind each other. Steel rings are used as transmission elements between the friction cones. Pairs of friction cones can be shifted in relation to each other for continuous speed variation under full operating load (fig. 4/7).

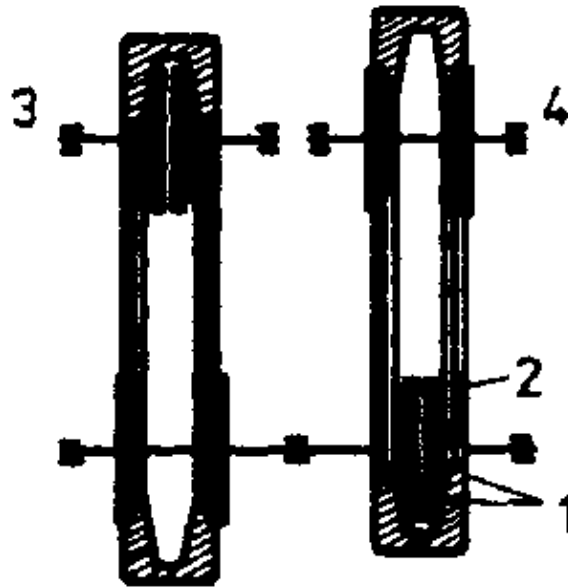


Figure 4/7 Heynau friction gearing

1 pair of friction cones (4 x); 2 steel ring; 3 driving side; 4 driven side

Gearings to Reverse the Direction of Rotation

This kind of transmission is made up of two crown wheels and of a friction wheel (fig. 4/8). The two crown wheels can be shifted to the right or left by a corresponding mechanism. This means that the friction wheel can be set for clockwise or anti-clockwise rotation. Continuous speed variation is obtained if this friction wheel can also be shifted axially.

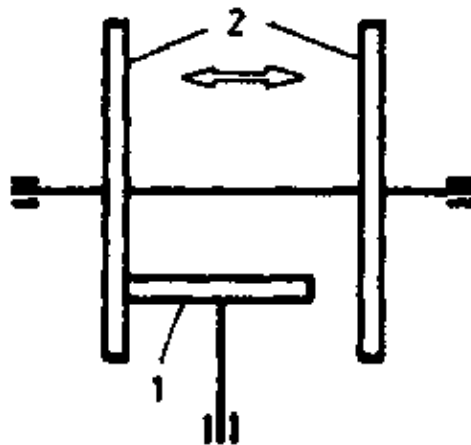


Figure 4/8 Reversing gearing with crown wheels

1 friction wheel; 2 crown wheels

4.1.4. Mounting Technology

Friction gears are assembled according to the same principles and rules as those explained in the sections on keyed connections, feather fastenings, shafts, bearings and spring connections.

After mounting, each of these gears should be checked while they are being run in. Special attention must be paid to friction-lining heating. Excessive heating in spur friction gears indicates that the shafts are not positioned precisely parallel. Such a fault must be immediately remedied because it will not only destroy the friction lining but also bring about undesirable axial loading of the bearings. When mounting soft friction linings

made of leather, rubber, etc., care must be taken to ensure that the slanting end of the material does not run against the rotating direction of the driving wheel because the resulting excessive stresses will cause it to peel off (fig. 4/9).

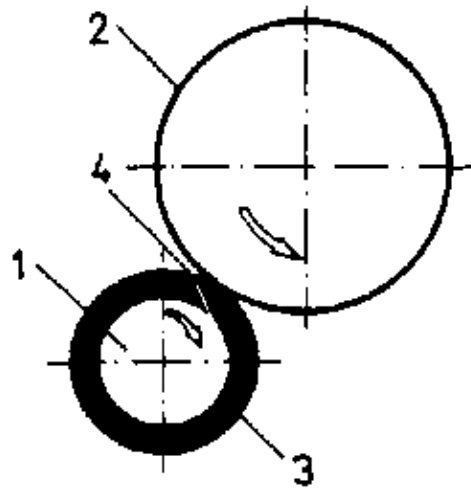


Figure 4/9 Mounting the friction lining on the friction wheel with due consideration to slanted cut

1 friction wheel; 2 crown wheel; 3 friction lining; 4 connecting point of the friction lining

Questions:

1. The power-transmitting capacity of friction gears depends upon the contact pressure and upon the friction surface. What should the condition of the friction surface be like to transmit high powers?
2. The rotating speed of friction gears is continuously variable by moving the friction wheel in relation to a disk or drum. Explain how the rotating speed is changed in relation to the diameter.
3. How must the shafts be aligned in relation to each other when friction gears are being mounted?

4.2. Belt Transmissions

Belt transmissions are employed to bridge wider shaft spacings between the driving wheel and the driven wheel. Belt transmissions can also be used to drive several working elements simultaneously. V-belts are employed when the power is transmitted between closely spaced shafts, while flat belts are used for wider inter-shaft spacings. Belt transmissions safeguard the working elements of a machine against overloads on account of belt slip. The elasticity of the belt has a damping effect so that it can absorb shock loads. Belt transmissions are employed in machine building, fine-limit engineering, medical equipment, and in high-frequency and electrical engineering.

Belt transmissions are of simple construction, cheap to produce and easy to maintain. Belt pulleys and belts can be easily exchanged. The efficiency of belt transmissions is not so good as toothed gear transmissions (due to slip).

4.2.1. Design

The power of a driving pulley is transmitted by a belt (or rope) to one or more driven pulleys. Power and motion transmission are by the friction created between the belt and the pulley. In order to create this frictional connection, the belt must press against the pulley with a certain amount of force that is known as normal tension. This is generated by the initial belt tension (see fig. 4/10). The coefficient of friction (see Section 4.1.2.) between pulley and belt must be as high as possible. This prevents excessive normal tensions that would otherwise subject the bearings to high loads. The largest possible arc of contact (wrap) should be achieved to keep the belt tension as low as possible. Figure 4/11 shows the influence of pulley diameter and axial spacing on the arc of contact.

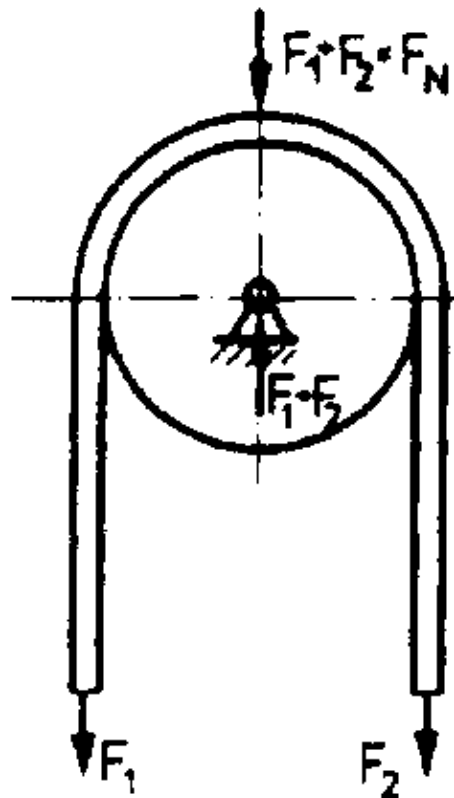


Figure 4/10 Initial belt tension

F_n normal tension; F_1 and F_2 holding forces

The necessary initial tension can be created by the stretch tension of the belt, the use of tensioning rollers or tensioned shafts, or by a self-tensioning drive.

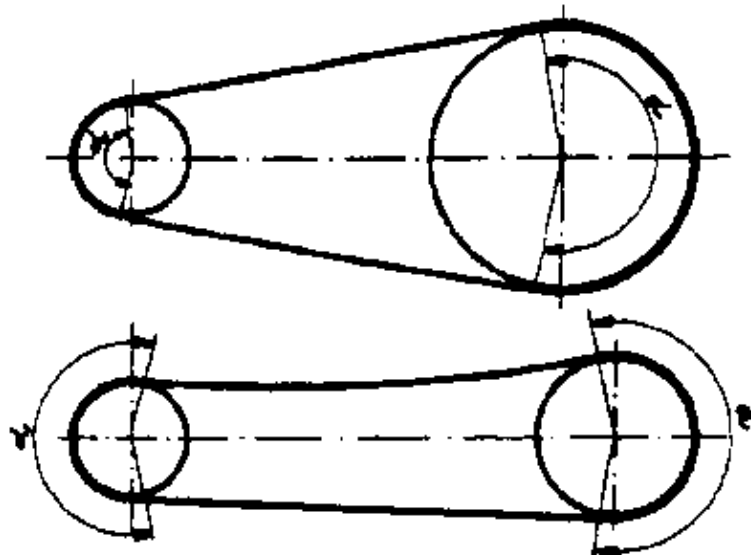


Figure 4/11 Arc of contact (wrap)

? arc of contact

Stretch tension: The belt is stretched when it is mounted on the pulleys (fig. 4/12).

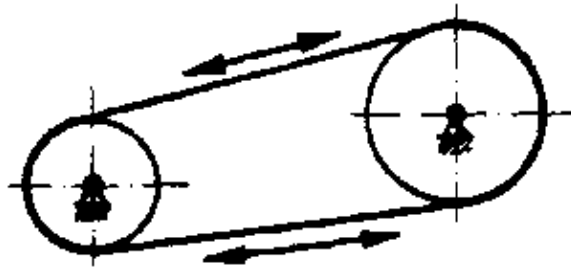


Figure 4/12 Stretch tension

Tensioning shaft: The belt is loosely wrapped around the pulleys. The spacing between the shafts is widened to produce the tension (fig. 4/13).

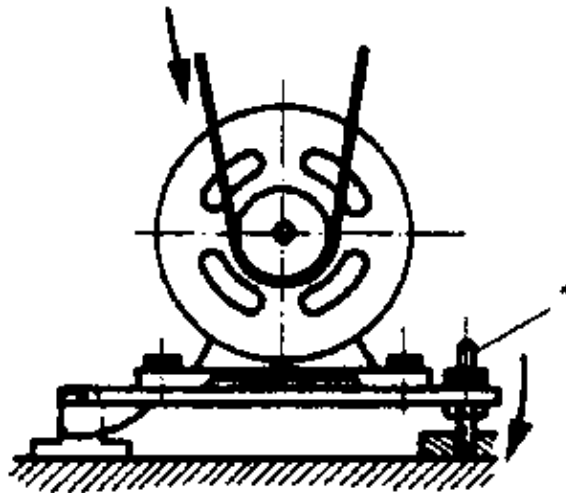


Figure 4/13 Tensioning shaft

1 tensioning screw

Tensioning roller: The slack side is tensioned by an additional roller running in a linkage system that is pressed by a weight or spring. The tensioning roller increases the arc of contact (fig. 4/14).

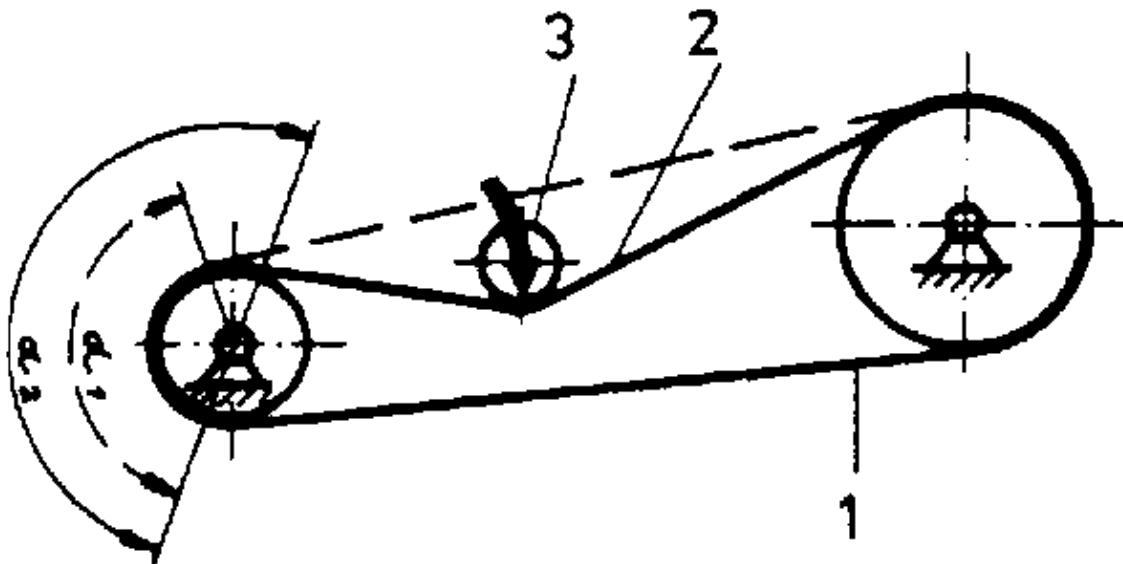


Figure 4/14 Tensioning roller

1 driving side; 2 slack side; 3 tensioning roller α_1 arc of contact without tensioning roller α_2 arc of contact with tensioning roller

Self-tensioning drive: The electric motor is float-mounted on the base plate. When the motor is started the motor casing is given an opposing momentum of reaction (recoil) by the belt pulley which tensions the belting (fig. 4/15). The higher the start load, the higher the moment of reaction, thus producing the self-tensioning

effect. This system produces a load-dependent initial tension which spares the belts and makes it easier to mount untensioned belts. The arc of contact around the small pulley can be very small (less than 90°) so that high transmitting ratios can be obtained at shortest shaft spacings.

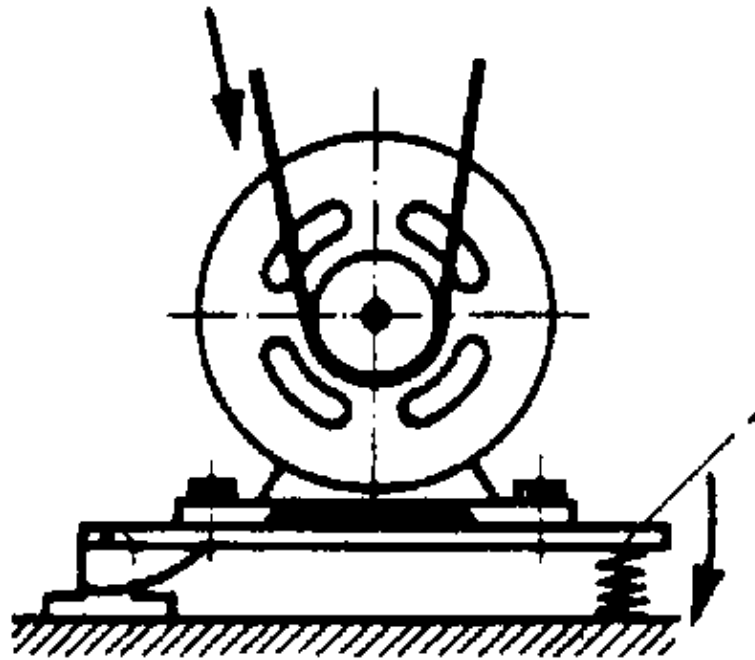


Figure 4/15 Self-tensioning drive

1 compression spring

Another method of self-tensioning exploits the weight of the motor itself. The motor is firmly mounted on a rocker. The initial tension is applied by the tilting moment of the motor around the bearing of the rocker (fig. 4/16).

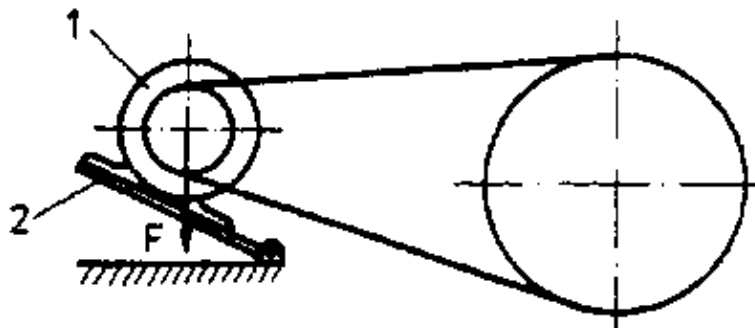


Figure 4/16 Initial tension created by the weight of the motor

1 motor; 2 rocker; F motor weight

In principle, the pulleys of belt transmissions can be arranged in any relation to each other. If, however, the pulleys are mounted at approximately the same height, then the transmitting arrangement must be selected in such a manner that the driving side of the belt is at the lowest level and the driven side is at the highest level (fig. 4/17).

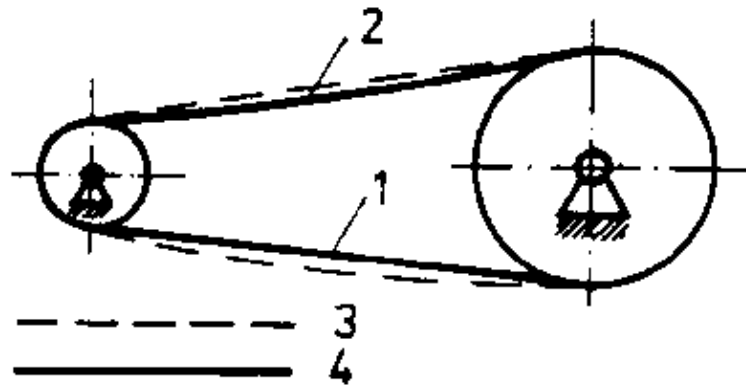


Figure 4/17 Belt in rest and operating position

1 driving side; 2 slack side; 3 belt in rest position; 4 belt in operating position

Both sides sag by their own force of gravity when they are in rest position. The driving side is tensioned when transmission starts, while the driven side sags still further down. In this manner the arc of contact around both pulleys is increased.

Belting: The belting consists of flat belts and wedge-section belts (V-belts). Cords are frequently employed as belt transmissions in fine-limit engineering, high-frequency and electrical engineering, and for medical equipment.

Flat belts have a rectangular cross-section. They are made of leather, fabric, balata (cotton belts impregnated with a South American variety of rubber), and plastics (a composition of leather and plastics).

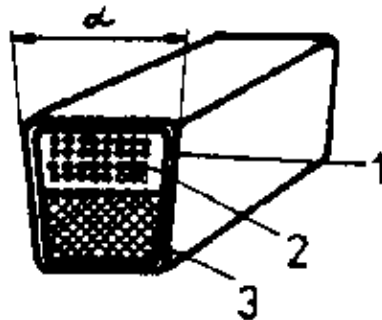
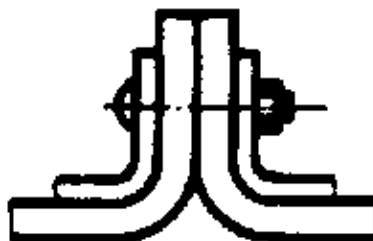


Figure 4/18 Cross-section of a V-belt

? wedge angle; 1 cord fabric; 2 longitudinal threads; 3 rubber

V-belts have a wedge-shaped section (fig. 4/18) and consist of cords of rayon as the central tension member, an outer rubber cushion that covers the internal cords to give the V-belts their specific profile, and the surface-vulcanized fabric cover.

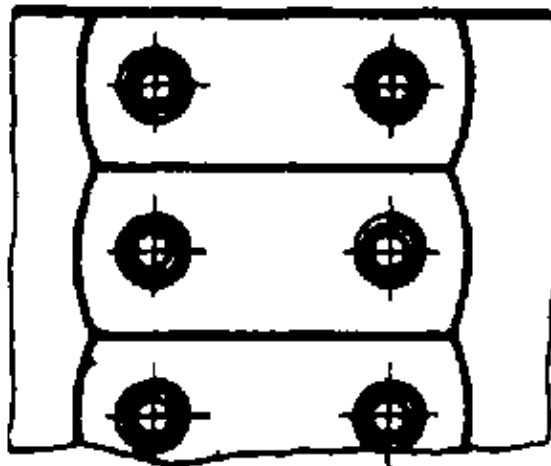
Figure 4/19 Flat belt fasteners



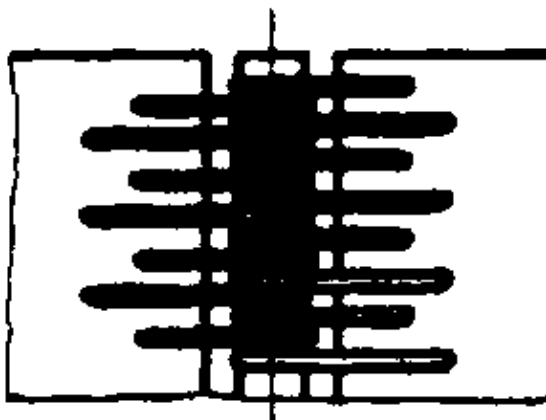
a Rail-type fastener (the hollow space can be compensated by interposing a felt strip to enhance smooth running)



b Rod-type fastener



c Plate-type fastener (should be avoided for heavy-duty drives and for very small pulleys)



d Hook fastener for leather belts



e Hook fastener for textile belts (sew butt leather on the ends of the belts to prevent fabric fraying)



f Joining leather belts by an obliquely cut joint



g Joining leather-plastic belts by an obliquely cut joint

The endless type of belt is preferred for both types of belting. Joined belts (by the meter) are only employed when it is impossible to mount endless, sewn or bonded belts. Endless belts have smoother running characteristics and a longer service life. Continuous lengths of belting mean that the belt ends have to be joined by appropriate fasteners. Figure 4/19 shows the different types of belt fasteners commonly employed.

V-belts are supplied as endless belts, but also as continuous lengths of belting for subsequent joining according to the required length. Here, too, the endless V-belt should be preferred if mounting makes this feasible. V-belt fasteners (fig. 4/20) are available to join continuous lengths of V-belting.

Figure 4/20 V-belt fastener (plate fastener)



a in stretched position;



b in fully curved position

4.2.2. Operating Characteristics

The belts must press against the pulleys with a certain pressure to create the necessary frictional link between the belt and the pulleys. This normal force is created by the initial tension of the belt (see Section 4.2.1.). A friction must be selected that is sufficiently large to prevent belt slip during power transmission. The factors determining efficient power transmission are friction, correct belt tension, and arc of contact (wrap).

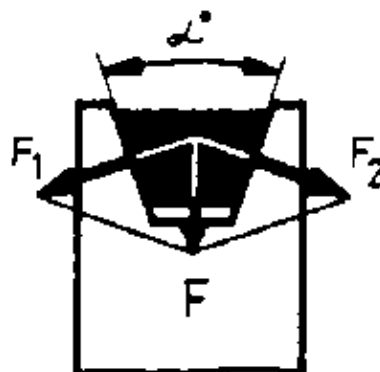


Figure 4/21 Normal force prevailing at V-belts

? wedge angle, F normal force; F_1 and F_2 dissected normal forces

Friction between belts and pulleys can be intensified by applying wedge slots or grooves (fig. 4/21). The wedge effect is the result of the conversion of the force F into two normal forces F_1 and F_2 as a result of the wedge angle. The smaller the wedge angle α , the better the wedge effect. There is, however, a lower limit for the size of the wedge angle because the belting will jam if the angle α is too small. The wedge effect has the advantage of running the belt at a much lower initial tension on the driven side. Several V-belts are often mounted next to each other on one pulley to transmit higher powers (fig. 4/22). Pulleys having 1 to 16 grooves are employed. The groove angle varies between 35 and 39° . Figure 4/21 shows that the trapezoid V-belt profile is commonly employed. But it is also possible to mount round cords in the V-shaped grooves of the pulley to increase the power-transmitting capacity.

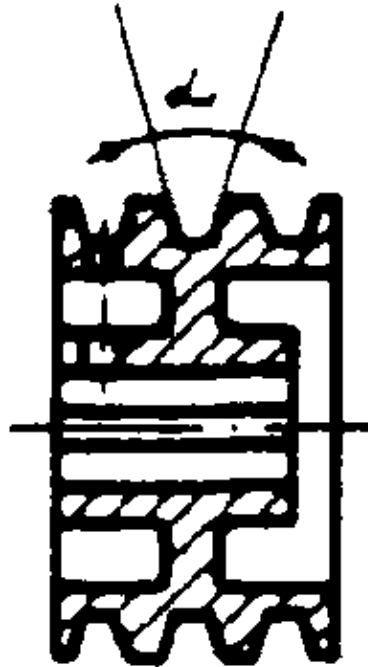


Figure 4/22 V-belt pulley with several grooves Cast version

The driving side has a much higher tension than the driven side when a belt transmission is employed (fig. 4/23). The section of belt passing over the driving side is stretched more than at the driven side. This means that there is a constant alternation between belt stretch and belt contraction. This phenomenon causes a relative movement between belt and pulley. This relative movement is known as stretch slip. It means that the driven pulley runs at a slightly lower circumferential speed than the driving pulley. Furthermore, centrifugal force acts upon each particle of the belt.

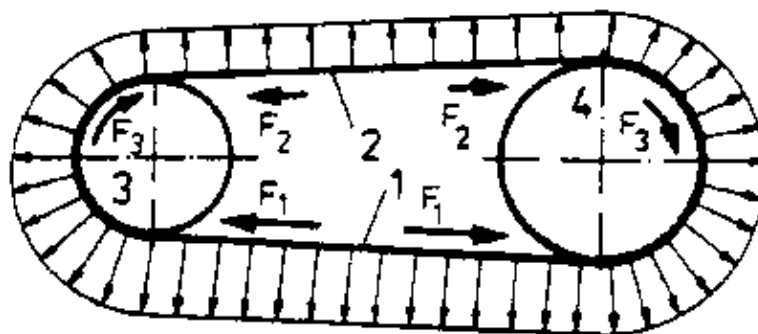


Figure 4/23 Belt tension during operation

1 driving side; 2 driven side; 3 driving pulley; 4 driven pulley; F_1 and F_2 tension force; F_3 circumferential force

When a belt transmission is overloaded the circumferential force becomes larger than the frictional force. The belt starts to slide, resulting in a sliding slip. This slip is usually associated with flat belts and it diminishes the efficiency of power transmission. Belt drives transmit a certain amount of power. This power is the product of force and velocity:

$$P = F \cdot v$$

where:

P = transmitted power

F = force

v = circumferential velocity

Depending upon the given driving assignment, a transmission can run with a low force F and a high velocity v , or a high force F and a low velocity v , to achieve the required driving capacity.

The transmission ratio (see also Section 4.1.2.) should not exceed the value 1 in 10 for simple belt transmissions, and 1 in 15 for tensioned belt transmissions. The belt speed, notwithstanding slip, equals the pulley speed.

It is calculated from:

$$v = d \cdot \pi \cdot n$$

where

v = circumferential velocity

d = pulley diameter

n = number of revolutions

4.2.3. Types

Belt transmissions can be distinguished by the number of shafts that are to be linked:

- Simple open belt transmissions that only link two shafts (fig. 4/24)

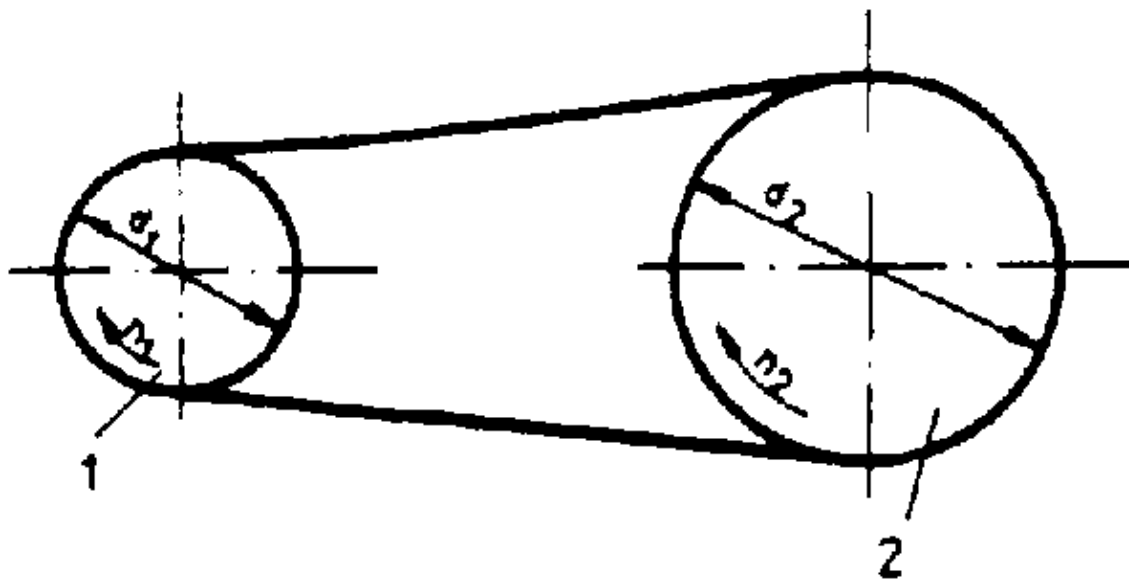


Figure 4/24 Simple open belt transmission

1 driving pulley; 2 driven pulley d_1 diameter of the driving pulley d_2 diameter of the driven pulley n_1 speed of the driving pulley n_2 speed of the driven pulley

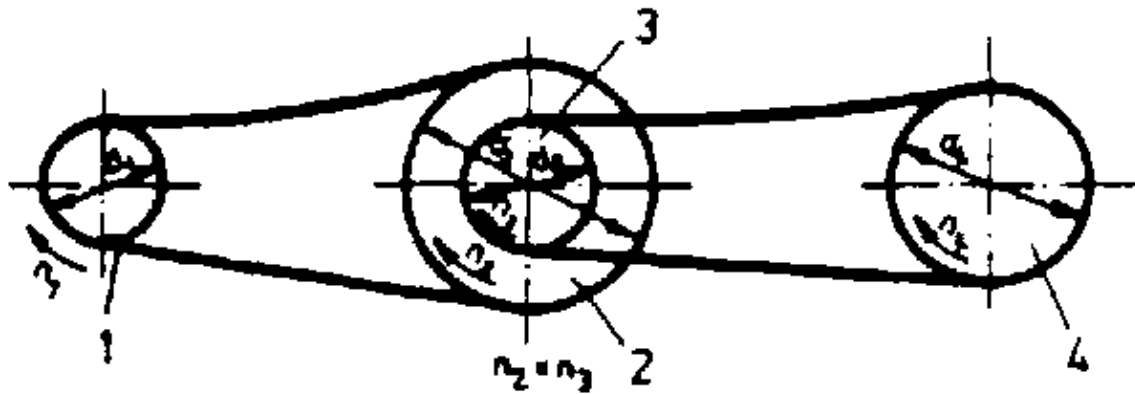


Figure 4/25 Multiple open belt transmission

1 and 3 driven pulleys; 2 and 4 driven pulleys d_1 diameter of the driving pulley d_2 diameter of the driven pulley d_3 diameter of the 2nd driving pulley d_4 diameter of the 2nd driven pulley n_1 speed of the driving pulley n_2 speed of the driven pulley n_3 speed of the 2nd driving pulley n_4 speed of the 2nd driven pulley

- Multiple open belt transmissions that link more than two shafts (fig. 4/25)

Belts are also classified by their cross-section:

- Flat belt transmissions
- V-belt transmissions
- Round-section belts

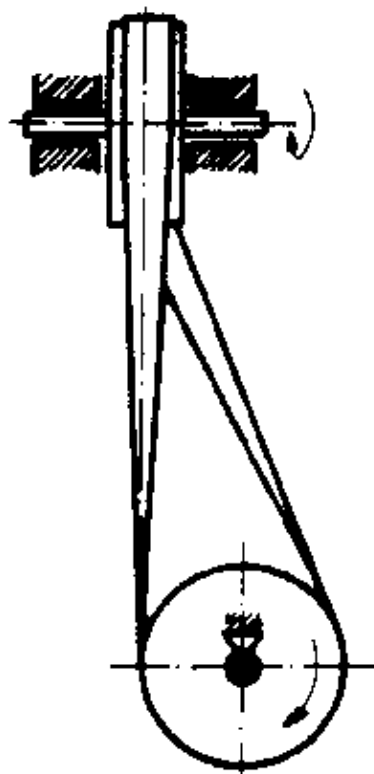


Figure 4/26 Right-angle belt transmission without guide pulley

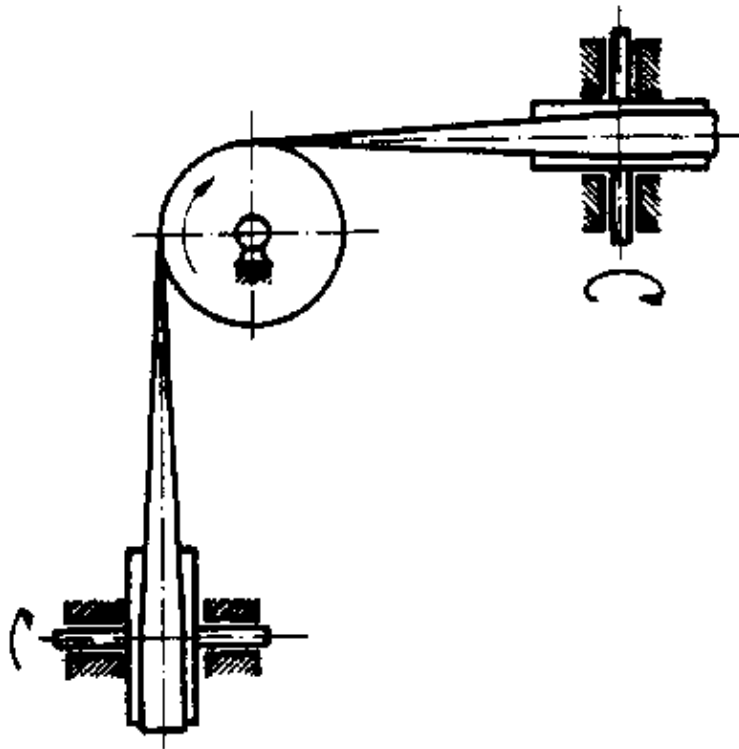


Figure 4/27 Right-angle belt transmission with guide pulley

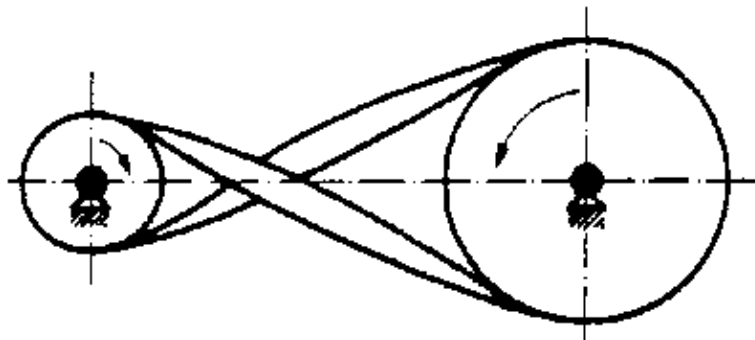


Figure 4/28 Crossed belt transmission

Flat belt transmissions employ belting of rectangular cross-section. Next to belt transmissions with or without tensioning facilities (see Section 4.2.1.), it is also possible to arrange the shafts at an angle of 90° in relation to each other. Figures 4/26 and 4/28 show right-angle belt transmissions in which the shafts are crossed in relation to each other. Figure 4/26 shows a right-angle belt transmission without guide pulley? figure 4/27 with guide pulley. Figure 4/28 shows a crossed-belt transmission. It is also possible to change the other constant transmission ratio with the help of belt transmissions. Stepped speed-changing transmissions employ stepped pulleys which have diameters matched to the required rotating speed. If such a transmission is not fitted with special tensioning devices, the counter pulley must be provided with the opposite steps (fig. 4/29) to assure that the belt length fits properly.

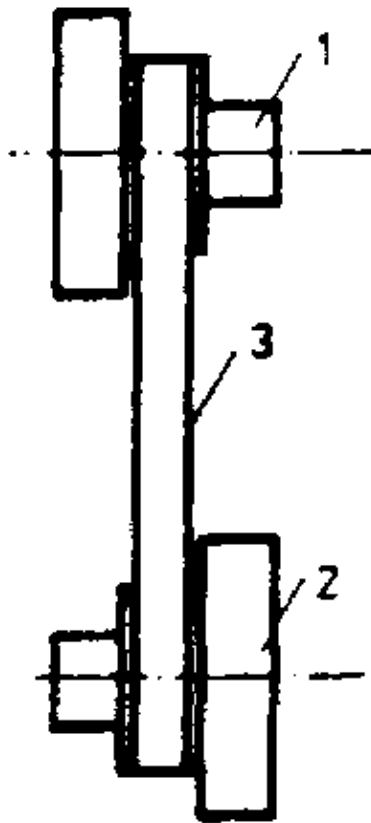


Figure 4/29 Stepped speed-changing transmission

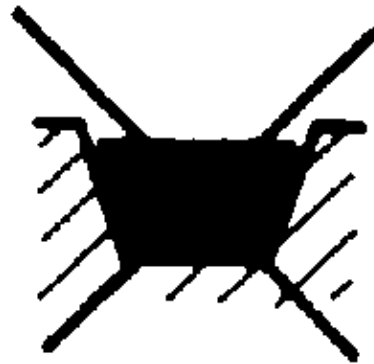
1 driving side; 2 driven side; 3 belt

V-belts are increasingly replacing flat belts on account of their advantages (see Section 4.2.1.). The V-belt must fit perfectly in the sides of the grooves of the V-belt pulley. That is why the grooves of the pulley and the sides of the belt must have the same angle. This angle is between 35° and 39° . V-belts are usually of the endless type as they are capable of transmitting higher powers than the finite (by the meter) V-belt of the same cross-section. The relation of the endless V-belt is based on the largest V-belt width and the inner length (inner circumference). The disadvantages of the V-belt compared with the flat belt are its higher bending loss, greater eccentricity and higher heating. The point of force contact of flat belt transmissions is at the circumference of the pulley. With V-belt transmissions the V-belt is squeezed into the wedge-shaped groove of the pulley as a result of the influence of initial tension and load (see fig. 4/21), thereby transmitting the power only with the angular sides of the belt. The depth of the V-belt must be selected in such a manner that there is a certain amount of clearance at the bottom of the pulley groove (friction contact cannot be increased any further), and that the belt top is approximately flush with the stop of the pulley. The transmitting power capability of a V-belt is reduced if the V-belt top runs on the upper edge of the pulley. Figure 4/30 shows incorrect and correct seating of the V-belt.

Figure 4/30 Position of the V-belt in the pulley groove



a wrong



b wrong



c wrong



d right

Multiple V-belt transmissions require careful selection of V-belt lengths to ensure that all pulley grooves and V-belts have the same ratio of power transmission. Good friction contact, and near slip-free drive, give such transmissions an efficiency of practically 100%.

4.2.4. Mounting Technology

The following points must be observed when belt transmissions are mounted:

- Checking the position of the shaft and pulley
- Fitting belt fasteners
- Running in a belt transmission
- Care and maintenance
- Labour safety measures

Checking the Position of Shaft and Pulley

Belt transmissions will only run perfectly and achieve maximum efficiency if the driving and driven shafts are positioned absolutely parallel to one another and if they are running concentrically. Furthermore, the pulleys must be precisely aligned and positioned in the same plane. The procedure described in Section 2.4. must be observed when mounting pulleys on shafts.

Pulleys can be lined up with a plumb or aligned with a rule. A plumb is used when the pulleys are located under each other. The plumb is held against the front face of the upper pulley. The pulleys are then shifted in relation to each other until the front faces of the two pulleys are perpendicular with the line of the plumb (fig. 4/31).

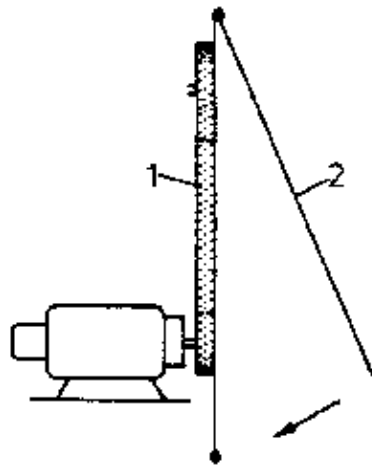


Figure 4/31 Checking perpendicular alignment with a plumb

1 belt; 2 plumb

Alignment with a rule requires a rule of adequate length that is placed against the front face of one of the pulleys. The other pulley is then laterally shifted until the rule contacts all points of the pulley (fig. 4/32).

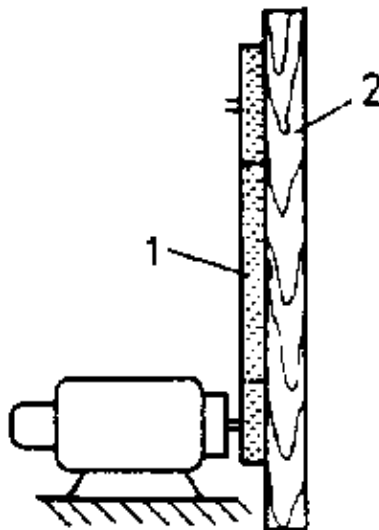


Figure 4/32 Checking perpendicular alignment with a wooden ruler

1 belt; 2 wooden ruler

Non-aligned pulleys will cause lateral belt slip to the side at which the shaft spacing is larger. This makes it necessary to align the pulley in such a manner that the belt runs precisely in the centre of the two pulleys and at a right angle to the shafts. This method is not applicable to V-belt and round-section belt transmissions. Figure 4/33 indicates the direction of belt shift when the pulleys are not aligned.

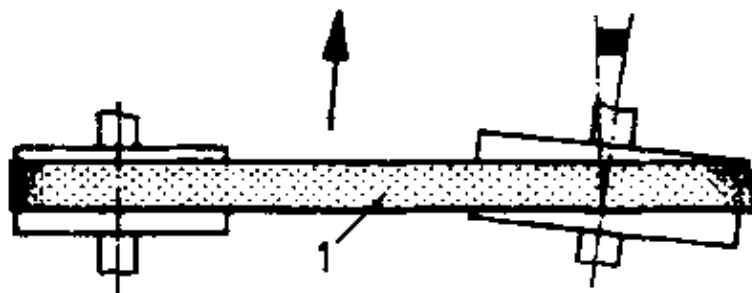


Figure 4/33 Direction of belt shift when the pulleys are not aligned

1 belt

Fitting Belt Fasteners

It is very important to produce a correct belt joint. Flat belts are often supplied by the meter. The belt ends are connected by wire staples, belt fasteners, and by sewing or adhesive bonding. Endless belts can be produced by adhesive bonding. The belt is cut off in the right length under consideration of the bonded joint. The ends are tapered over a length that equals double the width of the belt. The ends are then clamped in the jaws of a clamping device (fig. 4/34). The belt is wrapped around the pulleys and tightened with the clamp until the required initial belt tension is achieved. The two ends are then pasted together. The pressure on the bonded joint must be maintained until the adhesive is fully set. This form of adhesive bonding, however, is only necessary if the belt transmission has no tensioning devices.

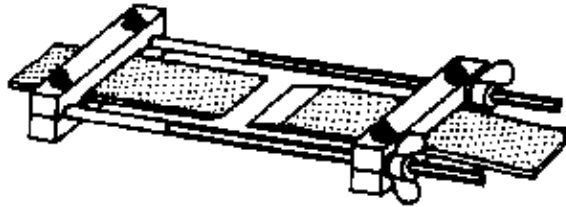


Figure 4/34 Belt clamping device to adhesive bond flat belts

Disconnectible belt joints are obtained with belt fasteners. The wire staple is commonly employed for leather belts (fig. 4/35). The staples must be firmly pressed together and must be bedded in the belt. The holes in belt joints for screwed connections must not be punched as, otherwise, the durability of the joint will be diminished by the serration of the fibres within the belt material.

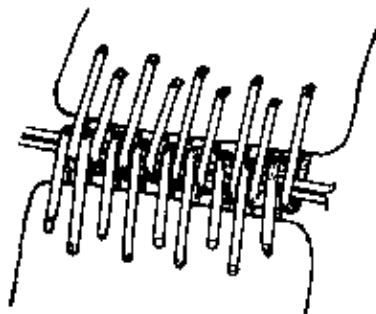


Figure 4/35 Wire staple connection

The screw head and end must not protrude out of the belt joint. If this point is not observed, the screw ends will hit the groove base of the pulley so that the screw ends will become a serious accident hazard (fig. 4/36). Joints created with fasteners must not be significantly thicker than the belt itself. This is because the belt will be repeatedly subjected to a higher initial tension as the joint runs over the pulley.

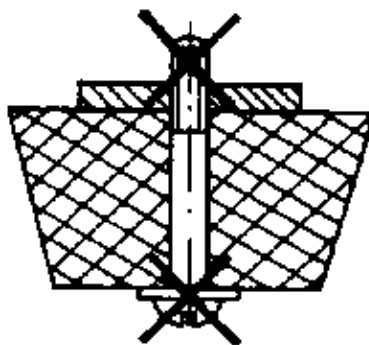


Figure 4/36 Faulty V-belt connection

Continuous lengths of V-belts are easier to join than flat belts. A V-belt fastener is employed for this purpose (fig. 4/37). The advantages of continuous V-belts are:

- Simple stocking (by the meter)
- Mounting and tensioning is possible without having to shift the shafts
- Longer fractured lengths of V-belt can be used again

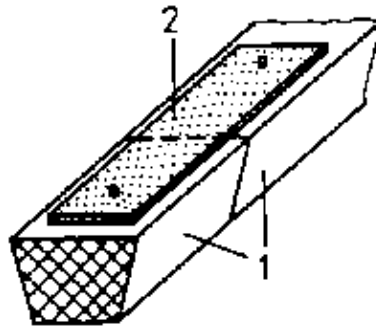


Figure 4/37 V-belt fastener

1 V-belt ends; 2 V-belt fasteners

An endless V-belt has no joint so that it can transmit higher powers than a joined V-belt of the same cross-section.

Pulleys should be carefully inspected to make sure that they are free of burrs before the belt is mounted. All rust, grease and dirt must be carefully removed. If these points are not observed the belt will be destroyed by mechanical and chemical action.

Care must be taken to ensure that the bonded joint has the correct position when flat belts are mounted. The belt joint should not run against the pulley (fig. 4/38). The flat belt is first mounted on the pulley with the smaller diameter and then on the larger pulley through manual rotation.

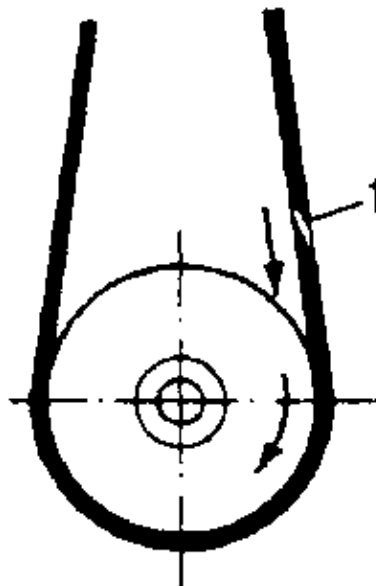


Figure 4/38 Correct running direction of an adhesive-bonded belt joint

1 bonded joint

V-belts must be properly seated in the grooves of the pulleys (see fig. 4/30). Incorrect seating will mean that the wedge action of the V-belt is not fully effective so that correspondingly less power will be transmitted. The adjustment of an initial tension for V-belts requires an adjustable spacing between the pulley shafts.

The spacing must be reduced so that the V-belts can be easily slipped on. The required initial tension is achieved when the spacing of the shafts is 1% higher than the spacing without initial tension. Divided pulleys (fig. 4/39) can be used to adjust the initial tension if the shaft spacing is not variable.

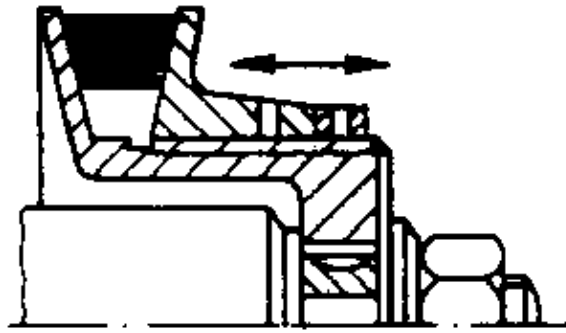


Figure 4/39 Divided pulley

Adjustment on one side of the pulley sets the depth at which the belt runs in the groove (higher or lower). If of several belts running next to each other breaks it is necessary to renew the entire set of belts.

Running in Belt Transmissions

After the belts have been mounted on the pulleys the transmission is run without load. When it is clear that the belt has been properly seated or positioned, the transmission can be gradually run up with increasing load until maximum transmitting load is reached. The bearings of the shafts should be touched with the hand. They should only be hand-warm. If bearing heating is higher it means that the initial tension of the belt is too high so that it must be reduced accordingly.

The curvature of the pulleys extend flat belts while they are being run in. Belt dressing is then applied to the running side of the belt. This causes the belt to slip on the pulley. The resulting heat liquifies the belt dressing so that the leather belt will absorb the liquid grease, thereby shortening its length by about 2%. The leather belt should run on the hair (grain) side so that this side is not within the pull zone. Friction contact between belt and pulley depends primarily upon the quality of the contacting surfaces.

V-belts are extended after a brief period of operation. Endless V-belts can be retensioned by adjusting the shafts accordingly. Joined V-belts, on the other hand, must be shortened. V-belts must not come into contact with grease.

Care and Maintenance

Care and maintenance of belt transmissions covers the bearings and the flat belts made of leather. The rules described in the Sections 3.3.1. and 3.3.2. should be observed when attending to the bearings.

The service life of a leather belt depends primarily upon the care it receives. The following points should be observed in this connection:

- The running sides of the belt and pulley must be always kept perfectly clean.
- Belts must not be cleaned with sharp objects as these could damage them.
- A soft wooden splint, or the back of a knife, should be used for cleaning.
- Slip should be remedied by shortening the belt.
- The running side of the belt must not be coated with an adhesive belt dressing. It makes the leather hard and brittle, leading to premature wear, diminishing its power-transmitting capacity, and increasing operating noise.

Labour Protection Measures

Running belt transmissions are always associated with an extra accident hazard. They must always be fitted with a cover guard to prevent accidental touch.

- The guard should only be removed when the belt transmission is stationary. It should be immediately mounted again when the maintenance work has been completed, and before the belt transmission is started again.

- All work on belt transmissions should only be completed if they are fully protected against being accidentally set into operation.
- Close-fitting garments should be worn. Long hair must be protected by appropriate headgear. Even smooth shafts will seize loose garments and long hair.
- A running belt should never be touched with bare hands. The belt fastening can produce deep wounds.
- The belt should only be mounted or removed when the transmission is stationary.

Belt transmissions can become electrostatically charged, leading to discharge sparks. Such sparks will ignite dust and gases in explosion-endangered rooms. Driving belts can be impregnated with a conducting substance to offset this danger. Likewise, metal brushes can be applied which conduct off the electrostatic charge to the ground (fig. 4/40).

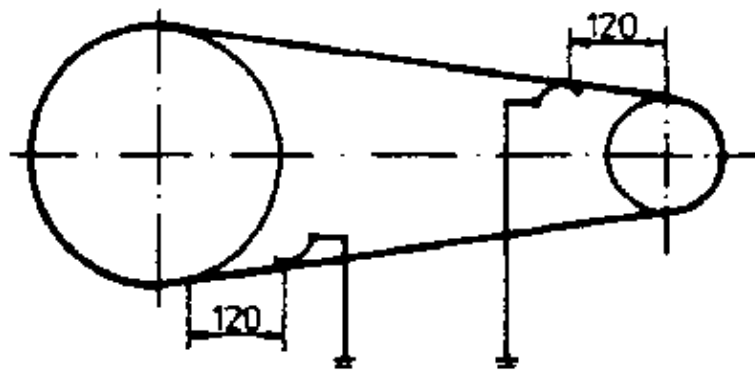


Figure 4/40 Grounding a belt transmission to conduct off electrostatic charge

Questions:

1. How can the necessary initial belt tension be created?
2. Find out which belt transmissions are being used in your area of work and the purposes they are being used for.
3. The flat belt of an open belt transmission always runs one-sided. What can be the cause of this?
4. Describe the procedure of joining a leather belt with wire staples.

4.3. Chain Drives

Chain drives unite the advantages of belt transmissions and of gearings. As opposed to belt transmissions where the power is transmitted by friction between pulley and belt, the chain transmits a positive drive through the moving chain meshing with the sprockets.

The chain drive operates at the shortest centre distances between shafts without any slip, even at the highest transmitting ratios. A chain will also drive several shafts. Chain drives have a good transmitting efficiency, a long service life, and handle wide power ranges. Their quiet running and shock absorbing properties are making them invaluable also under tough operating conditions in all fields of machine and vehicle building.

4.3.1. Design

Chain drives use a chain for the pull. The commonest types of chains are the sleeve-type chain and the roller chain. They consist of side plates (side links) held together by riveted or cottared bolts bearing a bushing or roller. The chain speed and capacity can be increased by using different types of steel for the chain and the sprockets.

Quiet running is achieved by ensuring that the sprockets are free to move in and out of the chain links. Sprockets usually have an odd number of teeth, whilst the chain has an even number of links. This means that the chain links do not repeatedly mesh with the same sprocket teeth, thus assuring uniform wear.

The number of chain links should not be a multiple of the number of sprocket teeth. The shafts of sprockets of chain drives should be arranged next to or at an angle to each other.

The angle θ should be between 30° and 60° (fig. 4/41). This will largely eliminate vibrations. Favourable shaft positions in relation to each other are shown in the figures 4/42 to 4/44. These arrangements give the chain a long service life. The arrangement shown in figure 4/45 is not favourable because the chain sags on both sides so that it will start to vibrate.

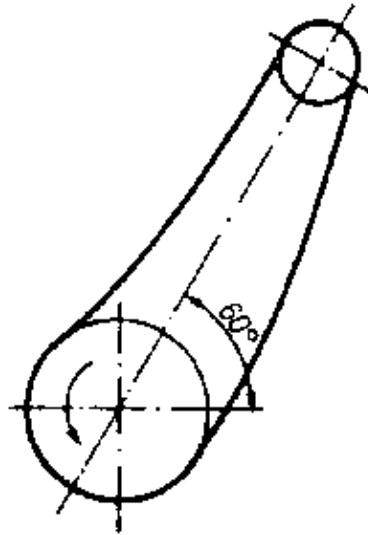


Figure 4/41 Proper arrangement of chain drives

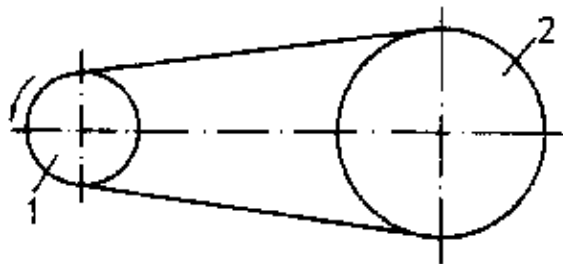


Figure 4/42 Chain drive – horizontal position

1 driving sprocket; 2 driven sprocket

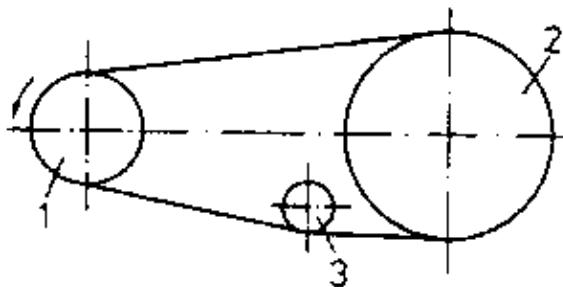


Figure 4/43 Chain drive – horizontal position with tensioning roller

1 driving sprocket; 2 driven sprocket; 3 tensioning roller

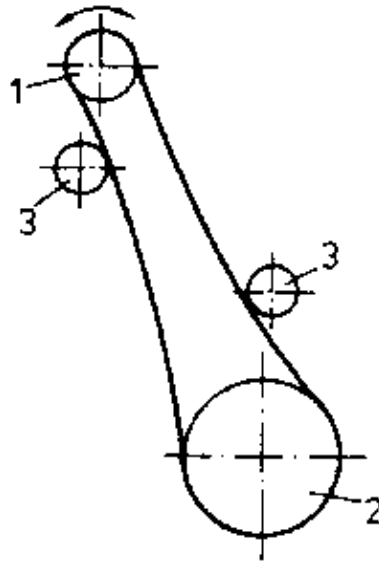


Figure 4/44 Chain drive – Oblique position of the tensioning rollers

1 driving sprocket; 2 driven sprocket; 3 tensioning rollers

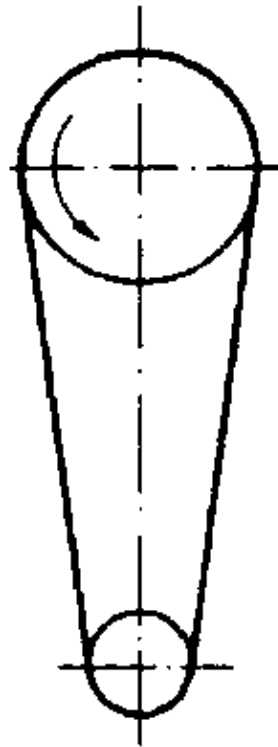
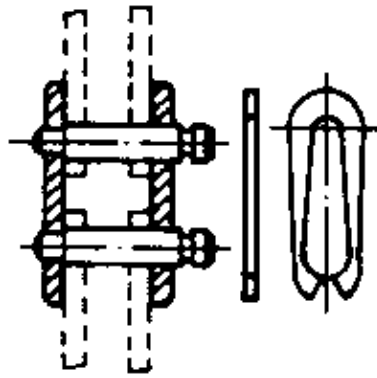


Figure 4/45 Inappropriate arrangement of a chain drive

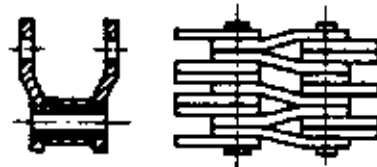
Endless chains are supplied in the customary lengths, but clip links can also be supplied to join the ends of continuous lengths of chain. The clip for an even number of chain links is usually designed as an insert link with a rivet through one end. The other free end of the clip is connected to the free end of the chain by a rivet, spline, wire or bolt link. A special joining link is used to connect an endless chain having an odd number of chain links.

Figure 4/46 gives a survey of the linking elements.

Figure 4/46 Chain joining links



a roller chain link for an even number of links



b roller chain link for an odd number of links

4.3.2. Operating Characteristics

Transmitting ratio, centre distance between shafts and chain length, are the important operating characteristics determining the most favourable size of chain drive. Although these characteristics are established by the designer, it must still be possible for the workshop to calculate these values for mounting and repair work.

Transmission ratio: Similar to the friction-wheel and belting transmissions, the transmission ratio is defined as the ratio of the speeds in the direction of the flow of power:

$$i = \frac{n_1}{n_2} = \frac{z_2}{z_1}$$

Circumferential speed: The circumferential speed of the two sprockets is identical because the two are positively connected by the chain which has the same speed as the sprockets.

Centre spacing between shafts: The 50-fold value of the pitch of the chain has proved to be the most favourable centre spacing between shafts for chain drives. The arc of contact around the small sprocket is diminished by a shorter spacing, and only a few teeth of the sprockets engage in the chain to transmit the torque. The chain tends to vibrate easily at wider distances, resulting in impermissible bearing loads, unquiet running and chain breakage. These vibrations can only be eliminated by vibration dampers or by tension-adjusting jockeys.

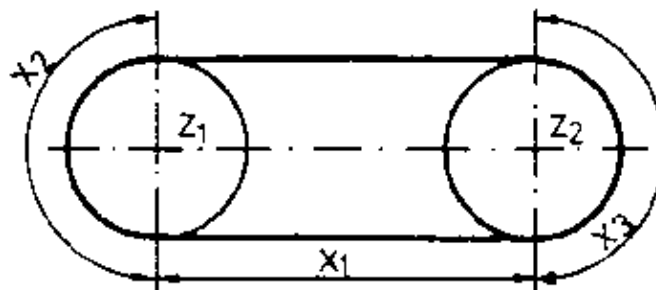


Figure 4/47 Chain length at $i = 1$

Chain length: The chain length can be calculated from the number of chain elements. When the two sprockets have the same number of teeth (fig. 4/47), then the number of chain links x will be:

$$x_1 = \frac{2a}{t}$$

$$x_2 = x_3 = \frac{z_1}{2} = \frac{z_2}{2}$$

$$x_2 + x_3 = \frac{z_1 z_2}{2}$$

$$x = \frac{2a}{t} + \frac{z_1 z_2}{2}$$

Where:

a = shaft spacing

t = chain pitch

z_1, z_2 = number of sprocket teeth

Example:

The following values are given for a chain drive:

Centre shaft spacing a = 600 mm

Chain pitch t = 12 mm

Sprocket teeth $z_1 = z_2 = 61$

How many links are required for the chain?

Solution:

$$x = \frac{2a}{t} + \frac{z_1 + z_2}{2}$$

$$x = \frac{2 \cdot 600}{12} + \frac{61 + 61}{2}$$

$$x = 100 + 61$$

$$x = 161 \text{ links}$$

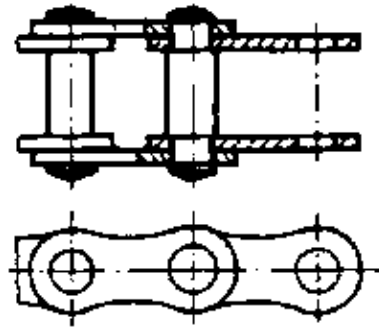
4.3.3. Types

Kinds of chains: Steel link chains are employed for most chain drives. Table 4/4 summarizes the most important types. Further remarks on chains are given in Section 4.3.1.

Sprockets: Shape and quality of the sprockets are just as important for the impeccable performance of a chain drive as the design and quality of the chain. The profile of the sprocket teeth must ensure that they enter and withdraw from the chain links freely, and that the first teeth involved in power transmission must not be overloaded. Running noise should be low and chain extension negligible. The sprockets require a special tooth shape conforming with the shape of the chain link (fig. 4/48).

Table 4/4: Kinds of Chains

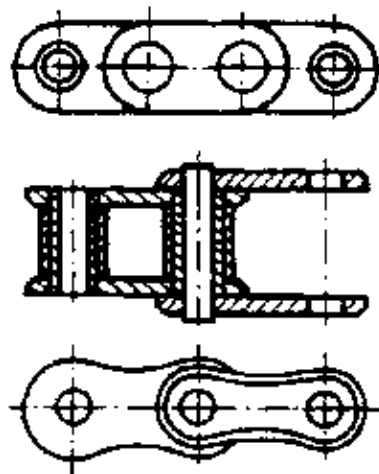
Bolt chains: Used primarily for heavier loads and low speeds.



Bushing chains: Employed for fast-running transmission (motor vehicle engineering), mainly in gear boxes. Careful lubrication is necessary.



Roller chains: The commonest type of chain used in machine building; they can run at high speeds (up to 15 m/s) and transmit high loads.



Silent chains: High-capacity transmission used in all areas of machine building; high load carrying capacity; insensitive to dust and heat; allows speeds of up to $v = 40$ m/s.

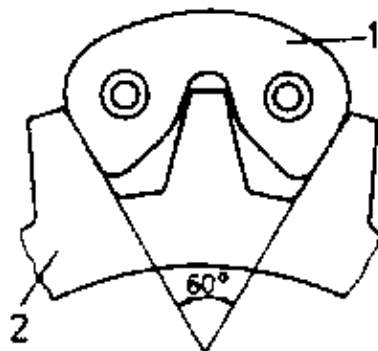
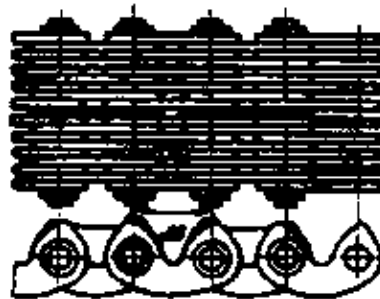


Figure 4/48 Sprocket

1 chain link; 2 sprocket rim

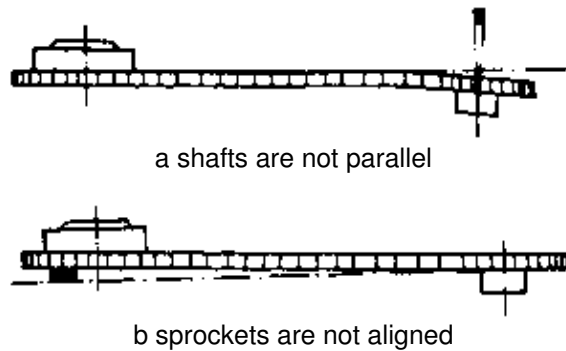
4.3.4. Mounting Technology

Sprockets and chain tension must be properly adjusted when mounting a chain drive. Care and maintenance are required during operation.

Adjusting the Sprockets

Sprockets are usually mounted on the shafts with a spline. The sprockets must be precisely aligned (with a rule), and they must be positioned parallel to each other. The chain will run with a skew if these points are not observed, resulting in premature wear. The same fault will arise when bearing clearance in axial direction is excessive (fig. 4/49).

Figure 4/49 Misaligned chain



Adjusting the Chain Tension

The tension of the chain can be varied by removing chain links, by adjusting the tensioning jockey, and by changing the distance between the shafts. The chain must not be too taut as this will cause intense heating and lead to rapid wear.

A chain should sag by about 2% of the centre spacing between the shafts.

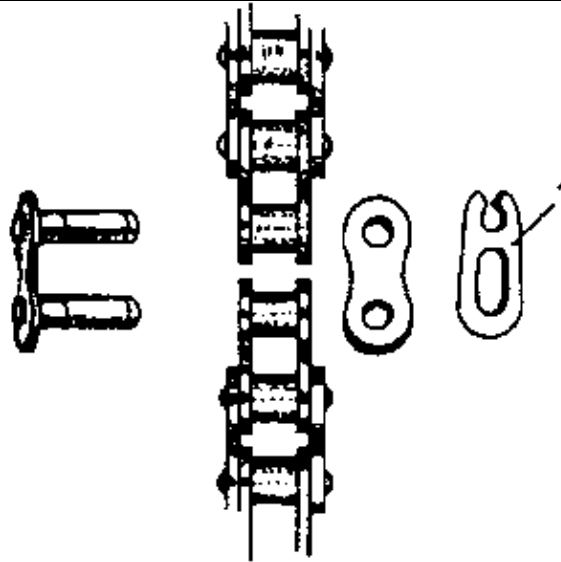


Figure 4/50 Chain ends for chain lock

1 bow spring

To remove the links of an endless chain, the rivet head of the link is filed off. The link is then placed on an appropriate base over a hole and the bolt is knocked out with a punch. When the chain is joined again care must be taken to ensure that the bow spring of the chain lock is installed in such a manner that its opening is facing in the opposite direction of chain travel (fig. 4/50). The bow spring can loosen itself if this is not observed. A straight insertion clip must be used to link up the two ends of the chain when two inner links are facing each other. An offset clip is required when an inner and an outer chain link are facing each other or, alternatively, the inner and outer links can be joined with a hardened bolt (fig. 4/51).

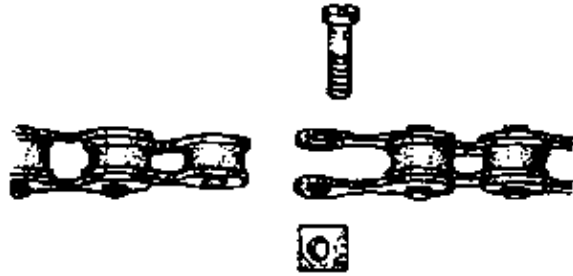


Figure 4/51 Chain ends for connection with hardened bolt

The chain tensioner is pressed against the chain by spring power or weights. This means that the chain is always under tension and its arc of contact around the sprocket is enlarged. The chain tensioner must be always fitted on the driven side of the chain. A change of the centre spacing between the shafts to tension the chain must always be followed by readjustment of the shafts and sprockets to make sure that they are perfectly parallel and aligned.

Care and Maintenance

Liberal lubrication greatly extends the service life of the chain. The lubricant should be supplied to the inner side of the chain and in the vicinity of the driving sprocket.

The transmission must be lubricated at regular intervals where permanent lubrication is not possible. Lubricant exchanging for high chain speeds and high contact pressure must be adequate to ensure that all spent lubricant is replaced and that all abraided particles are removed. Manual, drip, immersion, circulating and spray lubrication are applicable. Chains that are exposed to severe dirt pollution should be protected by dust-tight enclosures in the form of a chain box or a protective tube.

Cases may arise where chain drives cannot or must not be lubricated, e.g. inaccessible position or the material handled by the chain-driven machine must not be contaminated with lubricant. In such cases good results are achieved if the chains are provided with sliding sleeves made of plastics.

After about six months of service chains should be cleaned with petroleum. The chains are then immersed in hot grease. Two chain links are removed if the chain has been stretched by the length of two links. Maximum permissible chain extension is 3 to 5% of the normal chain length. The chain must be remounted with the same direction of travel and with the same inner side as previously. Chain renewal should always be combined with the replacement of the sprockets because otherwise the chain and sprockets will no longer mate properly. Never forget to fit the chain guards after maintenance work. The same labour protection code is applicable to chain drives as to belting transmissions.

Lubrication, driving tension and sag of chain drives must be constantly checked.

Questions:

1. What are the points that must be observed when mounting chain drives?

4.4. Toothed Gearings

Toothed gearings convert or change the direction of torque and rotating speeds. They are widely employed in machines and motor vehicles for positive power transmission without slip. Differing demands can be fulfilled by different types of toothed gears. Thus, spur gears are employed when shafts are arranged parallel to each other in the same plane (fig. 4/52). Bevel gears are used when shafts arranged in the same plane intersect (fig. 4/53), Helical gears and worm gears are used when the two shafts are arranged in two planes and when they intersect (figs. 4/54 and 4/55).

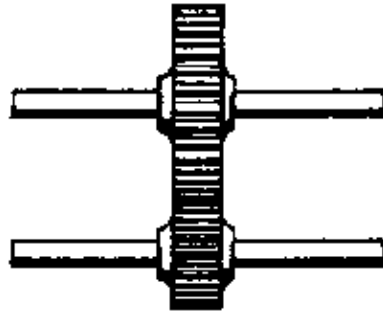


Figure 4/52 Spur gear

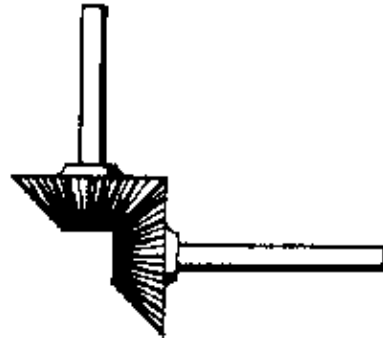


Figure 4/53 Bevel gear

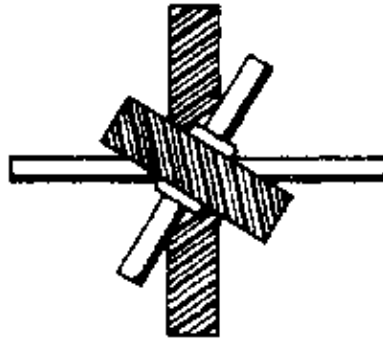


Figure 4/54 Helical gear

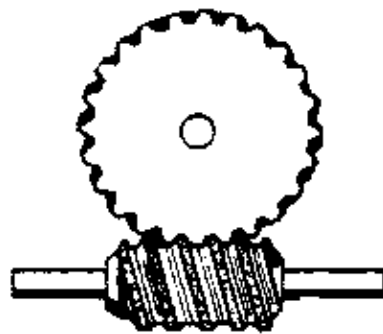


Figure 4/55 Worm gear

4.4.1. Spur Gearings

4.4.1.1. Design

A spur gearing consists of at least one pair of meshing spur gears on shafts or axles that are arranged parallel to each other. Transmission of the rotary motion from one gear to the other is positive. The teeth of one wheel engage in the tooth gaps of the other wheel. The points of contact of the teeth take place in lines. The surfaces with which the gears engage and which roll off or slide off each other during rotation are known as tooth flanks (fig. 4/56).

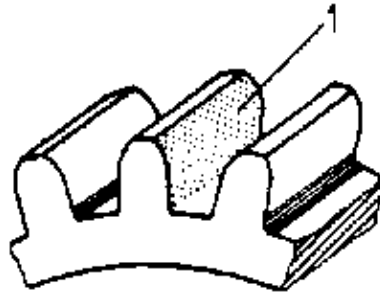


Figure 4/56 Position of tooth flanks on spur gear

1 tooth flank

Four conditions have to be fulfilled to assure perfect performance and efficient use of spur gearings:

- The tooth flanks must roll off perfectly against each other. The transition from tooth to tooth must be smooth and shock-free.
- The teeth must be able to mesh freely.
- The gears must be economical to produce by mass manufacturing methods.
- The gears must be relatively insensitive to manufacturing and mounting errors.

The most important parts and interdependencies of a spur gear are as follows:

Number of teeth: The number of teeth z of a wheel is the number of existing (or feasible) number of teeth accommodated on a closed wheel body.

Pitch diameter: The pitch diameter d_0 is a purely mathematical magnitude and cannot be measured on the gear (see fig. 4/57).

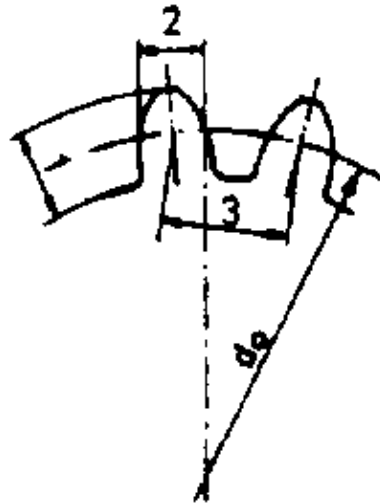


Figure 4/57 Designations of the parts of a spur gear

d_0 pitch diameter; 1 tooth height; 2 tooth width; 3 pitch

Module: The number m that is calculated from multiplication with z (number of teeth) of the pitch diameter is known as the module. At a given pitch diameter and an unknown number of teeth, the module has to be calculated according to

$$m = \frac{d_0}{z}$$

4.4.1.2. Operating Characteristics

Transmission ratio: The pitch diameters of a pair of gears are in contact with each other. Similar to belt transmissions, the rotating speed is inversely related to the diameter. Hence, the transmission ratio i of a pair of gears is the relationship of the pitch diameter, the rotating speed and the number of teeth of the driving wheel in relation to the driven wheel (driving wheel 1 and driven wheel 2).

$$\text{Transmission ratio } i = \frac{d_{02}}{d_{01}} = \frac{n_1}{n_2} = \frac{z_2}{z_1}$$

The spur gearings considered hitherto had a constant speed, and thus also a constant transmission ratio, in conformity with the adopted gear dimensions. In order to adapt operating conditions as closely as possible to prevailing requirements, toothed gearings are produced with which the driven speeds can be changed at unvarying driving speeds. Such speed-changing gears are extensively employed in motor vehicle and machine tool building. A series of speeds can be formed with such gears.

Axle or shaft spacing: This spacing is calculated from the sum of the two half pitch diameters:

$$a = \frac{d_{01} + d_{02}}{2} \quad (\text{see fig. 4/58})$$

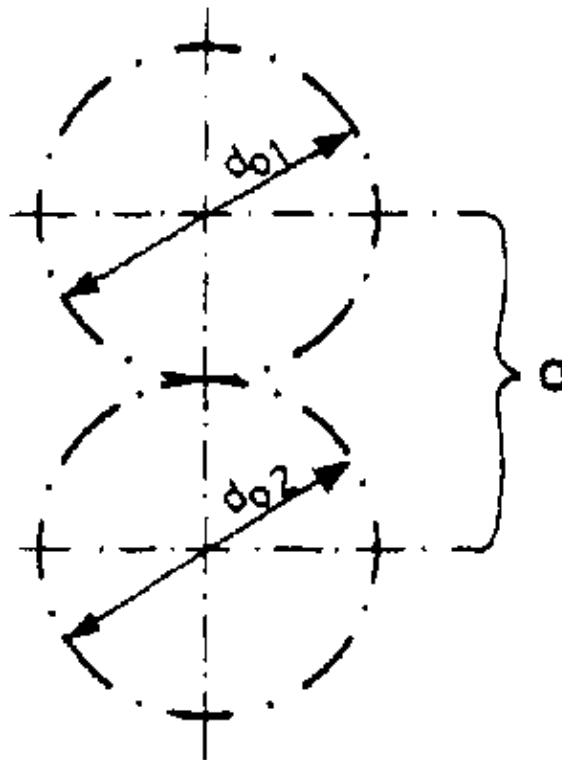


Figure 4/58 Shaft spacing for simple transmission d_{01} pitch diameter of driving gear, d_{02} pitch diameter of driven gear, a shaft spacing

4.4.1.3. Types

Spur gears are distinguished by:



- Tooth profile
- Pitch line (length of the teeth in relation to wheel axis)

The distinguishing features of spur gears by pitch lines are shown in table 4/5. A gearing with a variable transmission ratio is known as a speed-changing gearing. This is distinguished by the manner in which the gear pairs are engaged and disengaged. This can be done by one of the following three methods:

- The toothed wheels are axially shifted on the shaft (sliding gear)

- The toothed wheels are engaged by radial and axial motion (tumbler gear)
- The toothed wheels are inserted in the power transmission by a clutch (clutch gears)

Table 4/5: Distinguishing Spur Gears by their Pitch Line

Designation (illus.)	Remarks
Straight– toothed gear 	Linear mesh of the teeth over their entire width causing negligible vibrations that can be heard as running noise.
Helically–toothed gear 	The teeth mesh only gradually over their entire width to assure soft transmission from one tooth to the next without giving rise to any vibrations. The arising axial forces depend upon the angle of the teeth in relation to the axis of the gear. The flexural strength of the teeth is higher than that of straight-toothed gears.

4.4.1.4. Mounting Technology

The gear casings should be mounted on appropriately designed swivelling stands to simplify the installation and removal of parts of the gearing. Only the correct tools must be used to prevent damage to the gearing parts.

- Drive punches should be made of light metal, copper or brass.
- Only mallets made of rubber, wood or lead should be used as hammers.
- Auxiliary shafts or axles must be slightly undersize compared with the original parts so that it is unnecessary to apply excessive force when parts are being installed or dismantled, and to ensure that these parts do not become jammed.

Toothed gearings are usually mounted as assemblies. The job is completed in a definite sequence of steps:

- Mount the gears on the shafts.
- Insert the shafts with mounted gears in the gear casing or frame.
- Adjust the mesh of the gears.

The following points must be observed when assembling gears and shafts into assemblies:

- The parts must be thoroughly cleaned as otherwise particles will adversely affect the surface quality of the bearings, hub holes and other seating surfaces.
- Establish whether the surface quality and accuracy of the seating surfaces conform with the specifications in the drawing
- Soft intermediary packings made of wood, lead or light metal must be placed between the parts and the jaws of the vice when the parts are clamped in a vice.
- Wherever possible, the shafts should be clamped in a vertical position when gears and shafts are being assembled (use corresponding fixture).
- Prior to assembly, check whether the chamfer is sufficiently large when the gear is pushed up against the shaft collar so that the face side of the hub is uniformly in contact with the collar.
- When mating a plastic and a metal gear wheel, care must be taken to ensure that the wider metal wheel protrudes uniformly on both sides.

Forms of Connection

The commonest forms of connection are used to mount toothed wheels on shafts:

- Driving connection with bolts (fig. 4/59)
- Driving connection with splines (fig. 4/60)
- Driving connection with pins (fig. 4/61)
- Driving connection by pressed fit (fig. 4/62)
- Rotational mounting on the axle (fig. 4/63)

The details given in Section 2 must be observed when producing these connections.

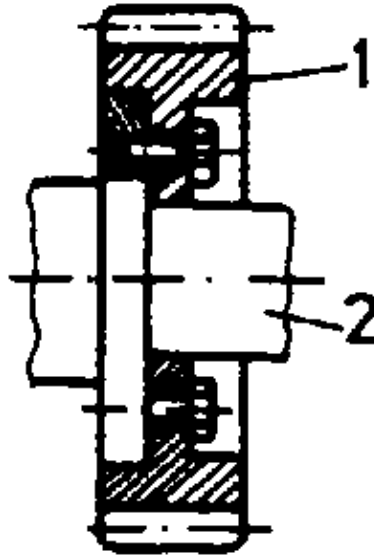


Figure 4/59 Bolt connection

1 gearwheel; 2 gear shaft

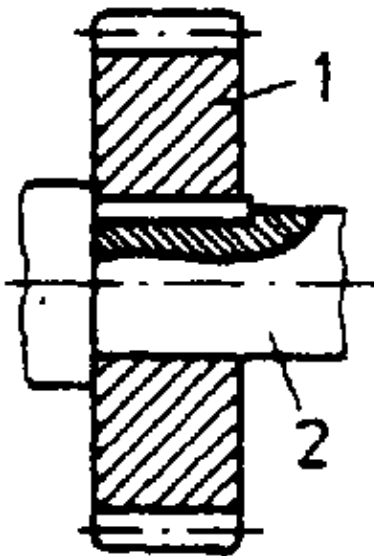


Figure 4/60 Splined connection

1 gearwheel; 2 shaft

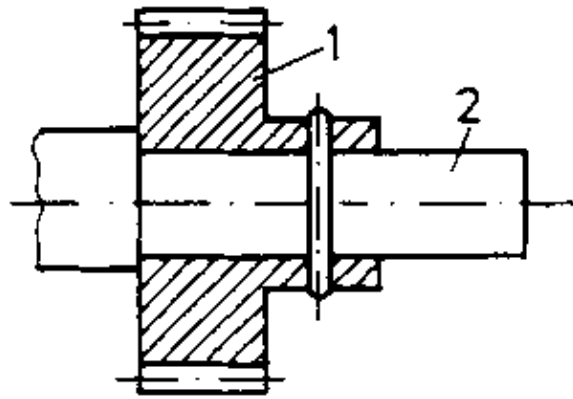


Figure 4/61 Pin connection

1 gearwheel; 2 shaft

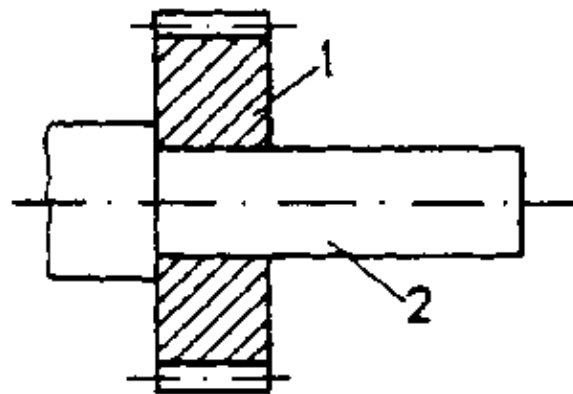


Figure 4/62 Pressed fit

1 gearwheel; 2 shaft

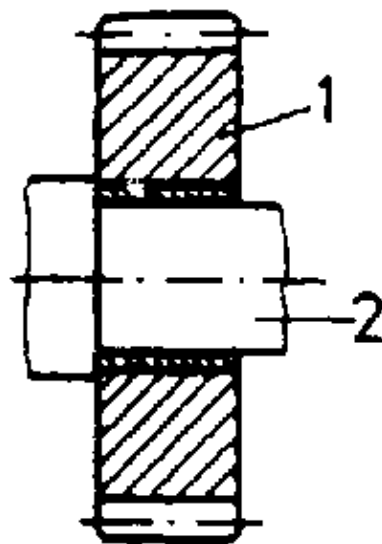


Figure 4/63 Rotational mounting on the axle or shaft

1 gearwheel; 2 shaft

A press is required to mount gears when a tight fit (splined or keyed connection) has to be established between the shaft and the gearwheel. This applies to pressed fit. If a press is not available for the job, the gears should be heated to 80 °C in an oil bath and then driven on with a rubber mallet. This job can be simplified with a matching driving sleeve (fig. 4/64). A removing device (fig. 4/65), similar to the one used for rolling-contact bearings, is employed to remove gears from shafts.

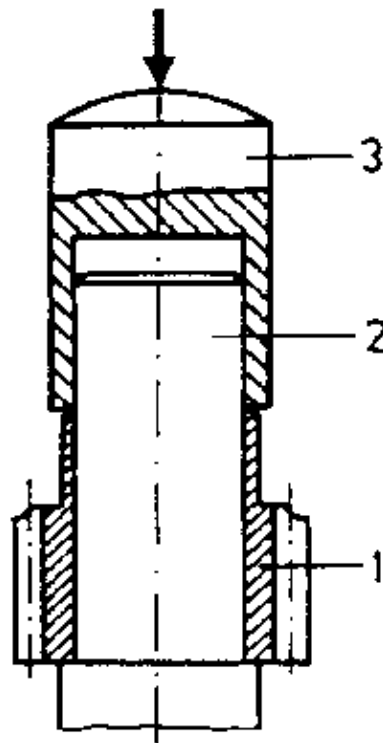


Figure 4/64 Driving sleeve to mount shaft and gear

1 gearwheel; 2 shaft; 3 driving sleeve

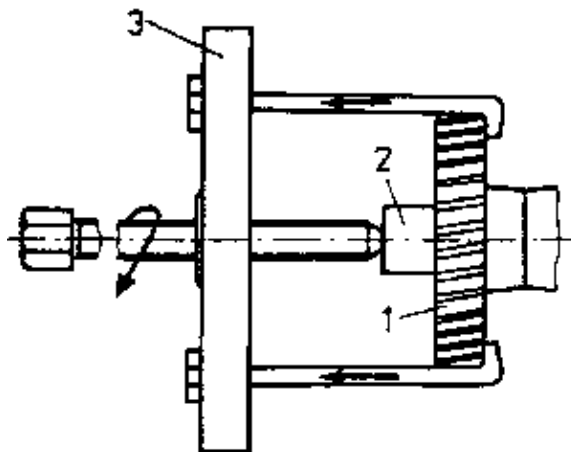


Figure 4/65 Gear removing device

1 gearwheel; 2 shaft; 3 removing device

Assembly of a Gearing

The casing must be thoroughly cleaned prior to the assembly of a gearing. Split casings offer the advantage of greater accessibility for assembly. The shafts can be inserted in the casing bearings without any trouble. The mesh of the gears, bearing clearance, and the performance of the gearing, can be easily observed when the casing is open. The specified axial clearance and the correct tooth mesh must be maintained when a gearing is assembled.

Checking a Gearing

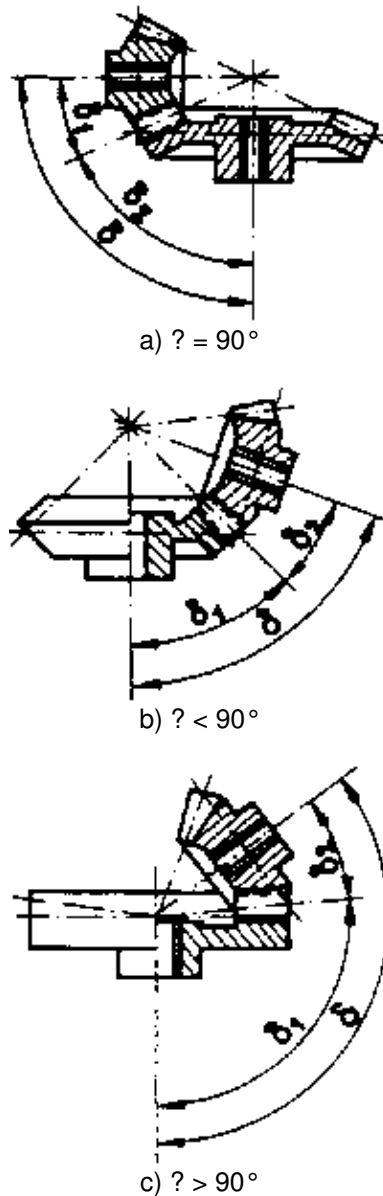
The gearing is filled with the prescribed quantity of oil when it has been fully assembled. A tightly sealed casing has to be evacuated to compensate for the rising pressure due to heating. Filters, felt packings, etc., have to be carefully examined to make sure that there is not too much resistance for the free passage of air. Other checks are conducted according to the stipulated vetting and acceptance procedure.

4.4.2. Bevel Gearings

4.4.2.1. Design

Bevel gearing is used to transmit motions between two shafts located at an angle to each other. The shaft angle δ (delta) can have values between 0 and 180, although a shaft angle of 90° is most widespread. Various shaft angles are shown in fig. 4/66. The motion of two meshing bevel gears corresponds with the rolling motion of two cones in contact with each other at their circumferential lines and which have a common point of intersection. Bevel gears use only a narrow section of their circumferential surface for meshing. That is why only two cone fulcrums are rolling off each other. The cone of a large bevel gearing can be so big that it resembles a plate. Such a cone is called a crown wheel (fig. 4/67).

Figure 4/66 Shaft angles on bevel gears



Bevel gear pair with crown wheel

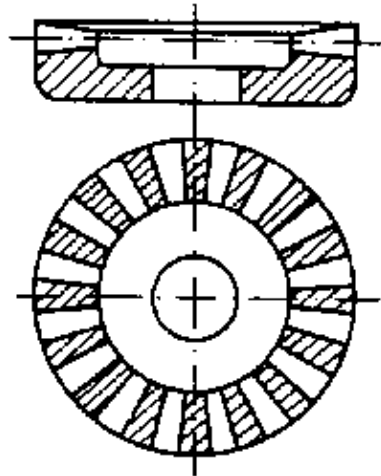


Figure 4/67 Crown wheel

The designations of the parts of a bevel gear, shown in fig. 4/68, are identical to those of a spur gear with a few exceptions.

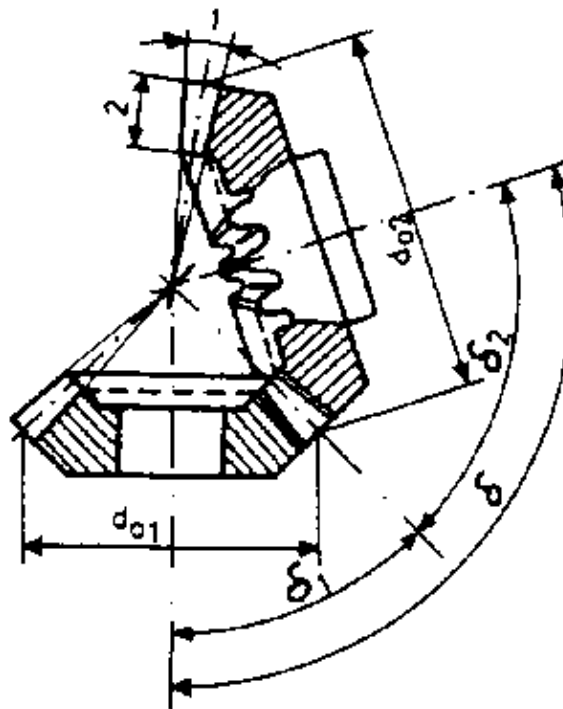


Figure 4/68 Designations of the parts of a bevel gear

d_0 pitch diameter δ_1 half taper angle of a gearwheel δ_2 half taper angle of the second gearwheel δ shaft angle 1 tooth height; 2 tooth width

Similar to the spur gear, the module is the quotient of the pitch diameter and the number of teeth:

$$m = \frac{d_0}{z}$$

4.4.2.2. Operating Characteristics

Transmission ratio: The transmission ratio i is calculated from:

$$i = \frac{n_1}{n_2} = \frac{z_2}{z_1}$$

4.4.2.3. Types

Bevel gears are distinguished by:

- The tooth profile
- The course of the pitch (straight-tooth bevel gear) (table 4/6). These gears can be assembled into the gearings shown in figures 4/69 to 4/71. The straight-tooth gearing was shown in figure 4/68.

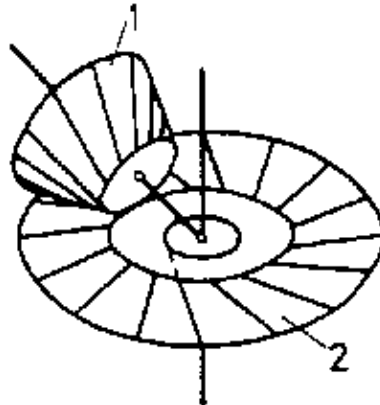


Figure 4/69 Helical bevel gear

1 bevel gearwheel; 2 crown wheel

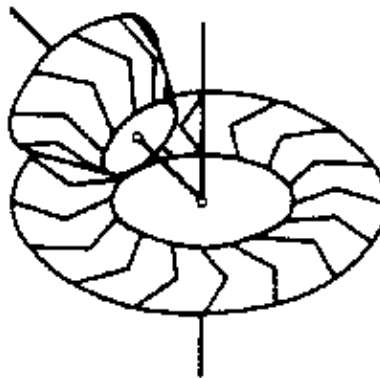


Figure 4/70 Double-helical bevel gear

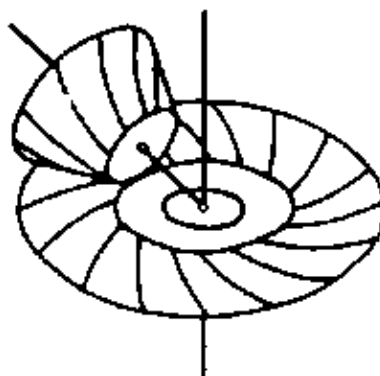


Figure 4/71 Curved-tooth bevel gear (curved pitch line)

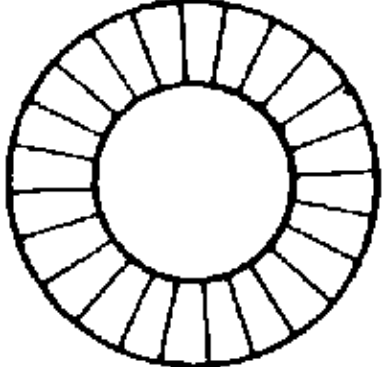
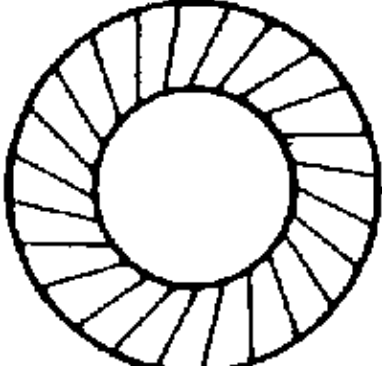
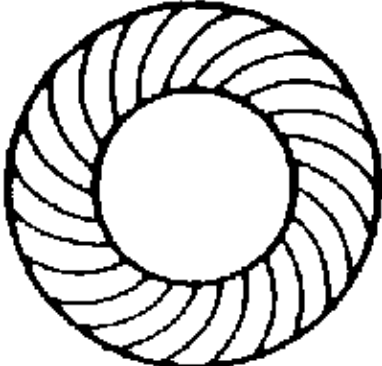
Bevel gearings are also distinguished by the kind of motion of the shafts or axes:

- Bevel gearing (with at least two fixed shaft axes)
- Epicyclic bevel gearing (the axis of at least one gear revolves on an arm around the axis of another gear).

The mounting rules for bevel gears are the same as those for spur gearings. The pair of bevel gears will only mesh perfectly if the points of their base cone meet at the intersection of the axes.

Bevel gears are tested after their manufacture and are matched into pairs according to their performance. That is why only mated pairs should be installed.

Table 4/6: Distinguishing Bevel Gears by their Pitch Line

Illus.	Designation	Remarks
	Straight-toothed bevel gear	The teeth proceed in a straight line; their direction points towards the vertex of the cone; head and root edges merge at the tip of the head. Simultaneous linear mesh of the teeth over their entire width gives rise to audible vibrations.
	Helically – toothed bevel gear	The helical teeth mesh only gradually, resulting in very smooth running (see spur gears).
	Curved– tooth bevel gear	The pitch lines can proceed in a circular arc or as a spiral. Gradual tooth meshing results in smooth running.

The prescribed axial clearance in the casing must be observed when the bevel gear shafts are inserted in the bearing body. It can be adjusted with a feeler gauge. The gears must be adjusted according to the specified values to assure proper mesh. The tooth contact pattern must be carefully examined after installation. Bevel gears can be adjusted in relation to each other by the following methods:

- Interposing fitting rings between the faces of the bevel gears and the shaft flange or bearing bushing (fig. 4/72).
- Interposing packings between the fitting surfaces of the casing parts and the bearing covers (fig. 4/73).
- Shifting the entire bearing body by a thread (fig. 4/74).

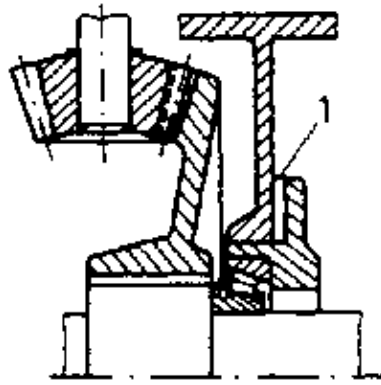


Figure 4/72 Mounting a fitting ring

1 fitting ring

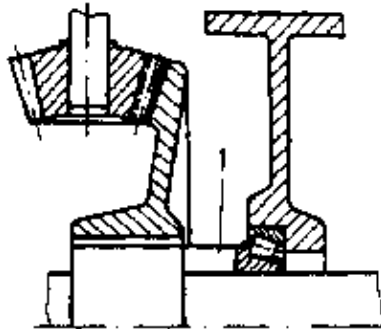


Figure 4/73 Packings between casing parts

1 packings

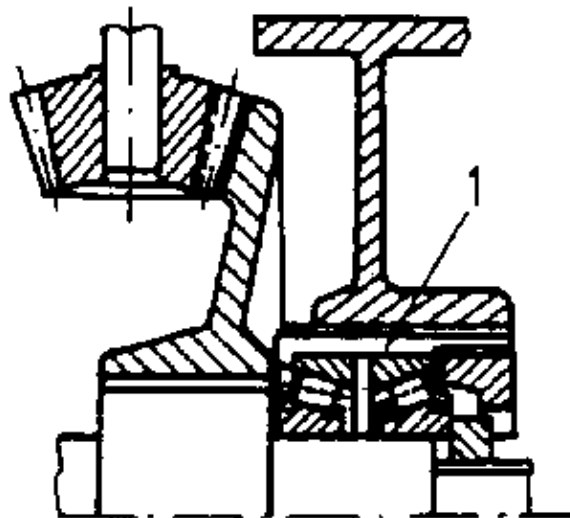


Figure 4/74 Setting the bearing body

1 threaded bushing

The tooth flanks are coated with marking ink to reveal the tooth contact pattern on the teeth of the bevel gears when they are rolled off against each other. The different kinds of possible tooth contact patterns are shown in table 4/7.










Adjusting the Bevel Gears

- Check whether the shafts of assembled gearings can be easily turned by hand.
- Mount the gearing on the running-in stand and fill it with oil.
- Run the gearing at the rated speed and assess the running noise. Vary the setting of the bevel gears to find

the quietest running position.

- Blow the oil out of the gearing and rinse it thoroughly with petroleum or wash oil.
- Coat the gears with marking ink and turn the gearing by hand for a longer period.
- Assess the tooth bearing pattern and adjust accordingly. Adjustment must be repeated until the correct tooth contact pattern is obtained.
- The marking ink is carefully removed; the gearing is once again filled with oil and the running noise of the gearing is assessed at the prescribed running speed.

Table 4/7: Tooth Contact Patterns

Contact pattern	Correction	Remarks
		Correct mesh
		Incorrect mesh. The crown wheel has to be shifted out of contact.
		The crown wheel must be shifted more into contact.
		The crown wheel has to be shifted more into contact, while the pinion has to be shifted out of contact.
		The pinion has to be shifted more into contact, while the crown wheel has to be shifted out of contact.

The backlash between the teeth of the gears must not exceed the specified limits. The backlash must cover the entire tooth uniformly.

Incorrectly set gear pairs will cause loud running noise, generate excessive heat, and give rise to the tendency of tooth seizure.

4.4.3. Helical Gearings

4.4.3.1. Design

Helical gearings are obtained When one of two spur gears is given helical teeth of the same circular pitch as the other so that the pair can mesh. This type of gearing is used for non-parallel and non-intersecting shafts, i.e. shafts positioned at an angle to each other. The shaft angle may vary between 0° and 180° , depending upon the spiral angle of the teeth of the two gears. A shaft angle of 90° is usually adopted (as shown in figure 4/75).

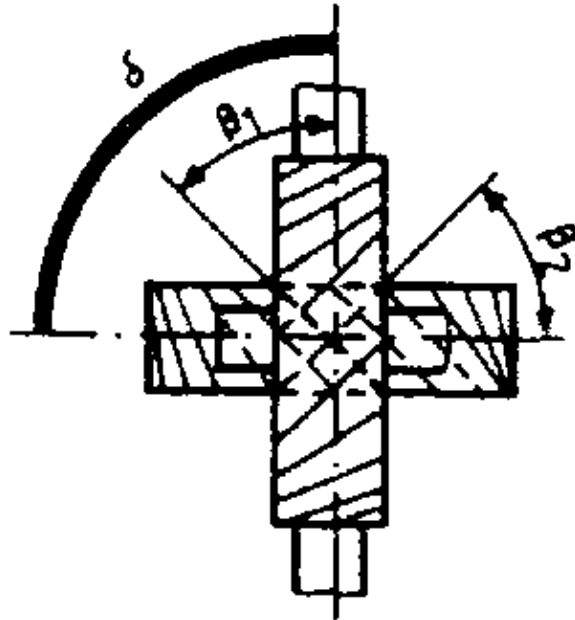


Figure 4/75 Shift angle of helical gearing

($\delta = 90^\circ$; $\beta_1 = \beta_2 = 45^\circ$? helix angle)

Helical gearings are employed when a high step-up ratio (e.g. centrifuges) is required. They have only limited load transmitting capabilities.

4.4.3.2. Operating Characteristics

The teeth of helical gears have the same pitch, but a differing spiral angle: (beta). Sliding friction of helical gears is much higher than that of spur or bevel gears. This is why their efficiency is poorer than straight-toothed gears.

The transmitting ratio is usually established in the same manner as normal-toothed gears, namely from the speed and the number of teeth.

4.4.3.3. Types

Smaller loads are transmitted by the type of helical gears shown in figure 4/76. Higher power transmitting capacities require worm gearings.

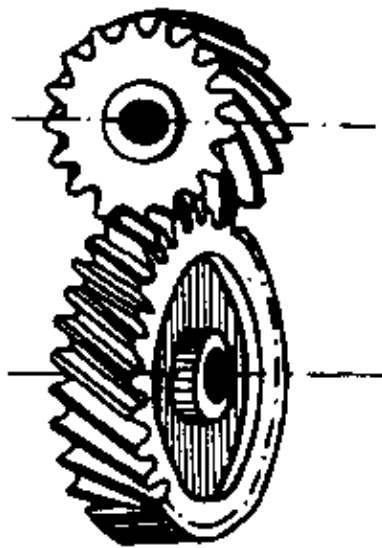


Figure 4/76 Helical gearing shaft angle $\delta = 90^\circ$

4.4.3.4. Mounting Technology

Helical gearings are usually composed of a large and a small helical gear. The shafts are arranged in two planes and intersect in most cases at an angle of 90° . Since the large helical gear must run with precise centricity it is often mounted on a multiple-splined shaft. The smaller gear is generated directly on the shaft so that the two form a single piece. The prescribed shaft angle must be accurately maintained when the gearing is assembled. The distance spacing between the shafts and tooth mesh have to be checked and corrected if necessary. Helical gearings involve only point contact between the gears. This means that an incorrectly adjusted gearing will cause high abrasion.

4.4.4. Worm Gearings

4.4.4.1. Design

Worm gearing has one gear that takes the form of a screw or worm with a thread of defined lead angle. This gear is known as the worm. The other gear – the worm-wheel – has teeth inclined at the same angle as the thread in the worm. A complete revolution of the worm causes the worm-wheel to advance by one tooth.

Worm gearings are employed for high step-down ratios. Their sliding mesh make them quiet running, and they can take up high shock loads. Worm gears of higher ratios are self-locking, i.e. they come to a standstill in any position without braking. This is because a worm gearing only transmits power in the direction of the worm in relation to the worm-wheel. The sliding friction of worm gearing is much higher than that of simple spur or bevel gearings. Worm gearings must be well lubricated to dissipate the friction heat. Additional cooling vanes or fans are sometimes employed for heat dissipation. The material of the worm must be harder than that of the worm-wheel to obtain good sliding action. Hardened case steel is employed for heavy-duty worms.

The worm-wheel is made either entirely or partially (rim) of phosphor-bronze. Brass, grey-cast iron, polyamide and other materials are employed for lesser stressed gears.

4.4.4.2. Operating Characteristics

The most important value of a worm gearing is the lead angle γ (gamma) of the worm (see fig. 4/77). The smaller the lead angle of the worm, the lower the efficiency of the worm gearing. The lead angle of the worm of high-class worm gearings should be in the order of 20° to 30° .

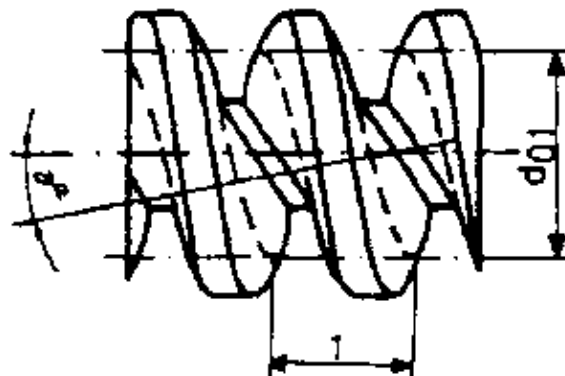


Figure 4/77 Lead angle of the worm

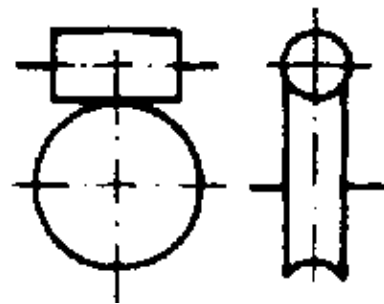
γ lead angle; d_0 pitch diameter; l lead

4.4.4.3. Types

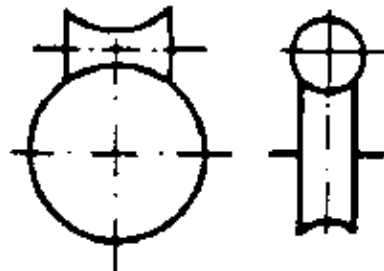
A worm gearing can have a right-hand or a left-hand worm. The worm gearing is distinguished by the shape of the basic bodies:

- Cylindrical worm gearing (basic bodies are a cylinder and a globoid)
- Globoidal worm gearing (basic bodies are two globoids).

Figure 4/78 Basic bodies of worm gearing



a) cylindrical worm gearing



b) globoidal worm gearing

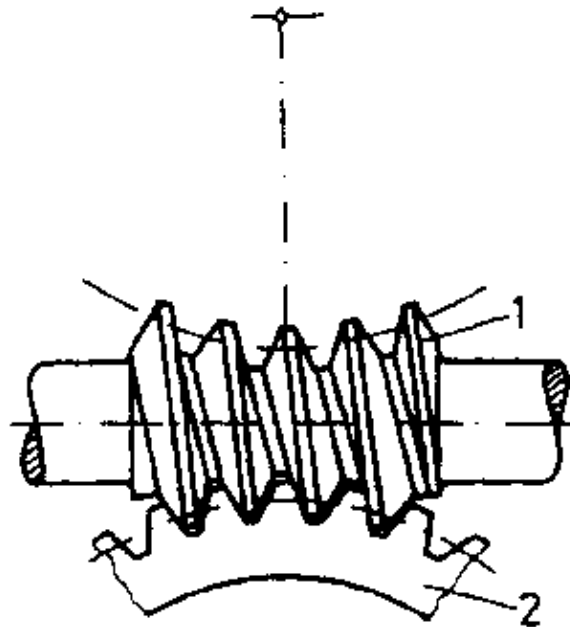


Figure 4/79 Globoidal worm and worm-wheel

1 globoidal worm; 2 worm-wheel

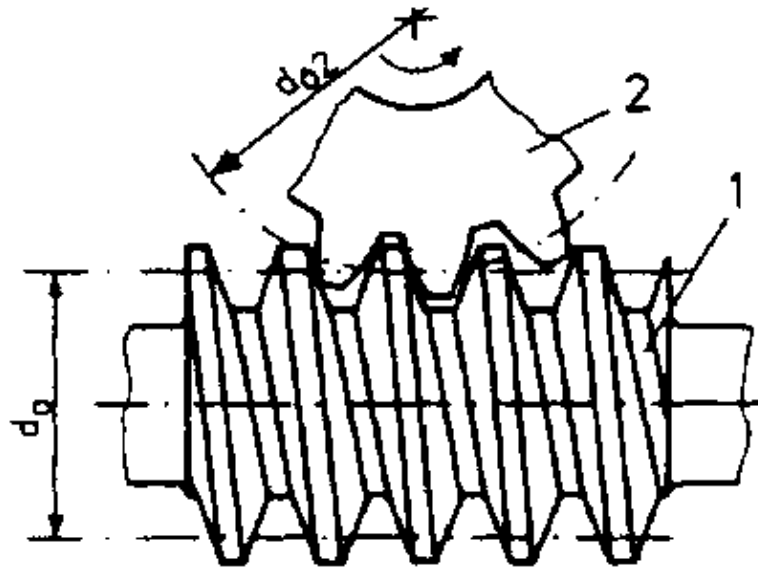


Figure 4/80 Cylindrical worm gearing

1 cylindrical worm; 2 worm-wheel

These basic bodies are shown in figure 4/78. Figure 4/79 shows a globoid worm meshing with a worm-wheel, while figure 4/80 depicts a 2-tooth cylinder worm.

There are two basic areas of application of worm gearings:

- To drive lifting machines (e.g., sets of pulleys to lift heavy loads with little effort). With this type of machine the lifted load must remain at the lifting height after the driving power is stopped (self-locking). Worm gearing used for this purpose should have a worm lead angle of not more than 5°.
- Electric motor drives for machines where the high rotating speed of the worm on the motor shaft is stepped down to the desired working speed by the worm-wheel. In this application the lead angle of the worm can be up to 30°.

4.4.4.4. Mounting Technology

The design of worm gearings depends upon the power that is to be transmitted by them. Worms and worm-wheels of lower power transmitting capacity are usually mounted on the shafts with splines or pins. Where higher powers have to be transmitted, as in machine building, the worm and the shaft are made in a single piece, while the worm-wheel is mounted on the shaft with splines. Bronze worm-wheels usually consist of a removable rim made of bronze fitted to a grey-cast hub. This offers the advantage of exchangeability when the rim is worn down. Worm-wheels are also manufactured with rims that are screwed or adhesive-bonded to the hub.

The following checks are necessary when mounting worm gearings:

- Worm-wheels with fitted rim must be checked for axial and radial run-out.
- The angle of a shaft guided in flanged bearings (flanged bearing bodies bolted to the casing) must be checked against the prescribed shaft angle. The manufacturing process guarantees the correct shaft angle for bearing holes.
- The centre spacing between shafts must conform with the specifications given in the engineering drawing (very important in connection with flanged bearings!).
- Inspection of the mesh between worm and worm-wheel.
- Trial run on test stand to assess whether permissible heating is exceeded.

The inspection of the proper mesh between worm and worm-wheel is a peculiarity of worm gearing. All the other checks are conducted in a similar manner as for other types of gearings.

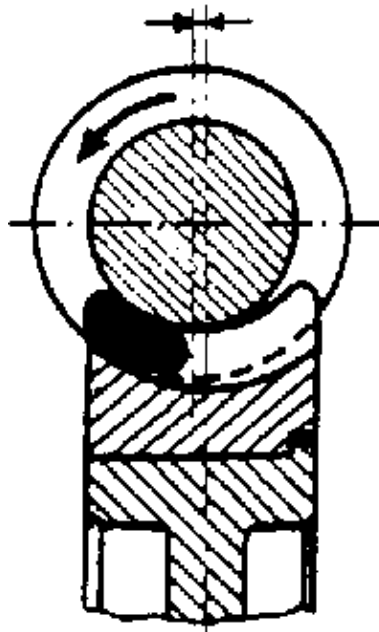
Proper running of worm gearings depends upon the correct position of the worm-wheel in relation to the worm, and upon torsional backlash.

Position of the Worm-Wheel in Relation to the Worm

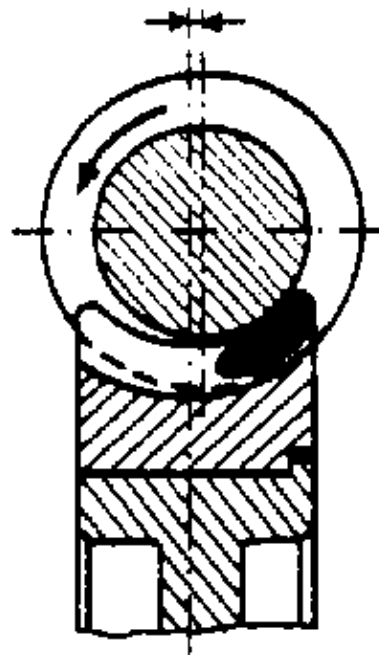
The bearing contact pattern test is the simplest method to assess the position. This involves the following procedure:

1. Coat the flanks of the worm with marking ink.
2. Turn the worm slowly.
3. Evaluate the gear contact pattern on the flanks of the worm-wheel (see fig. 4/81).

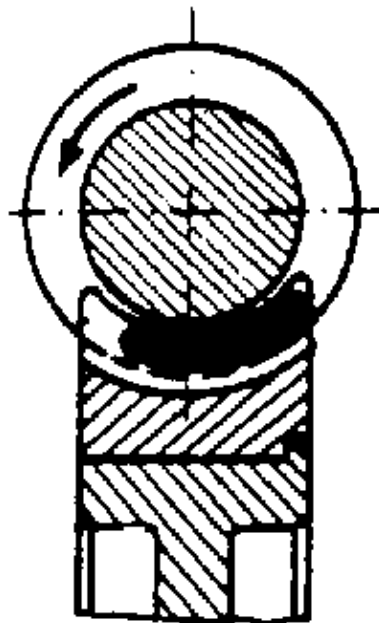
Figure 4/81 Worm-wheel contact pattern



a Off-centre deviation of the worm to the left



b Off-centre deviation of the worm to the right



c Perfect contact pattern

The deviation of the worm shaft from the middle plane of the worm-wheel can be seen from the position of the contact pattern. At least 50 to 60% of the height and width of the tooth flanks must be covered with marking ink if mesh is good. Deviations are corrected by axial adjustment of the worm-wheel shaft. This correction can often be completed in a similar manner as for bevel gearing.

The longitudinal centre of globoid worms must stand precisely at the lateral centre of the worm-wheel. Deviations are corrected in the same manner as for the worm-wheel, namely by adjustment of the worm. The centre line of the worm of globoid worm gearings must stand at a right angle to the diameter of the worm-wheel. Deviations are remedied by axial adjustment of the worm.

Torsional Backlash

Torsional backlash is the amount of possible torsional movement of the worm while the worm-wheel is being held. The amount of movement is measured in degrees. It is measured by the assembly shown in figure 4/82. A disk graduated in degrees is mounted on the shaft of the worm. Its pointer deflection is read off in degrees. The feeler pin of a dial gauge touches the flank of a tooth of the worm-wheel. The angle of worm movement until the worm-wheel is carried along is established. The permissible angle of torsional backlash is prescribed for the given gearing. In the event of deviations from the specified values it is necessary to check whether the tolerances for the inter-shaft spacing are maintained or whether the backlash of the bearings of the worm-wheel and worm shafts is too large.

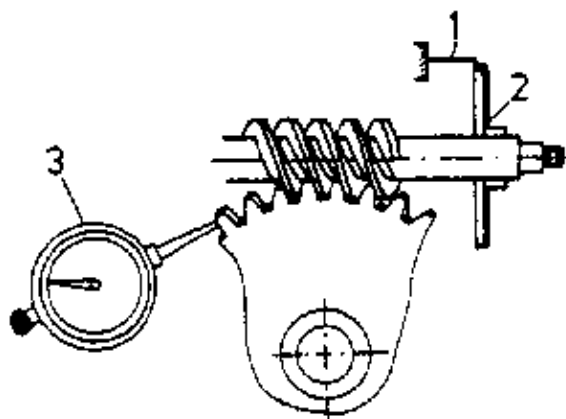


Figure 4/82 Assembly to measure torsional backlash

1 pointer; 2 degrees dial; 3 dial gauge

Questions:

1. Describe the aids that are necessary to securely attach the cone of the pressure screws of take-off devices on the shafts.
2. Describe how a shaft can be pressed out of a gear with the help of a press.
3. What purposes have bevel gearings?
4. What is the difference between worm gearings and helical gearings?
5. Describe how a worm gearing is assembled.

4.5. Linkage and Crank Transmissions

These mechanisms are extensively used throughout industry for the transmission of power by means of differently shaped rods, levers and guides. These mechanisms come under the category of linkage and crank transmissions. The members of these transmissions are connected by pivot or slide joints. The fulcrums of the levers – the joints – perform periodically widely differing curved movements if the mechanism is not mounted in a frame known as the fixed link. Since these transmissions allow for only a single movement (either rotational or sliding), and since they can only move within a single plane, they are commonly known as a planar linkage. Linkage and crank transmissions are widely used, for instance on railway engines, combustion engines and luffing cranes, to list a few typical examples.

4.5.1. Design

The 4-bar linkage forms the basis of all crank transmissions. It produces a closed crank chain in which the members are interlinked by four joints. If these members of differing length are denoted by the figures I, II, III and IV, as in figure 4/83, one will see that varying transmissions are created by using the different members as fixed links. In figure 4/84 member IV is the fixed link. This results in a crank and rocker mechanism whenever the lengths of the individual members fulfil the following mathematical conditions:

- I + II smaller than III + IV
- I + III smaller than II + IV
- I × IV smaller than III + II

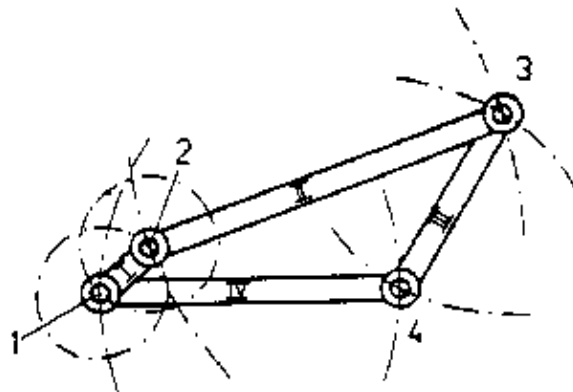


Figure 4/83 4-bar linkage

1, 2, 3, 4 links; I, II, III, IV members

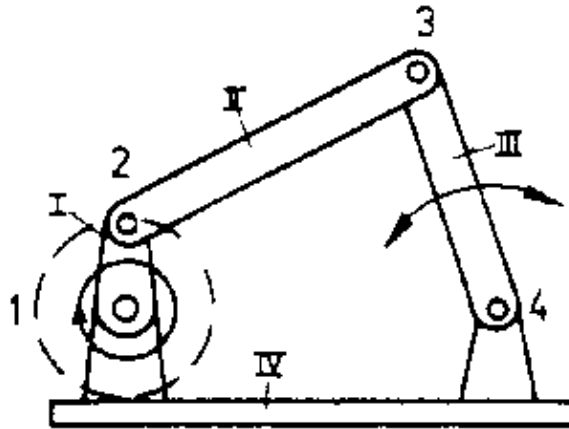


Figure 4/84 Crank and rocker mechanism

1, 2, 3, 4 links; I crank; II coupling; III rocker; IV fixed link

A drag-link mechanism (fig. 4/85) is formed when member I is used as the fixed link. A double rocker link (fig. 4/86) is obtained when member III becomes the fixed link.

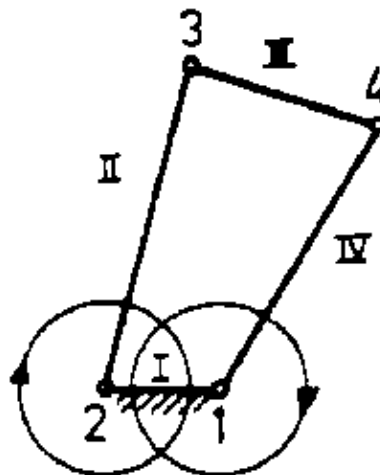


Figure 4/85 Drag-link mechanism

1, 2, 3, 4 links; I fixed link; II crank; III coupling; IV crank

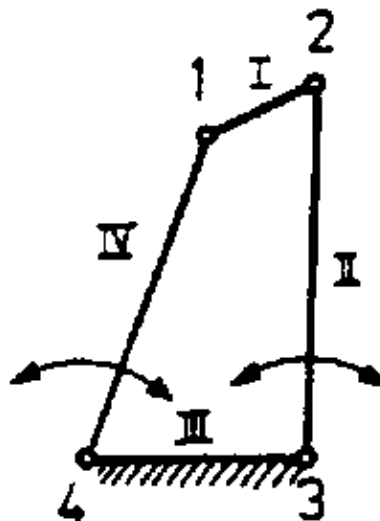


Figure 4/86 Double rocker link

1, 2, 3, 4, links; I coupling; II rocker; III fixed link; IV rocker

The members are the rigid bodies, while the joints, are the moving links. One member of a transmission is driven so that the transmission can fulfil its function. This driving power is usually derived from a rotating shaft

that is rigidly connected to the transmitting member. The driving member is known as the crank. The driven member is connected with the driving member by one or more intermediary members and joints. The connecting member is known as the coupler. When the rotary motion of a transmitting member is restricted in its movement, i.e. when it can only reciprocate within a certain angular range, then this transmitting member is known as a rocker. Perfect performance of the given type of transmission is only assured if the movement of all its members is interdependent. The movement of one of the members automatically causes all other members to move positively along defined paths. This is particularly obvious in the 4–bar linkage presented here. If, however, another member is incorporated in this linkage (fig. 4/87), then the path of the individual members is no longer clearly defined.

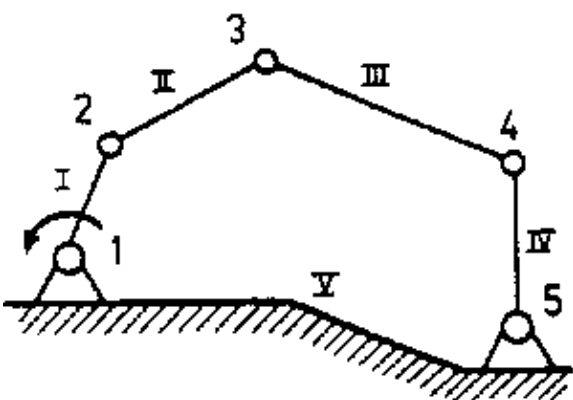


Figure 4/87 Undefined linkages

1, 2, 3, 4, 5 links; I, II, III, IV, V members

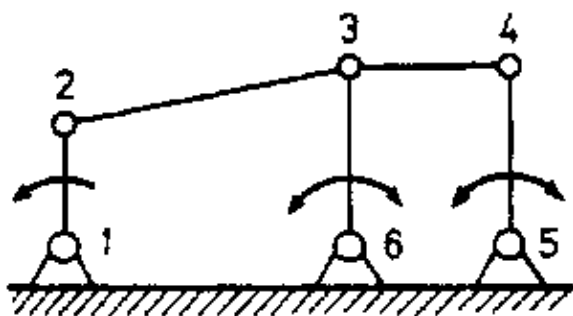


Figure 4/88 Defined linkage

The situation is different when two members are added (as in fig. 4/88). In this case the movement of all members once again becomes interdependent.

Joints can be distinguished by different aspects:

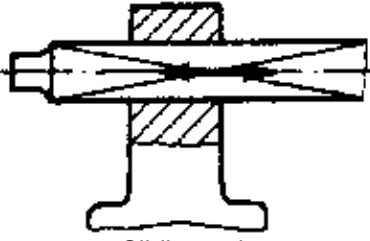
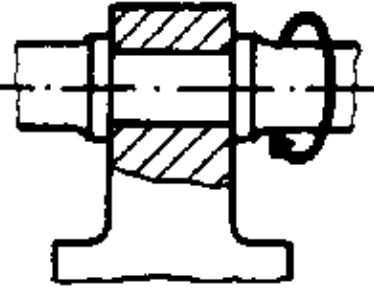
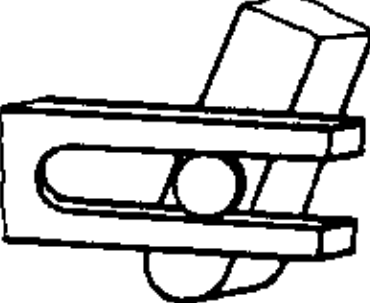
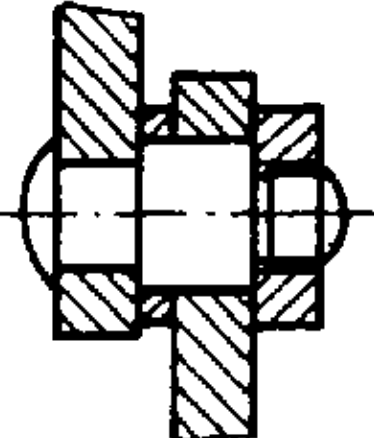
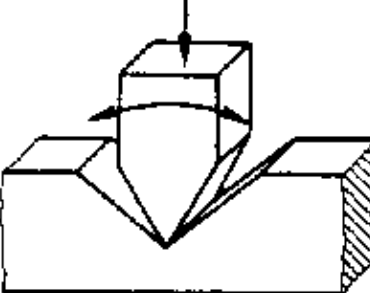

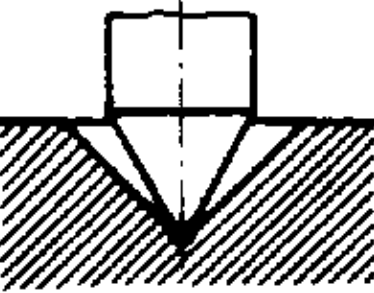
- According to the kind of movement (sliding pair, turning pair)
- According to the kind of closure (dependent or independent closure)
- According to the kind of contact (line, surface and point contact)

Table 4/8 gives the distinguishing characteristics of members of crank transmissions.

All transmissions that do not have a rotating member, but rather a rocking or reciprocating motion, have points at which the movement is reversed. These points are known as the inner and the outer dead centres. These points arise whenever two transmitting members of the 4–bar linkage are in their draw–in position(fig. 4/89) or in their drawn–out position (fig. 4/90).

Table 4/8: Distinguishing Features of Members of Crank Transmissions

Distinction	Design	
-------------	--------	--

Motion	 <p>Sliding pair</p>	 <p>turning pair</p>
Closure	 <p>dependent closed</p>	 <p>independent closed</p>
Contact	 <p>line</p>	 <p>surface</p>
		 <p>point</p>

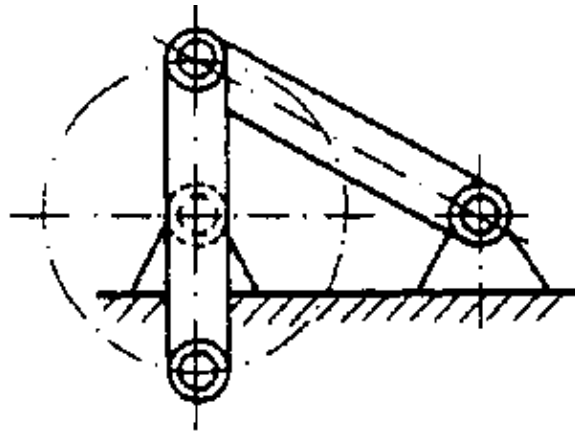


Figure 4/89 4-bar linkage in drawn-in position

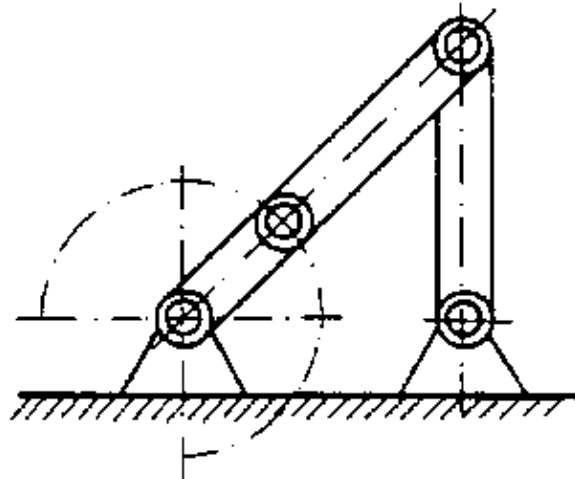


Figure 4/90 4-bar linkage in drawn-out position

In their drawn-in position the members take on their inner dead centre, in their drawn-out position their outer dead centre.

The velocity of the driven members in both dead centres equals nill. With each movement the driven member is accelerated from nill to top speed, and then from this maximum once again back to nill as the other dead centre is reached. This means that extra power, beyond the actual power that is to be transmitted, becomes necessary to accelerate and slow down the masses.

4.5.2. Operating Characteristics

It is important to ascertain whether a given transmission will fulfil the demands expected of it in practice. Hence, it is necessary to establish whether the extension of a luffing crane does actually describe a horizontal line. For other transmissions it is often necessary to establish the speeds and accelerations of certain points.

Alternatively, it may be necessary to define the path curve of a point of transmission. The movement conditions of simple coupling transmissions can be established by mathematical means, but such calculations rarely furnish the desired result because of the complicated paths described by certain points in the transmitting members can be very difficult to define mathematically. Instead, better practical results are obtained by drawings, or by creating models to simulate the desired conditions of movement.

4.5.3. Types

The different kinds of transmissions of the 4-bar linkage type (see Section 4.5.1.) are primarily distinguished by the varying length ratios of their individual members. The length ratios of the individual members must be defined in relation to each other in conformity with the kind of transmission problem in hand.

If the sum of the lengths of the shortest and longest member of a 4-bar linkage is smaller than the sum of the remaining members, then a crank and rocker mechanism (fig. 4/84) is created when the member next to the

shortest one is the fixed member.

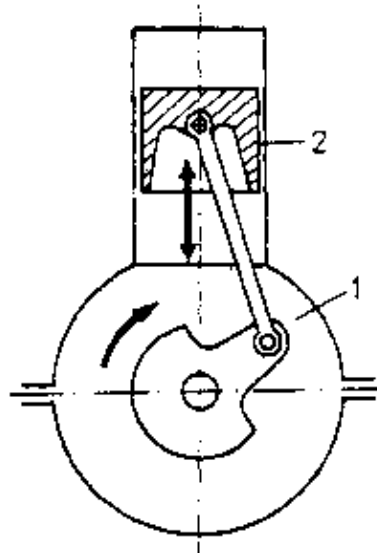


Figure 4/91 Slider joint

1 pivot; 2 slider

When the shortest member becomes the fixed member under the same length conditions, then a drag-link mechanism is created (fig. 4/85). All other length and fixed-member assemblies result in double rocker mechanisms (fig. 4/86).

- Slider crank transmission

In combustion engines the link of the crank shaft with the connecting rod in the swivel joint, and the guide of the piston in the cylinder, form a slider joint (see fig. 4/91).

- Oscillating slider crank mechanism (fig. 4/92).

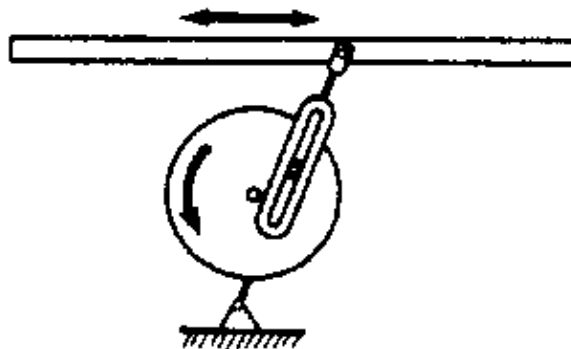


Figure 4/92 Oscillating slider crank mechanism

4.5.4. Mounting Technology

The preconditions for the perfect performance of a transmission mechanism are established already when the individual parts are manufactured. The holes through the rods and the fixed link must be precisely aligned parallel to each other. This is best achieved when all holes are drilled in a single clamping. It is also possible to employ appropriate jigs and fixtures to drill the transmission members.

Reciprocating or oscillating parts of a transmission require guides with very little play because otherwise impermissible jolts and shocks will arise in the dead centres, causing early destruction of the transmission.

It is not always possible to simply push transmission members on undivided cranks or crank shafts. That is why it is necessary to produce split bearings. The bearing shells are usually mounted and held together by anti-fatigue screws. Care must be taken to ensure that the bearing shells are mounted in the proper position in relation to each other.

They should be appropriately marked to exclude confusions. With inclined dividing joints it is necessary to ensure that the inclination of the connecting rod is always facing towards the right side when it is mounted. A certain amount of play will arise in the bearings after prolonged operation due to bearing wear.

This becomes noticeable in the form of stronger jolts and noisy running in the dead centres. In such cases the bearings have to be replaced because they cannot be reset by adjusting keys. The transmission member of simple cranks can often be directly mounted by its hole on the journal and kept in position by washers and nuts or by splints (see table 4/8).

Questions:

1. Why must resonant vibrations be avoided on machines?
2. What kind of maintenance and care jobs are being completed on linkage and crank transmissions in your workshop?

4.6. Cam Mechanisms

Cam mechanisms are in principle 3-bar transmissions consisting of the fixed link 1, the cam bracket 2 and the follower 3 (fig. 4/92). Similar to the crank mechanisms, they are used to convert a usually uniform driving motion into a desired driven working motion. The cam mechanism describes complicated, periodically recurring motions, often interrupted by prolonged pauses. This is achieved by giving the cam the corresponding shape. The cam mechanism shown in figure 4/93 has the disadvantage that the follower is constantly sliding on the cam, thus causing considerable wear. This shortcoming is overcome by mounting a roll on the tip of the follower. For this purpose the radius of the cam is diminished at all points by the radius of the roll.

A comparison with the crank mechanism reveals considerable disadvantages for the cam mechanism. The latter has a joint between cam bracket and follower (or roll) which only maintains linear contact. Consequently, this cam joint is subject to much higher stresses and wear than a pivot or slider joint. The shape of the cam curve, and hence also its path of curvature and motion, are continuously changed due to wear. The manufacturing expenses for cams, slider members and cylinders, are also much higher than for crank mechanisms.

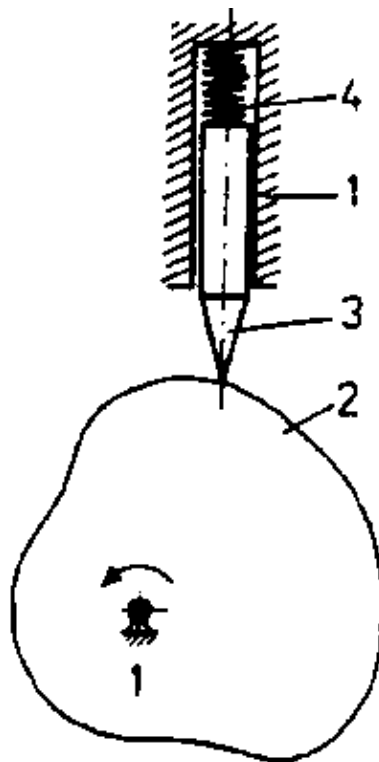
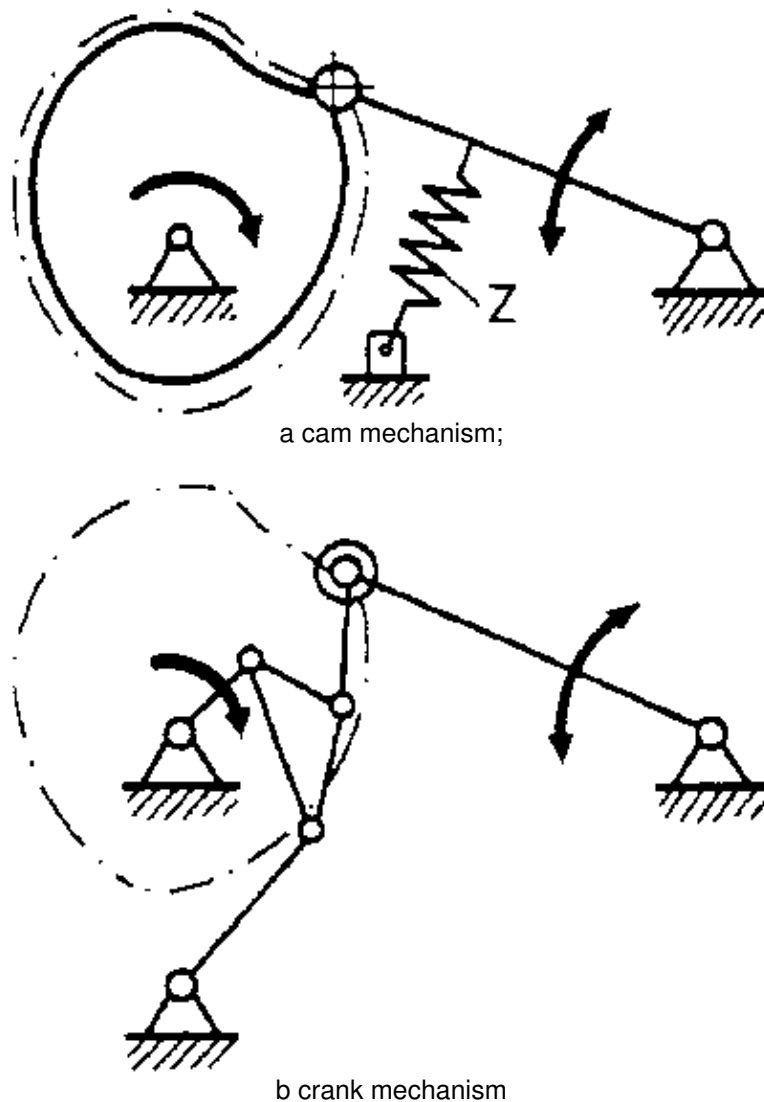


Figure 4/93 Cam mechanism (basic form)

1 fixed link; 2 cam bracket; 3 follower; 4 spring

Cam mechanisms can be replaced by crank mechanisms, but this calls for much higher constructional expenditures (fig. 4/94). In spite of all these disadvantages, cam mechanisms are nonetheless extensively employed because they can resolve complicated motion problems. The principal differences between crank and cam mechanisms are shown in table 4/9.

Figure 4/94 Comparison of cam and crank mechanisms



4.6.1. Design

As already mentioned, the basic form of the cam mechanism has three members. The uniform driving motion of the cam is transformed into a reciprocating or oscillating motion of the driven member. To ensure that the driven member executes the prescribed course of movement, it must be in constant contact with the cam. The frictional link required for this purpose can be created by tension or compression springs (fig. 4/95). A positive link is produced by using grooved cams or a bent lever in conjunction with two cams (fig. 4/96). Both solutions constrain motion by frictional or positive action.

Table 4/9: Comparison of Coupling and Cam Mechanisms

	Coupling transmissions	Cam mechanisms
Implementing specific complicated motions	Difficult to design; transmissions must consist of six or more members; the path of transmission is only approximately achieved.	Simple to design; the desired motion path is accurately achieved and depends solely on the manufacturing accuracy of the cam.
Space requirements		Little

	Usually considerable because the transmission members are long and are not arranged in a single plane so that they cannot obstruct each other.	
Connection of the transmission members	Pivot and slider joints have surface contact; hence little contact pressure and low wear.	Point or linear contact at pins or rolls; hence considerable material stress which causes high wear.
Course of movement	Wear has little influence on the desired path of movement.	Wear changes the path of movement.
Manufacturing accuracy and costs	Relatively low; involve only simple rods with holes.	Expensive; cams require highest standards of manufacturing accuracy.
Adjustability	Simple to accomplish by shifting individual members.	Cam bracket adjustability is difficult to achieve.
Running smoothness	Uniform and smooth running, also at higher speeds; little running noise.	Higher speeds are not possible; louder running noise.
Adjustment	Secured by simple installation	Necessary after installation

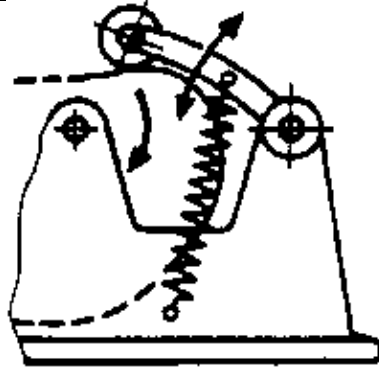
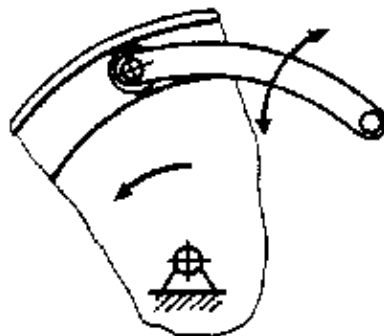
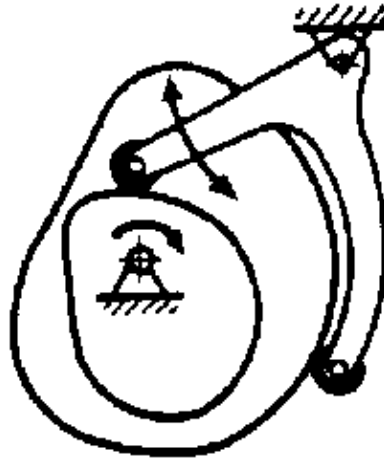


Figure 4/95 Constrained motion by frictional link

Figure 4/96 Constrained motion by positive link



a roll in groove



b double cam and double lever

An extra torque has to be applied to the cam when the constrained motion of the cam mechanism is achieved by frictional action. The periodic change of the spring tension will vary this extra torque, resulting in vibrations that will have an adverse effect on the smooth running of the mechanism. This additional load for friction action raises the pressure contact between cam and follower so that wear is intensified.

4.6.2. Operating characteristics

The periodic motions of cam mechanisms are generated by the cam. This produces a cam and follower (or driven member) mechanism that describes motion cycles in conformity with the required operating conditions. The course of motions of a cycle are plotted on a motion graph (fig. 4/97). The stroke is plotted in relation to the position of the curve in degrees.

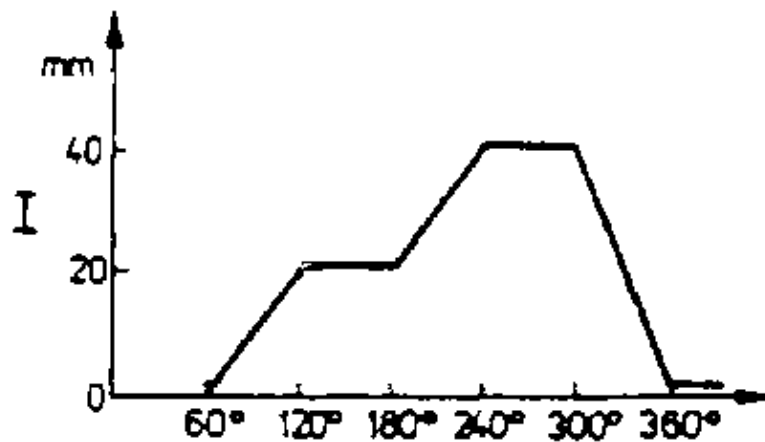


Figure 4/97 Motion graph

I hub

4.6.3. Types

Cam mechanisms can be distinguished by the arrangement of the cams on the bracket, the arrangement of the driving and driven members, and by the kind of driving and driven motion. A special type of cam is used to control the valves of combustion engines (fig. 4/98). Table 4/10 gives a survey of the different types of cam mechanisms.

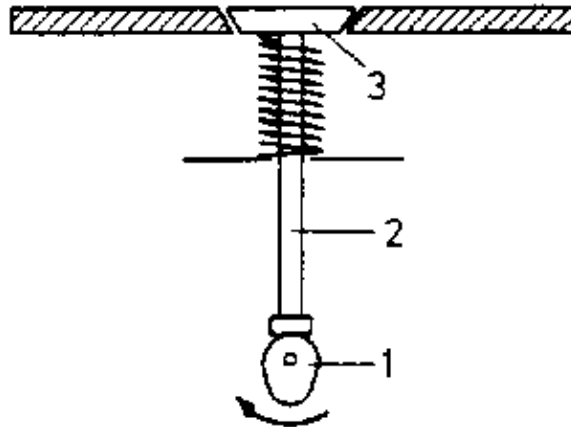


Figure 4/98 Crank drive with cams

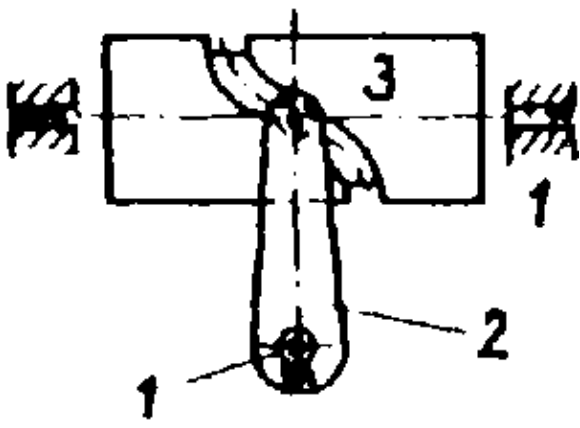
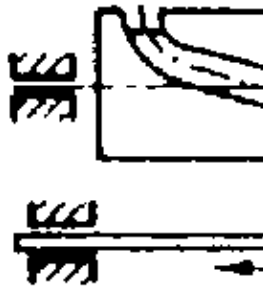
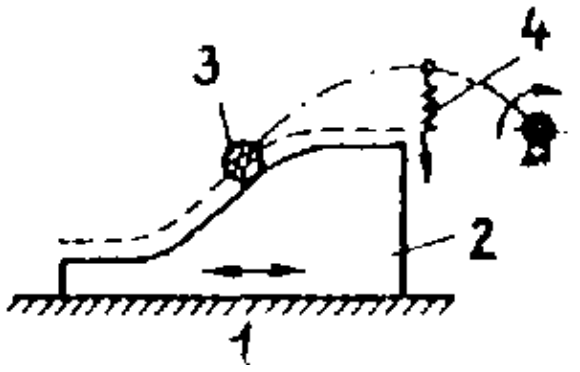

1 cams; 2 tappet; 3 valve head

4.6.4. Mounting Technology

The rules for mounting shafts, axles, etc., also apply to cam mechanisms. The driving and driven members must be precisely aligned. The follower must always be in contact with the cam in all positions. Shock loads will damage the mechanism if this is not assured.

Table 4/10: Cam Mechanisms

Arrangement of the transmission members	Driving motion	Driven motion	
		oscillating	thrust
	Rotary movement Rotary movement Thrust		
Spatial			

			
Planar			

The adjustment of the zero point is a special problem peculiar to cam mechanisms. When the cam is in its start position all the other members will take on a certain relative position. The zero position is usually marked on the cam. All other members of the cam mechanism must be brought into their corresponding positions relative to the zero position of the cam. The cam is then adjusted according to its zero mark. The cam is connected with the shaft (dowelled, screwed or keyed) for final mounting.

4.7. Hydraulic Transmissions

4.7.1. Design

Hydraulic transmissions transmit power by an operating fluid. The fluid power, generated by a pump, is transmitted to the driven member where it is transformed into mechanical energy. A special container for the operating fluid is required to obtain the closed circuit. The vessel collects the operating fluid flowing back from the driven member and from the controlling devices, and feeds the operating fluid back into the circuit (fig. 4/99). Special valves are often required to control the pressure.

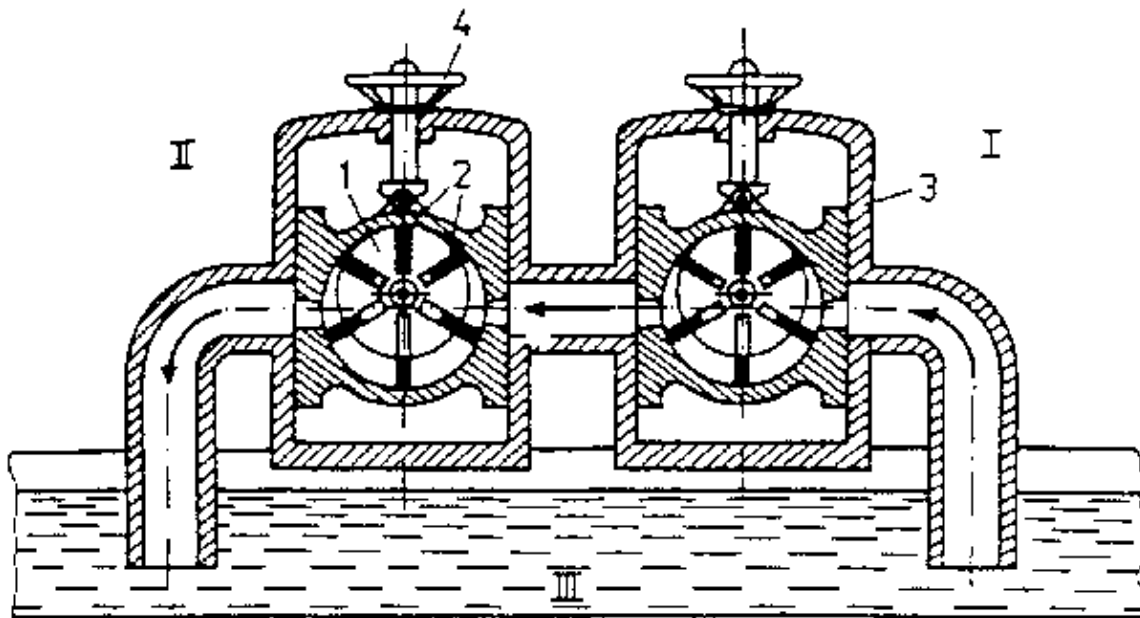


Figure 4/99 Hydraulic transmission with vane cells


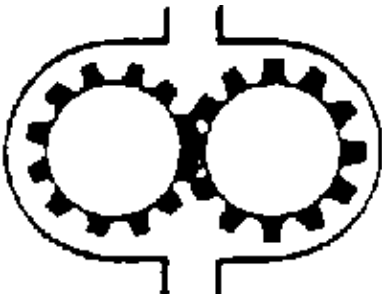


I pump; II fluid power motor; III oil tank 1 cylinder; 2 vanes; 3 casing; 4 handwheel

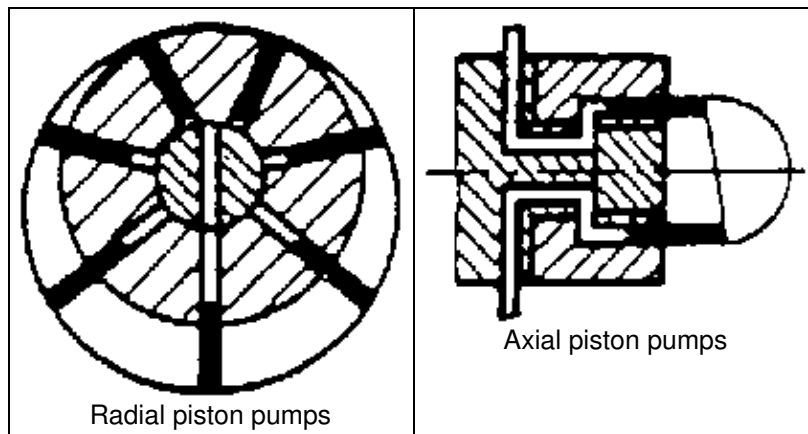
The following basic elements are required to produce a hydraulic transmission:

- Pumps
- Fluid power motors
- Controlling devices
- Ancillaries

Pumps

Table 4/11: Types of Displacement Pumps

Displacement pumps	
 <p>Piston pumps</p>	 <p>Gear pumps</p>
 <p>Screw pumps</p>	 <p>Vane pumps</p>



Hydraulic transmissions require pumps to convey and circulate the operating fluid. These pumps are driven at unvarying speed by electric motors or combustion engines. The pumps suck in the operating fluid (oil) from the tank and press it back into the circuit. Consequently, the pumping action breaks down into a suction phase and a pressure phase. The pumps operate according to the following principle:

A space within a closed casing is alternately enlarged and diminished by pistons, vanes, gears, **screws** or membranes, depending upon the type of pump. This produces a pressure difference in this space so that the oil is forced into this space by atmospheric pressure. From these brief explanations it becomes obvious that every pump has to generate a vacuum. Table 4/11 shows the different types of displacement pumps.

The sucking action of the pump is the result of equalisation between atmospheric pressure and the vacuum generated by the pump.

At a constant speed of the driving unit a difference is made between two groups of pumps:

- Constant displacement pumps (gear and screw pumps).
- Variable displacement pumps (vane and piston pumps).

Gear pumps: These will generate high pressures at a low cost. They generate high constant flow rates at pressures of up to 160 kp. cm⁻² (160 bar).

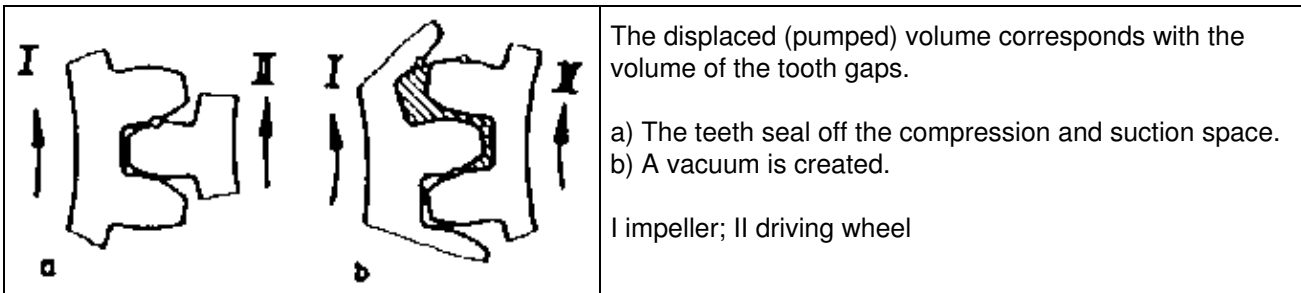
Advantages

Gear pumps take up little space and they are of simple design. They are cheap and dependable. Self-lubrication gives them a long service life.

Table 4/12 shows the action of gear pumps.

Table 4/12: Manner of Operation of Gear Pumps

Manner of operation	Procedure
	<p>The pumping action is the result of displacement. The gear wheels displace the fluid as a result of the meshing action of the teeth. Rotation produces gaps between the teeth which suck in the fluid and transport it from the suction side to the pressure side from whence it is pressed into the pressure line by tooth engagement. I suction; II pressing; 1 casing; 2, 3 pairs of gear wheels; 4 tooth gap</p>



Piston pumps: These are usually installed in presses where they function as pressure pumps. They achieve capacities in the order of 1100 kW. They are primarily of the horizontal type (fig. 4/100). The return stroke of the piston (suction stroke) produces a vacuum in the cylinder. The operating fluid is drawn into the cylinder when the suction valve is opened. The piston moves up into the cylinder during the compression stroke. The suction valve is closed and the pressure valve is opened. The operating fluid is forced out of the cylinder and into the pressure line.

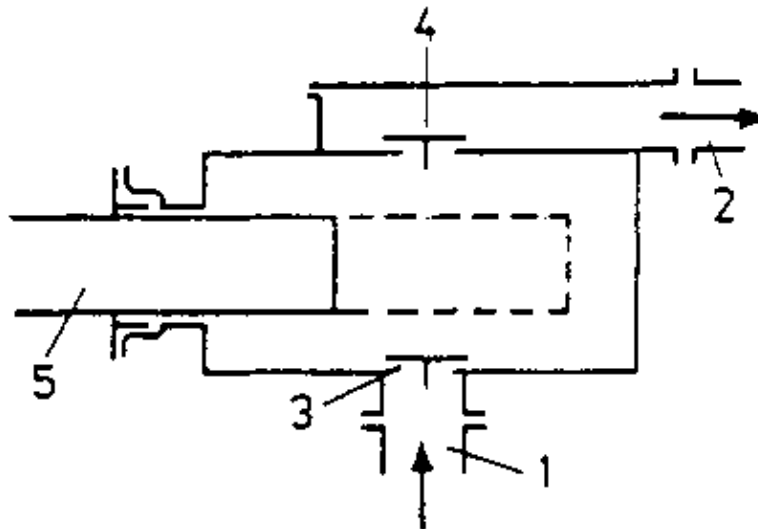


Figure 4/100 Principle of the piston pump

1 suction line; 2 pressure line; 3 suction valve; 4 pressure valve; 5 piston

Fluid Power Motors

Fluid power motors use the fluid power generated by the pump and convert it into mechanical power (e.g. to drive a machine tool).

Fluid power motors for rotary motions: The operating fluid is fed to the fluid power motor where it acts upon the pistons. The direction of rotation can be changed by reversing the direction of flow.

Fluid power motor and pump are interconnected by pipe lines. Pump and motor can be housed in a common enclosure (fig. 4/99) or set up separately. The driving energy can be generated by electric motors or combustion engines. The speed of the fluid power motor on the driven side (output) can be varied by changing the rate of displacement of the pump. The torque of the output will remain constant. This, however, presupposes a constant fluid pressure.

Fluid power motors for straight-line motions: Cylinders with pistons are required to produce this straight-line reciprocating motion. Thus, the assembly consists of the cylinder with piston and it is generally referred to as the working cylinder.

Working cylinders are of simple design and dependable. They transform the rotary motion of the pump into a straight-line movement. They generate high forces and permit continuous speed variation. Working cylinders allow direct application of force, thus making them very efficient.

Controlling Devices

All hydraulic transmissions require devices to control the fluid power. These controls change the volume of

flowing oil, its pressure or the direction of flow.

Most of the controlling devices used for this purpose are valves. Next to the afore-listed operations, these devices open or close pipes for the flow of oil. Valves can be of very complicated design so that the following explanations are limited to a few types which are described in simple terms in the interest of lucid presentation.

Overpressure valves: They have the purpose of limiting the pressure in a defined space. The valve opens as soon as the pressure prevailing in this space exceeds a certain limit, thus allowing excessive oil to flow out through a pipe. Figure 4/101 shows a ball valve.

Overpressure valves are extensively used as safety devices to protect equipment against damage and destruction by excessive pressure.

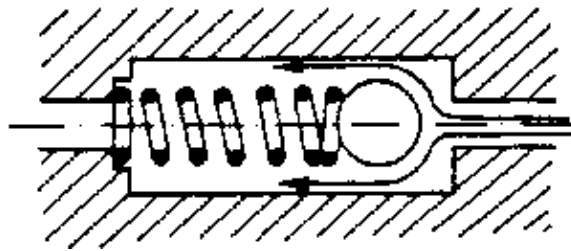


Figure 4/101 Ball valve

Pressure-reducing valve: These are employed when oil of a higher pressure in a space has to be distributed to one or more lines at a lower pressure. Such a valve is shown in figure 4/102. The piston of the valve remains closed as long as no oil flows out of the exit of the closed space, i.e. the pressure remains constant. A drop in pressure, however, releases the counter-force exerted by a spring so that the piston is opened.

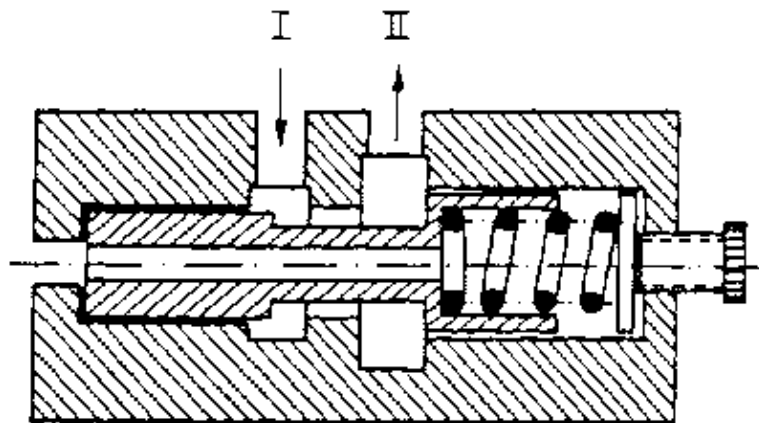


Figure 4/102 Pressure-reducing valve

I inlet; II outlet

Non-return valve: As its name implies, this type of valve only allows the fluid to flow in one direction (fig. 4/103).

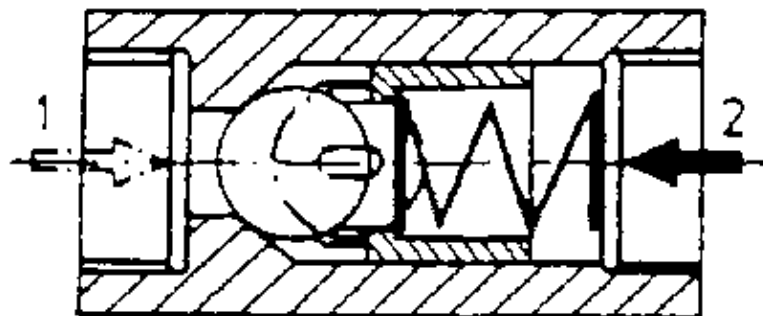


Figure 4/103 Non-return valve

1 free passage; 2 blocked passage

Directional control valve: This valve controls the entire operating procedure of a hydraulically actuated machine. The valve directs the fluid to the point where it is to be used as power. All controlling operations, also flow reversal, must be completed softly without any shocks. Sliding spool valves are the commonest type used for this purpose. Next to their actual task of directing the flow of oil, they can also be used for limit switching and to govern reciprocating movements.

Direction-control valves are classified by the number of directions in which they can direct the flow of oil. The device shown in figure 4/104 is a 2-way valve and is used to open or close a line.

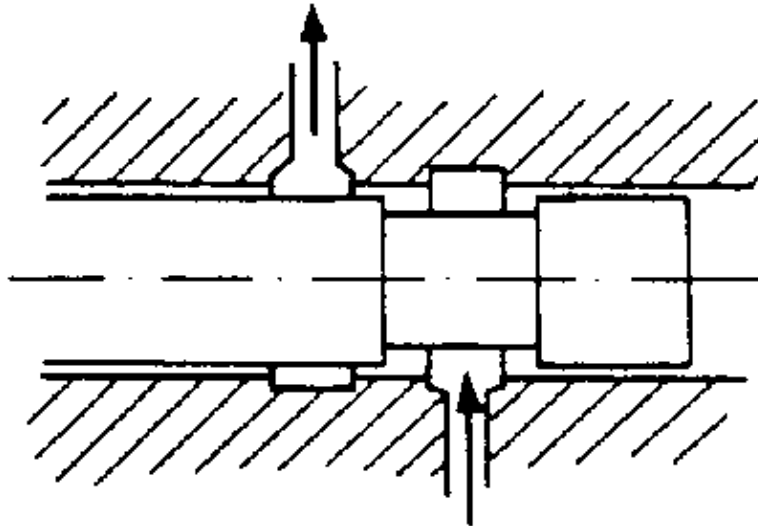


Figure 4/104 2-way valve

Ancillaries

Ancillaries are all those parts that are required for the correct operation of a hydraulic transmission system (apart from pumps, fluid power motors, working cylinders and valves).

Operating fluid tank: The tank holds the amount of operating fluid (oil) that is required to operate the machine concerned. The capacity of the oil tank must be sufficient to hold the same volume of operating fluid that can be displaced by a pump in one or two minutes.

Pipes and coupling facilities: The individual assemblies of a hydraulic transmission are interconnected by hoses or pipes. Hoses are unsuitable as connections when accurate controlling functions are involved. Hoses are primarily employed on farm machinery and motor vehicles. Pipes made of steel, copper or light metal are employed for low pressures. The pipes are linked to the assemblies and with each other by pipe couplings. These must fulfil the following demands:

- It must be possible to link and disconnect the couplings several times.
- They must be absolutely tight under all operating conditions. This precondition is essential for the proper operation of the machine.
- The strength of the coupling must at least equal that of the pipes to withstand pressure surges and vibrations.

Screw joints (fig. 4/105) and socket welded fittings (fig. 4/106) are the most important types of couplings. It is advantageous if the screw joint is replaced by a socket welded fitting, provided that all nipple dimensions are retained.

Washers made of rubber, light metal, steel or copper with asbestos packing are used as seals.

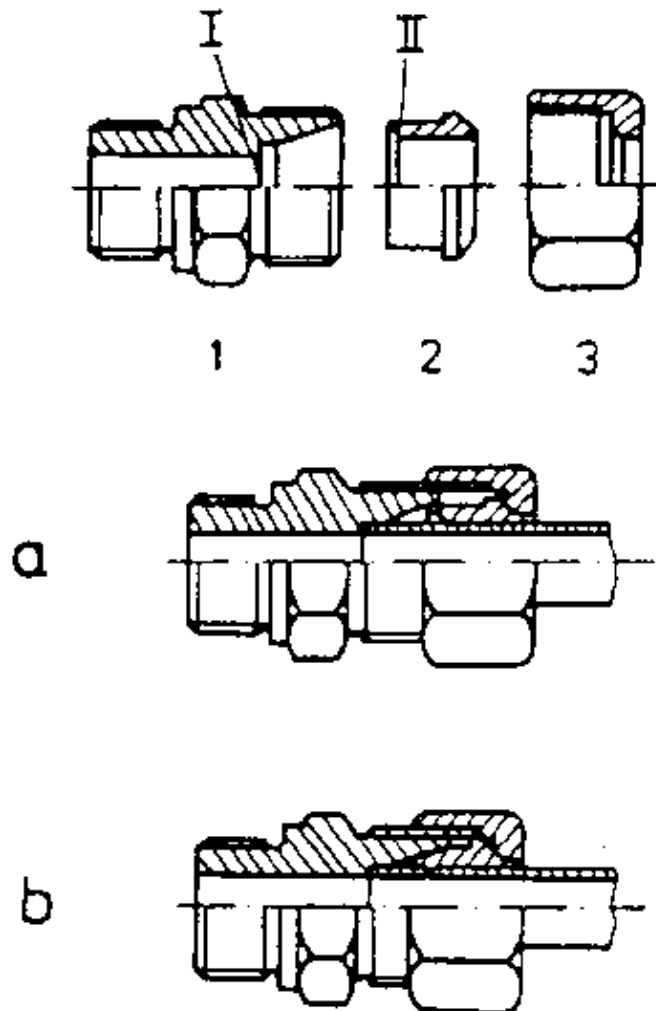


Figure 4/105 Screw joint with cutting ring: a prior to tightening; b after tightening

1 screw connection pieces; 2 cutting ring; 3 cap nut; I stop; II cutting edge

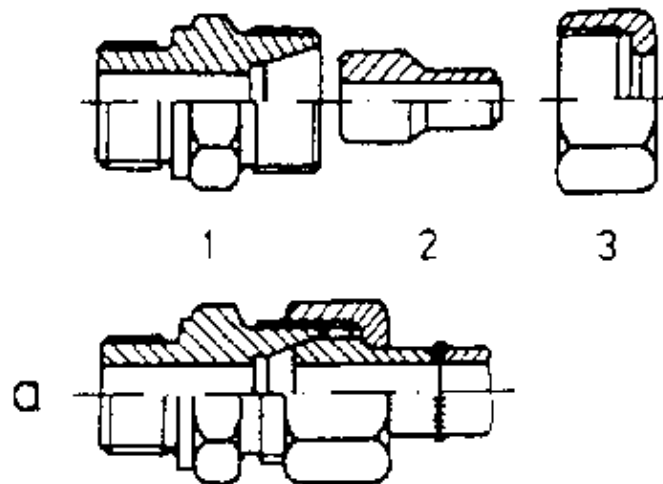


Figure 4/106 Welding socket fitting

1 screw connection pieces; 2 welding socket fitting; 3 cap nut; a after tightening

Filters: These have the purpose of cleaning the operating fluid (oil). Magnetic filters are mainly employed. They are provided with extra sieves to hold back non-magnetic particles. These filters retain metallic abrasion particles.

Transmissions: Hydraulic transmissions are subdivided into static transmissions and dynamic transmissions. Both of them are used to transmit fluid energy. Static transmissions exploit only the pressure of the operating fluid to transmit energy and velocity (e.g. piston pump). Dynamic transmissions utilize the kinetic energy of the

operating fluid, e.g. centrifugal pumps. Static transmissions can be distinguished by their transmitting function and by their manner of displacement:

- Conversion of a rotary movement into another rotary movement by transmissions involving:
 - Vane displacement
 - Gear displacement
 - Piston displacement
- Conversion of a rotary movement into a reciprocating thrust movement by controlling the fluid volume through:
 - Throttling
 - Pump adjustment

The first group is mainly employed for continuous speed variation, while the second is used for the advancing motions of the tool slides and presses, and for controlling and clamping operations.

Two types of hydraulic transmissions shall be explained here for a better understanding of the subject matter.

Hydraulic Transmissions with Rotary Movement on the Driving and Driven Sides

(see schematic representation, fig. 4/99)

The transmission consists of two closed parts (encapsulated). The primary part is formed by the pump, the secondary by the fluid power motor which passes on the motion transmitted to it. The pump is driven at constant speed. Speed variation between the driving and driven sides is completed by the following methods:

- By continuous variation of the volume of oil displaced per second by the pump (control with constant torque).
- By changing the volume of oil consumed by the fluid power motor per revolution (control with constant output).
- By a combination of 1. and 2.

The vane pump shown in figure 4/99 could also be a geared pump or a piston pump. It draws oil in from the tank. This oil is pressed into a fluid power motor which is of identical design as the pump. The rotating speed of the motor depends upon the volume of oil supplied to it and upon the adjusted motor displacement. The oil is continuously circulating. The oil implements the work in the fluid power motor and then flows back into the oil tank.

The pump and the motor of the depicted vane-type transmission consists of a shaft linked to a cylinder (1) which incorporates radially mounted vanes. The eccentric mount of the cylinder produces the stroking action of the vanes resulting from the centrifugal force acting upon the vanes. The vanes slide in their guides and press against the interior walls of the casing. This produces a series of small cells or pockets which expand to maximum value (suction phase) as the cylinder rotates, and then back to minimum value (compression phase). Adjustment of the eccentricity affords continuous variation of the volume of oil displaced per revolution. When eccentricity equals nought, then the amount of sucked-in oil will also equal nought, i.e. the fluid power motor is motionless.

Hydraulic transmissions are systems in which the operating fluid, usually oil, is given power by a pump as it flows in a closed circuit. Utilization of the pressure of this fluid produces a static hydraulic transmission. The exploitation of its pressure energy or velocity energy produces a dynamic hydraulic transmission.

4.7.2. Operating Characteristics

The most important characteristics of a hydraulic transmission are pressure, volume, power and torque. The output generated by a pump is expressed by flow with pressure. This flowing action results in power acting upon a part moving in a straight line or which rotates (piston, shaft).

The degree of efficiency is another vital characteristic. The mechanical efficiency of pumps and fluid power motors of a hydraulic transmission ranges between 0.7 and 0.85. The hydraulic efficiency is 0.9, and can be in the order of 1 with near perfect seal of all parts.

4.7.3. Types of Hydraulic Systems

Hydraulic systems are readily adaptable to widely differing operating conditions. Such systems can be mechanically, hydraulically or electro-hydraulically controlled, and appropriate combinations between the three are likewise possible. The important points, are that the volume, pressure and direction of flow within the hydraulic circuit can be precisely controlled.

Hydraulic systems are classified by:

- Their manner of control
- Their manner of operation
- Their manner of drive

Manner of Control

When proceeding from the manner of control, a difference is made between throttle-control and variable-displacement pumping. The throttle system involves the use of throttle valves (fig. 4/107) to control the flow rate generated by constant-displacement pumps (gear or screw pumps).

The variable-displacement pumping system harnesses the entire volume displaced by adjustable pumps to mechanical work (fig. 4/108). Throttle-control and variable-displacement pumping systems can be controlled manually, mechanically, hydraulically or electrically.

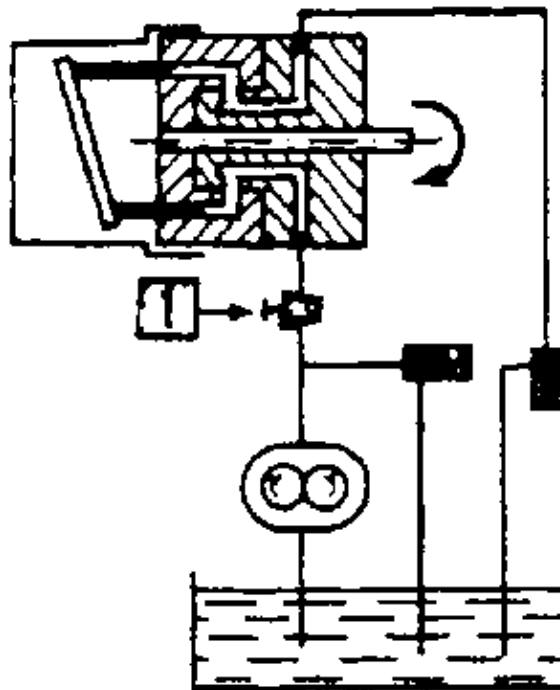


Figure 4/107 Throttle control

1 throttle valve

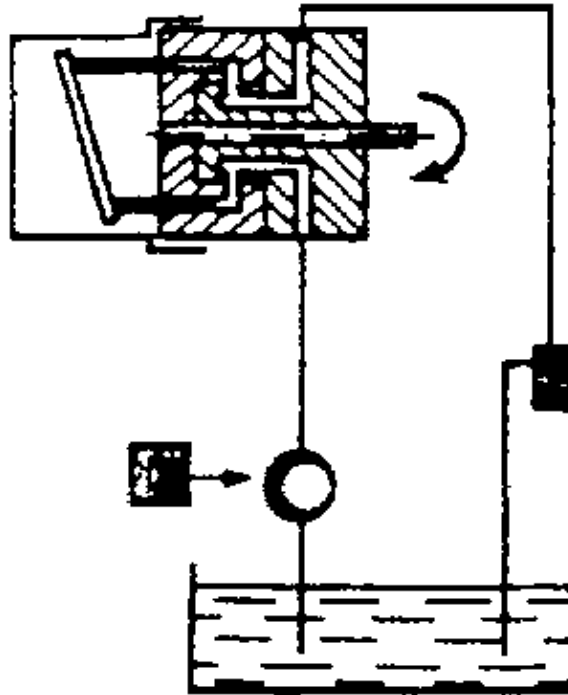


Figure 4/108 Pumped control

1 control pump

Manner of Operation

A distinction is made between the following systems:

- Direct manual control
- Remote electrical control

Direct manual control: The hydraulic section is directly actuated by a hand lever (fig. 4/109).

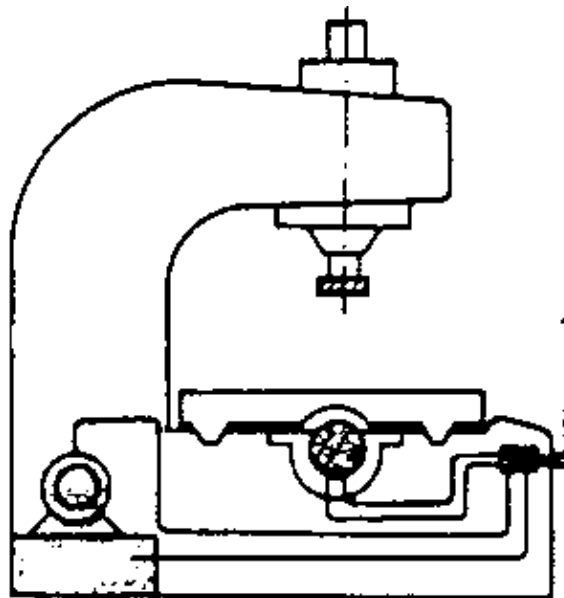


Figure 4/109 Direct manual operation

1 hand lever

Remote electrical control: The hydraulic section is remotely actuated by push-button control with the help of electro-magnets (fig. 4/110).

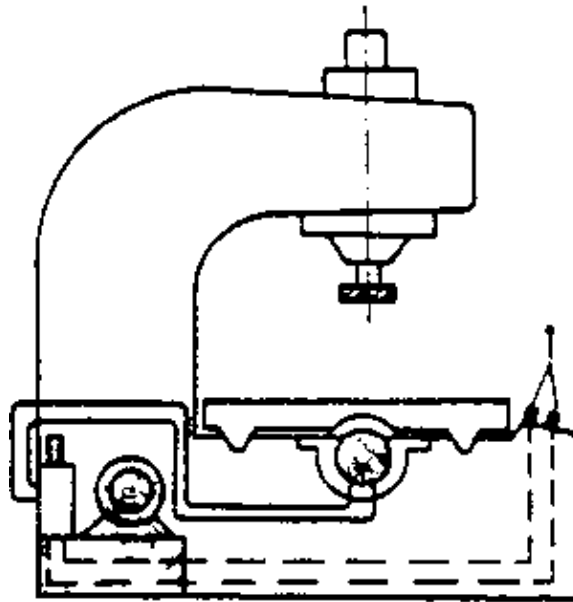


Figure 4/110 Remote electrical control

1 push buttons

Manner of Drive

The hydraulic power is generated either directly by pump drive or by accumulator operation.

Direct pump drive: Direct pump drive (the pump is directly driven by an electric motor) is adopted to power the hydraulic systems of lifting equipment, machine tools, farm machinery, building machines, textile machines, etc. With this kind of drive the output of the pump must always match the maximum power requirements of all connected fluid power motors.

Accumulator operation: With this kind of operation the power of the fluid is stored in pressure cylinders known as accumulators. Constant-displacement pumps press the operating fluid in pressure cylinders, together with compressed air generated by multi-stage compressors. The two are stored in the accumulators.

This type of driving system is ideally suited for power hydraulic systems that require high loads for short periods. This means that the pumps can be relatively small. The accumulators are charged during longer idling periods. When the maximum pressure is reached in the accumulators the pumps are automatically switched off, and a pressure drop in the accumulators causes automatic return of the pumping action. Accumulator operation is adopted for presses, and to open and close valves, sluices, vanes, etc.

4.7.4. Mounting Technology

The course of work to mount hydraulic systems depends upon the design of the transmission. This applies to the entire system as well as to the individual units and assemblies of hydraulic transmissions. The following fundamental points have to be observed:

All internal parts of hydraulic transmissions must be free of all traces of rust and dirt. The smallest contaminations can cause serious damage in view of the tight fits of the pumps, fluid power motors, controls and valves. Only non-fraying cloths should be used for cleaning. The workshop in which the mounting job is completed must be free of dust.

All sliding and guiding surfaces must be oiled before they are assembled.

The following mounting jobs usually have to be completed:

- Assembly and installation of the pumps and fluid power motors.
- Assembly and installation of the controlling devices.
- Connection of the pipe lines.
- Testing the entire system.

Whoever is working on hydraulic transmissions must be familiar with the operating instructions. He must have studied all the details and have had special points explained to him. This is essential because each hydraulic transmission has its own peculiarities.

Pumps and fluid power motors should only be assembled and repaired by especially trained personnel authorized to do such jobs. The same applies to the care and installation of the controlling devices. In many cases the controls are provided with a lead seal to prevent tampering. Useless parts are exchanged and regenerated in special workshops.

The individual parts of a hydraulic transmission are inter-connected by pipes. The overall performance of the system depends to a major extent also on the design of the pipe lines. The following points must be observed when installing pipes:

- The pipes must be installed with the fewest possible bends.
- A wide bending radius must be selected. The radius of the bend must be at least twice the pipe diameter. Special patterns made of wood or bending fixtures should be used for pipe bending.
- The cross-section of the pipe must not be changed as a result of bending. Pipes with buckled points are useless.
- Rigid holding brackets must secure the pipes against vibrations. Vibrating pipe lines can cause the valves to vibrate and lead to pipe failures.
- The length of hydraulic hoses must be selected in such a manner that they sag in free suspension (fig. 4/111). Replacement hoses must be constantly stocked because of the limited service life of hydraulic hoses.
- Clogged pipes and hoses must be blown out with compressed air.

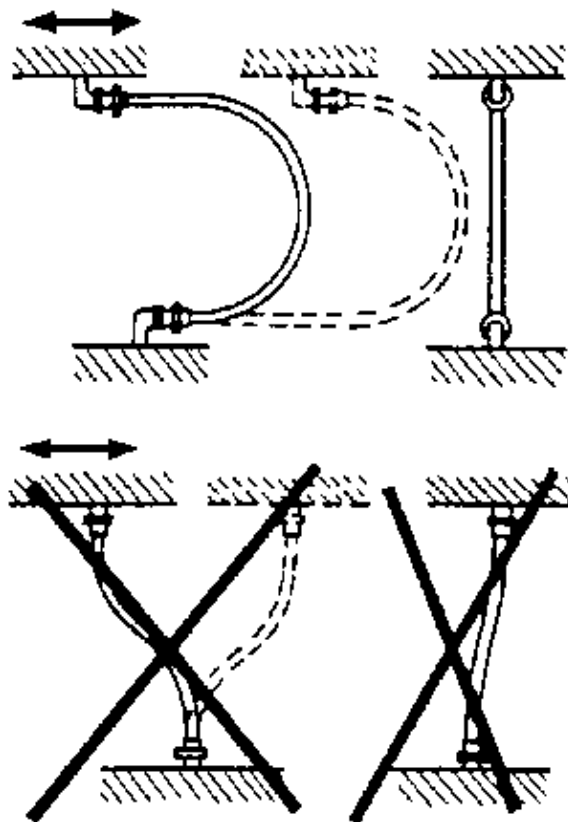


Figure 4/111 Arrangement of the hydraulic hoses

The following points must be observed when installing pipes:

- The lower edge of the suction and return lines must be located at a height over the bottom of the tank that is double the diameter of the pipe.

- The pipes must be tightly connected. Cutting rings are particularly suited for this type of connection.

The installation of pipe connections requires the following jobs:

- The pipe must be cut off at a perfect right angle and the cut surfaces must be deburred.
- All parts must be greased.
- The sleeve nut and gasket are pushed over the pipe. The conical side of the gasket must be facing the nut.
- Press the pipe firmly against the stop in the screw connection. The sleeve nut is then very firmly tightened for the first time. This applies particularly to steel pipes of more than 15 mm external diameter. The gasket can thus penetrate deep into the pipe.
- After the connection has been firmly tightened for the first time, the sleeve nut is lightly loosened again and then normally tightened.
- Check the seat of the gasket. Repeated loosening of the screwed connection does not diminish its quality. Screwed connections that are subject to considerable heat must be tightened again after they have been heated for the first time.

Oil filling: The operating safety and perfect performance of all hydraulic elements depend to a major extent on the quality of the oil used as operating fluid. Improper oil filling is often the cause of disruptions. The oil filling must be checked from time to time.

The following rules should be observed:

- The oil lever in the tank must coincide with the level mark.
- There should be no air in the oil circuit.
- Packings must be retightened, or new seals should be installed, if leakage losses are detected.
- Only the kind of oil prescribed by the operating instructions should be used for filling. The oil must be transported in closed cans.

Deaeration: It is important to ensure that all air is removed out of the oil circuit. The mineral oil employed for hydraulic transmission has the ability to dissolve gases. This solubility increases with growing pressure, and declines with diminishing pressure. This means that gas becomes separated when the pressure is reduced, forming bubbles in the circuit. Such bubbles will impair the performance of the hydraulic system.

The presence of air in the oil circuit can be recognized by the following phenomena:

- There is foam on the top of the oil in the tank and in the sight glass, and the oil has a light yellow colour.
- A loud sucking noise can be heard during operation.
- The fluid power motor moves jerkily and controlling operations are executed with a time lag.

Measures to remove air from the circuit:

- Prior to commissioning the system for service, the fluid power motor must be run up to the maximum permissible speed in both directions. The oil flows through the system at a high velocity, taking any bubbles along through the return line.
- The deaeration hose must be connected (fig. 4/112) where venting taps or sockets are available. The end of the hose is inserted in a vessel filled with oil. Oil is pumped through the line when the pump is switched on. This flowing oil will press out the air in the circuit. This can

be seen from the rising bubbles. The process is continued until no more bubbles rise, i.e. deaeration has been completed. The venting tap or socket is closed.

- Air is released more easily if the oil has become heated due to operation. The venting taps should be opened once a day after a brief operating period.

- Venting taps and sockets must be vented in the same sequence as they are arranged in the direction of oil flow from pump to fluid power motor.

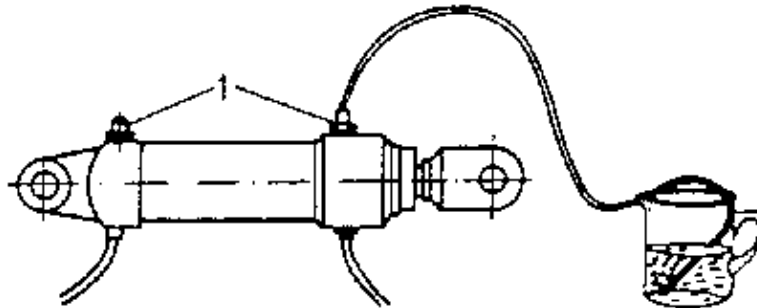


Figure 4/112 Deaerating a pipe

1 deaeration sockets

Oil testing: The oil must be inspected from time to time to see whether it has become contaminated by dirt and water. Such a check is performed by allowing a drop of the oil from the circuit to drip on a sheet of blotting paper. The oil is still good if it forms a uniform yellow spot on the blotting paper. It is useless if the centre of the spot is darker than the surrounding area. This is a sure indication of the presence of dirt particles in the oil so that oil changing is necessary.

Oil changing: Spent oil should be drained out while it is still warm from operation because it will run out entirely in this state. The entire circuit is then rinsed with fresh oil. This oil, in turn, is then blown out. The required quantity of new oil is then poured in through a sieve.

Oil changing must be completed in good time because otherwise the oil will resinify and silt-up, thereby impairing the performance of the system. This will cause expenses for dismantling and cleaning the system.

Trouble-shooting: Faults must be systematically located on the basis of the circuit diagram of the system. Wherever electrical components are present one should check all screwed and soldered connections to make sure that there are no loose connections, i.e. that dependable voltage transmission prevails.

Hydraulic lines incorporate pressure gauges that give visual readings of the pressure prevailing at the most important points of the system. Table 4/13 gives a guide to possible faults and their causes. Only a few of many causes of a fault can be listed. A fault should be located by a process of systematic isolation.

Table 4/13: Faults in Hydraulic Systems and their Elimination

Cause	Faults	Hydraulic motor is not working	Hydraulic motor works jerkily	Hydraulic motor works too slowly	Hydraulic motor controls out of time	Difficult pump starting	Pump produces loud noises	Pump does not convey enough oil	Incorrect control sequence	No pressure gauge reading
		1	2	3	4	5	6	7	8	9
Insufficient oil filling		X	X							
Oil of excessive viscosity				X						
			X		X		X		X	

Air in the circuit										
Leaking compensation line			X	X	X					
Leaking pressure line					X					
Insufficient pressure							X			
Line is clogged		X	X			X	X			
Leaking packing					X			X		
Leaking piston		X						X		
Piston has come off the rod		X								
Piston resinified and jams						X				
Valve piston jams					X					
Leaking control piston										
Valve spring fatigue					X				X	
Broken valve spring										
Leaking valve piston										
Valve guide knocked out					X					
Valve lags		X		X						
Voltage too low					X				X	
Defective pump						X				
Cam out of adjustment									X	
Defective switchgear									X	
Defective electric lines						X				
Piston or bore not cylindrical										

Questions:

1. What can be the cause of jerky operation of the fluid power motor, and how is the fault remedied?
2. The pressure gauge does not indicate any pressure when the pressure is tested. What could be the causes?
3. The piston of a controlling device in a hydraulic system does not operate. How is the fault remedied?
4. What should be checked if the control of a hydraulic system does not operate consistently?
5. How should oil be properly changed?