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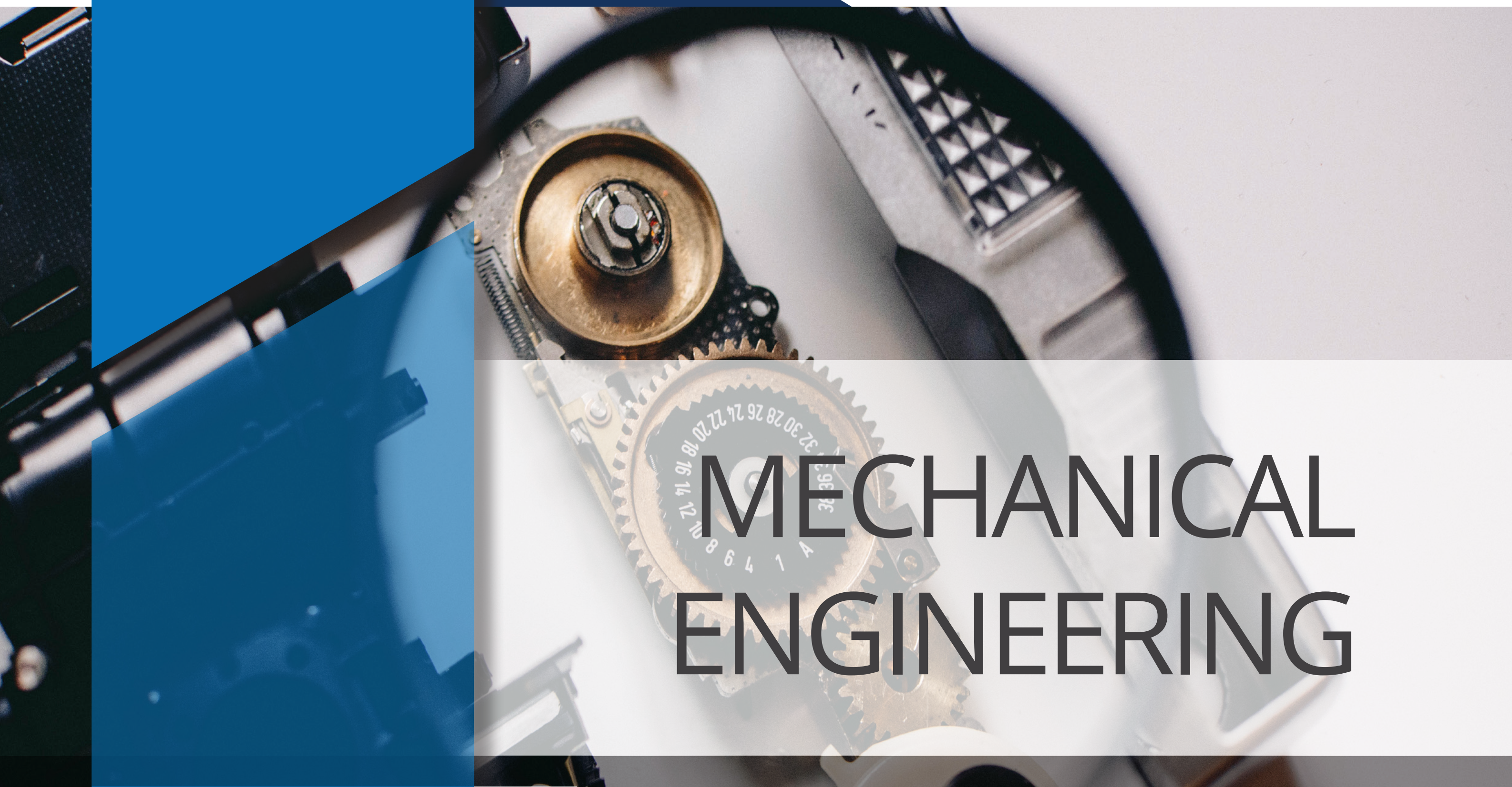


MECHANICAL ENGINEERING

Machine elements and mechanics

UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

VŠTE

EUROPEAN UNION

CONTENTS

1. INTRODUCTION TO JOINTS IN MECHANICAL ENGINEERING

1.1. Joints

Joints – machine parts (components), whose main function is to "**join**" (HW) the components of a technical product (TS) in **combination** with other function related to "**momentum**":

- **"not allow reciprocal movement",** if the original parts could not be designed from one piece due to manufacturability, interchangeability, adjustability, transportability, reparability, disposability, etc.

- **"allow reciprocal movement",** if the parts to be connected need to change their mutual position in order to ensure their function

Note:

However, if the function „to allow reciprocal movement" is a priority, these joints are considered independent classes of machine parts in the CR, and in Czech language, they are referred to according to the movement allowed (unlike in English and German):

- sliding movement: line
- for rotating movement: fit

In the following chapters, „joints" will thus refer to only „common joints" where the priority is the function „to allow connection" and function „to allow movement" will be required partly or not at all:

- **rigid joints (not movable in operation)** (i.e. function „not allow reciprocal movement")
- **movable joints** (i.e. function „to allow partial reciprocal movement")

Note:

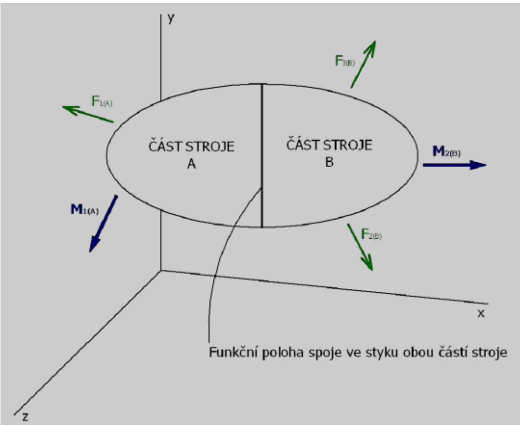
- The usual breakdown of „rigid joints" into „**detachable**" and „**attachable"** is not considered, since it is not a functional property or characteristics. This property (e.g. for assembly in production, and for dismantling & assembling in distribution, installation, maintenance, repairs and dismantling during disposal, etc.) is logically considered one of significant properties of (solid state) joints. The classification was thus simplified without neglecting this property.

- Note: in terms of machine parts, “**rigid joints”** refer to joints that (in operation) do not allow reciprocal movement of the parts or TS components being coupled or joined together

- For simplified illustration and designation of force loads applied **uniformly over the entire circumference** (e.g. clamp, friction surface, thread, etc.), the relevant variables are marked with i**ndex „o“ written to the left of the relevant force mark**, etc. (e.g Figure A 1.4-2)

1.2. External load of joint

It is calculated (after calculating external equilibrium TS!) as resulting effects of forces and moments acting on a part of TS on a side of a contact area of the joint in question (i.e. analogy as internal equilibrium corresponding to „section“). Usually, the side from which the solution is easier is chosen.



Legend: část stroje A – part of machine A, část stroje B – part of machine B, funkční poloha spoje ve styku obou částí stroje – functional position of joint at the place of contact of both parts of machine

Resulting force effects on the joint (from the “left” and “right” side):

$$F_{xSP} = \sum_{(i)} F_{ix_A} \qquad F_{xSP} = -\sum_{(j)} F_{jx_B}$$

$$F_{ySP} = \sum_{(i)} F_{iy_A} \qquad F_{ySP} = -\sum_{(j)} F_{jy_B}$$

$$F_{zSP} = \sum_{(i)} F_{iz_A} \qquad F_{zSP} = -\sum_{(j)} F_{jz_B}$$

Resulting moment effects (from the moments and forces) on the joint (from the "left" and "right" side):

$$M_{x_{SP}} = \sum_{(i)} M_{ix_A} \qquad M_{x_{SP}} = -\sum_{(j)} M_{jx_B}$$

$$M_{y_{SP}} = \sum_{(i)} M_{iy_A} \qquad M_{y_{SP}} = -\sum_{(j)} M_{jy_B}$$

$$M_{z_{SP}} = \sum_{(i)} M_{iz_A} \qquad M_{z_{SP}} = -\sum_{(j)} M_{jz_B}$$

2. SCREWED JOINTS AND THREADED JOINTS

2.1. Characteristics

(characteristic construction properties)
Dismountable connections of components on the principle of outer and inner threading.

By mounting of the outer threading, we distinguish between:

- **screw joints** (outer threading is created on the auxiliary joining part – screw)
- **threaded joints** (outer threading is created on one of the joining parts, inner threading is on the second one)

From now on, we will work only with more common screw (solid, i.e. immovable) joints „tightened“ (i.e. prestressed) during the assembly.

Notes:

- It shall be noted that in the literature, only important (mostly highly stressed) connections are referred to as prestressed connections. When designing and determining the properties of the connection, the main structure is modeled as a set of prestressed springs. In the case of less important prestressed („tightened“) screw connections, the influence of prestressing on increasing the outer stress is calculated in a simpler way by the coefficient depending on the screw diameter.

- The basic screw connection module is a single screw connection. Multiple screw connections are often referred to as flange joints (according to their most common design). What is important, however, is only the shape (and stiffness) of the contact area and adjacent parts of the connected components and the mounting and size of the connecting screws.

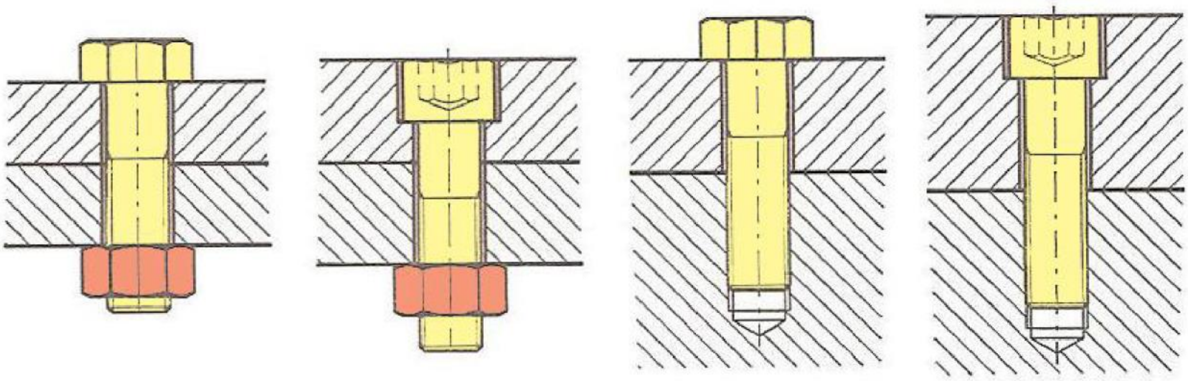
3.STRUCTURE

(basic construction properties)

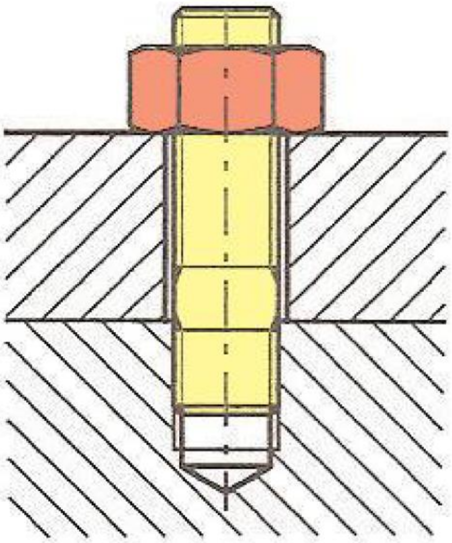
3.1. Typical Designs

A) Standard screwed joints

Connection by means of a screw with a head (with a nut and without a nut):

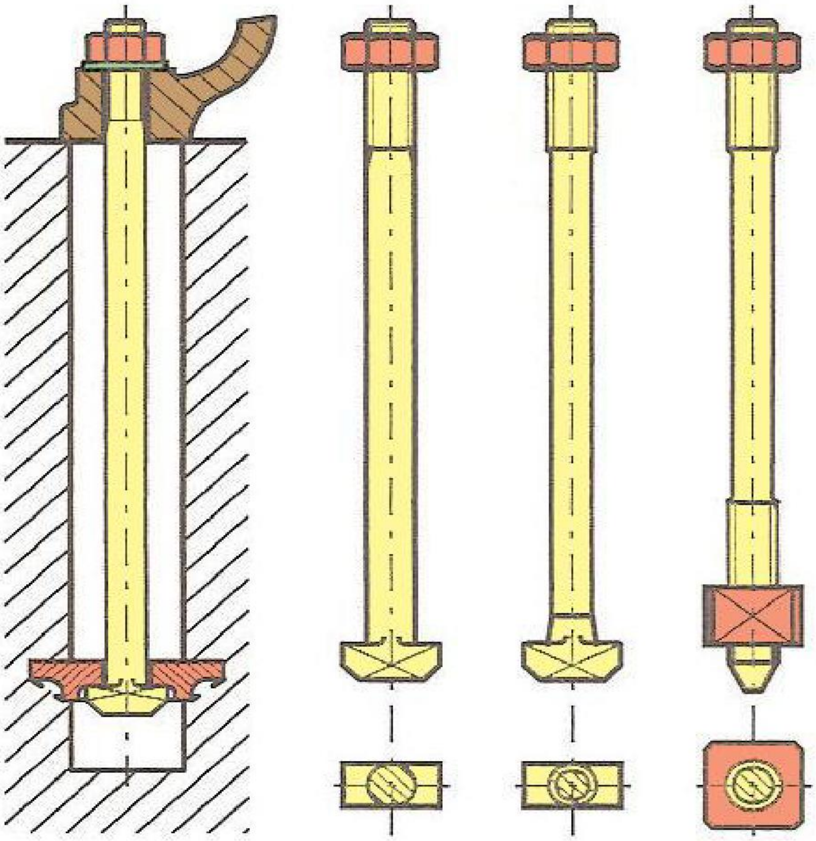


Connection by means of a stud (with a nut)**:**

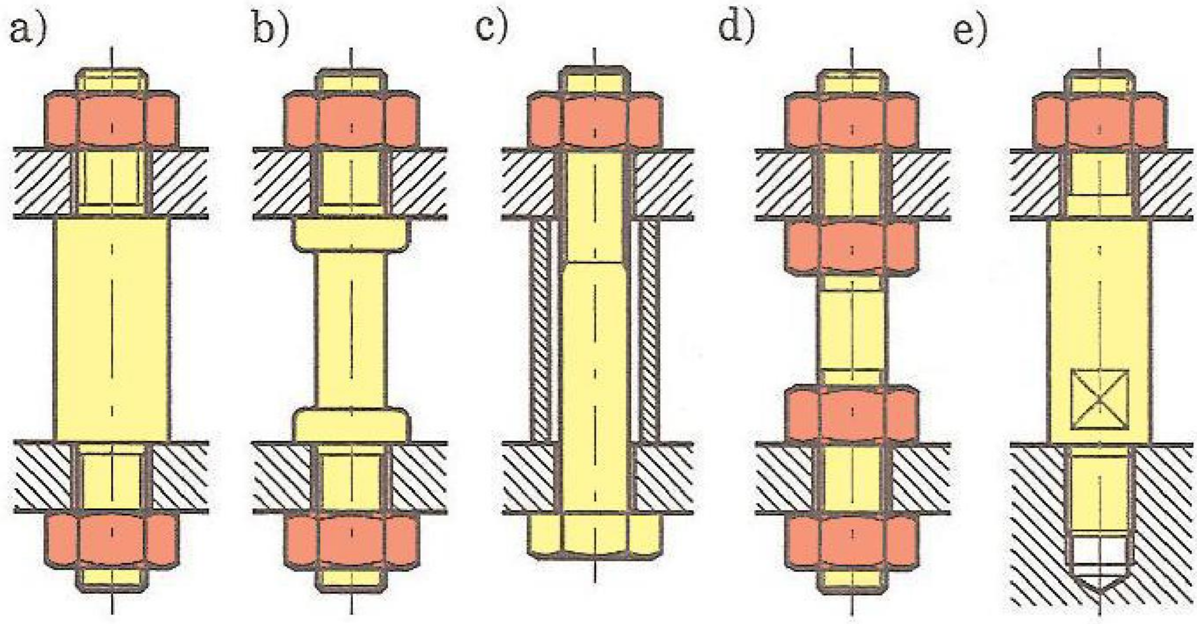


B) Special screwed joints

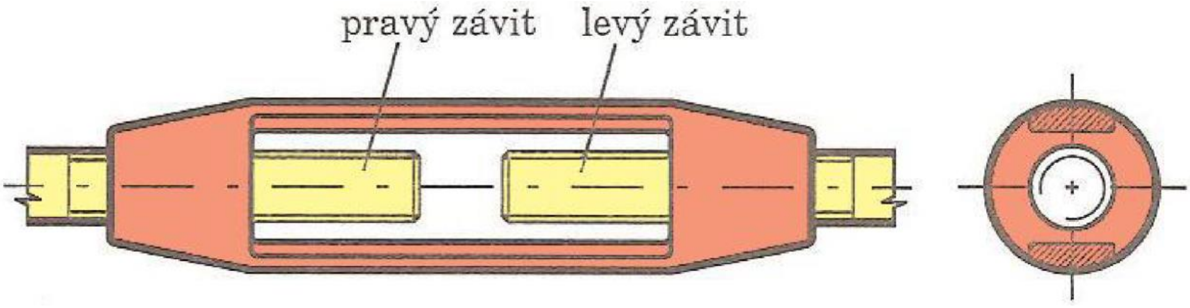
basic screwed joints:



Distance screwed joints:

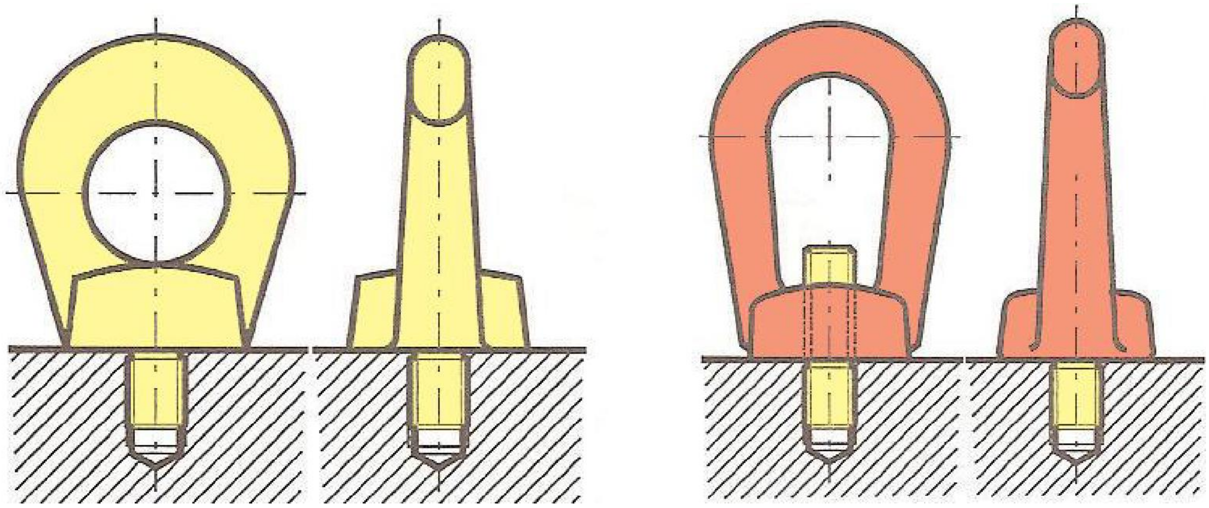


Tension screwed joints:



Legend: pravý závit - right threading, levý závit - left threading

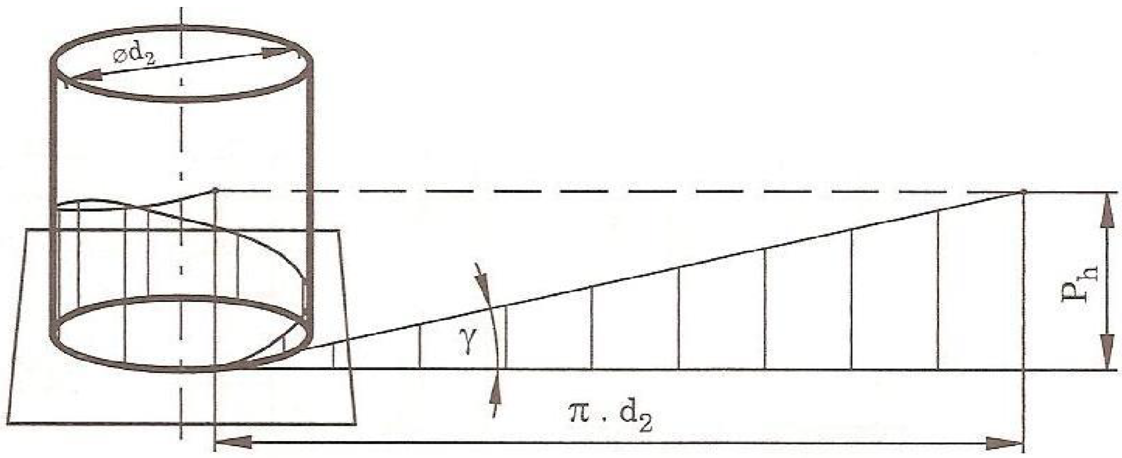
Suspension screwed joints (for "connecting" the machine part with a suspension eye-let):



3.1.1. Shapes, Dimensions and Tollerance of Screwed Joint Parts

Threading

Principle of threading (on a cylindrical surface):



$tg\gamma = Ph\pi \cdot d2$ $[rad]$

where:

Ph [mm] … degree of twist (Note: Ph = n·P ; where: n [1] … number of thread turns)
P [mm] … pitch
d2 [mm] … median diameter of thread 186

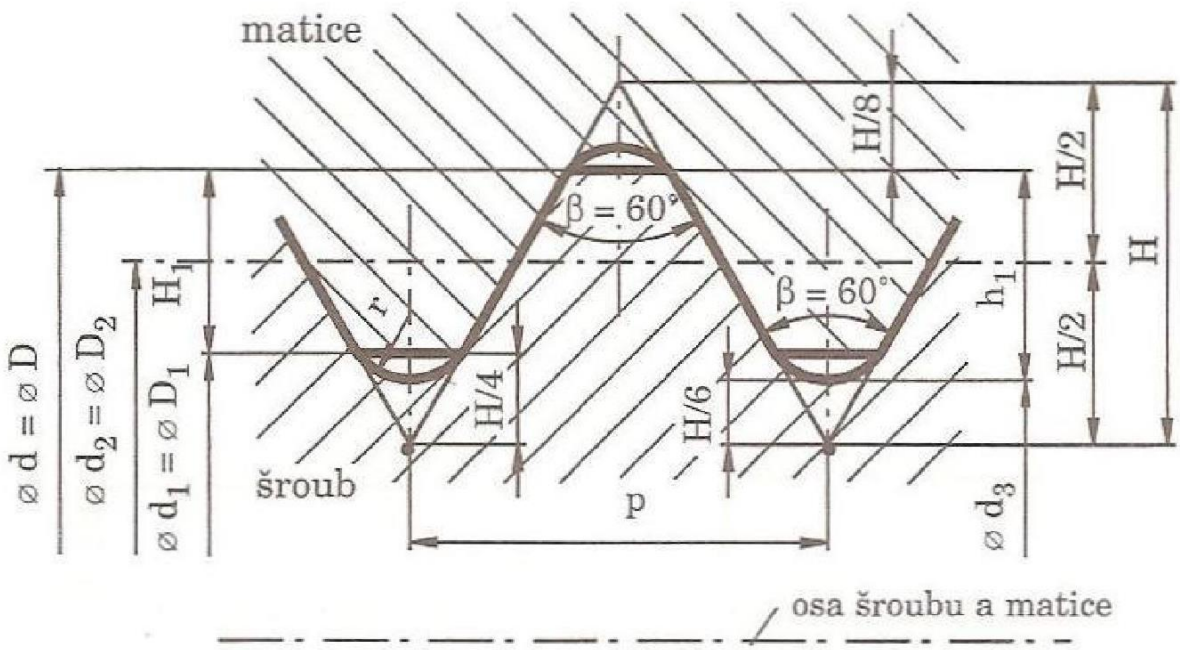
Threading types of screws connected (ČSN 01 4000):

- metric thread with a coarse pitch (ČSN 01 4008): Md , e.g. M16
- metric thread with a fine pitch (ČSN 01 4013): Md x P, e.g. M16 x 1.5

Notes:

- for a left-hand thread: Md x P LH, e.g. M16 x 1.5 LH
- for a multi-turn thread: Md x Ph/n , e.g. M16 x 3/2

Axial section (in the plane passing through the axle of the screw and nut):



Legend: matice – nut, šroub – screw, osa šroubu a matice – screw and nut axle

d, D – large ø of the screw and nut thread
d2 = D2 – median ø of the screw and nut thread
d3, D1 – small ø of the screw and nut thread
h1 – height of the screw and nut thread profile
H – height of basic profile (theoretical profile)
H1 – working height of profile (depth)
b – vertex angle
P – thread pitch

Metric threads fitting

For all bearings (ČSN 01 4314 – according to ISO)
Degree of accuracy: 1 - 10
Position of tolerance field:
d p (for d2 and d), e.g.: M16 7g6g
C H (for D2 and D1), e.g.: M16 5H6H
Examples of bearings: 5H6H / 7g6g
If there is a match, e.g. 6H6H / 6g6g, then: 6H/6g (common) 187

3.1.2. Material of Screws and Nuts

Basic rules

materials with high yield strength, especially in the case of screws;
for the same mechanical properties values, the material use depends on the method of making the thread (hot or cold forming, machining); therefore, instead of the kind of the material only the designation of the guaranteed mechanical properties for production is given:

Symbols of mechanical properties of screws and nuts: x.y**

x ...symbol of ultimate strength: numbers 4 - 12
y ...symbol of ultimate yield strength: numbers 4 - 8

Notes:

- Standardized mechanical properties of screws and nuts are marked with the first additional digit in the designation according to ČSN *

For the most common cases:

Shapes: screws and nuts ("socket head") with a cylindrical hexagonal head and inner hexagon

* first additional digit: .1 .5
** symbol of material: 5.6 8.8

$\sigma_{pt} \cong 100$ x ozn. vel. σ_{pt}	500 MPa	800 MPa
$\sigma_{kt} \cong (0{,}6 \div 0{,}8) \cdot \sigma_{pt}$	300 MPa (x 0.6)	600 MPa (x 0.8)
$\sigma_D \cong \sigma_{kt} / ([1{,}5 \div] 2{,}5)$	120 [÷ 200] MPa	240 [÷ 400] MPa
$\sigma_{DŠ} \cong 0{,}5 \cdot \sigma_D$	60 [÷ 100] MPa	120 [÷ 200] MPa – vliv vrubů závitu
$\tau_{DŠ} \cong 0{,}6 \cdot \sigma_{DŠ}$	40 [÷ 60] MPa	80 [÷ 120] MPa
vliv nerovnoměrného zatížení závitů:		
$p_{Dz} \cong 0{,}2 \cdot p_D \cong 0{,}2 \cdot \sigma_D$	20 [÷ 40] MPa	<— (rozhoduje materiál matice)
vliv pohybu:		
$p_{Dz\ poh\ zat} \cong 0{,}2 \cdot p_{Dz}$	5 [÷ 10] MPa	<— (rozhoduje materiál matice)

Legend: vliv vrubů závitu - influence of threading grooves, vliv nerovnoměrného zatížení závitů - influence of uneven thread load, rozhoduje materiál matice - matrix material is a decisive factor, vliv pohybu - influence of movement

Materials:

- less stressed joints: steel class 11 100 (11 109 and 11 100)
- commonly stressed joints: steel class 11 300 (11 340 and 11 370)

11 500 (11 500)
11 600 (11 600)
12 000 (12 040 a 12 050)

- highly stressed joints: steel class 13 200 (13 240)

14 200 (14 240)
15 200 (15 230)

- in aggressive environment: drawn brass class 42 3200 (42 3213 and 42 3223)

3.2. Properties

3.2.1. Characteristics of Complex Quality Properties

Operation, maintenance, repairs

- Transfer of all load types (transfer of tangential forces either by friction or fitted screws).
- Easy disassembly.
- Protection against loosening can be increased by structural changes.
- Reliability under dynamic load is reduced by the number of notches.

4. LOAD AND STRENGHT OPERATION

4.1. Operating load (max. load of screw joint) (rated)

Typical examples:
(SJ - screw joint, r - rated)

I. nSJ of screw joints is loaded □ on the axis by force Ftotal□ :
(if the shear force is not captured by inserted elements by means of e.g. pins, springs, etc. or fitted screws)
FSJr⟸ Ftotal ⊥=nSJ·FSJr·f·1sf indicatively sf □ (1.5 □ 2.5) (5.1 - 2)

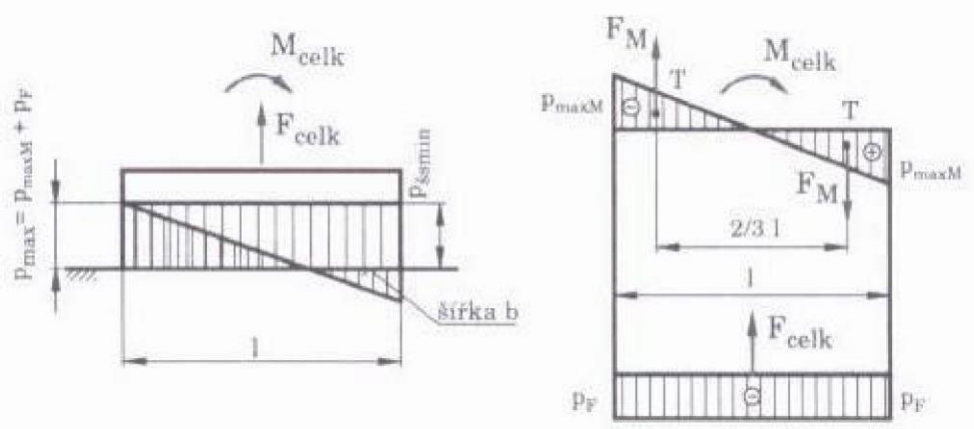
Note:

Since it is assumed that another solution can be statistically indeterminate, the maximum (limit) load is not determined, only the maximum operating (rated outer) load of screw joint FSJr is determined.

II. lSJ of screw joints are loaded parallel to the axis:

Uniform load by force Ftotal:

FSJr ⇦ Ftotal = nSJ . FSJr

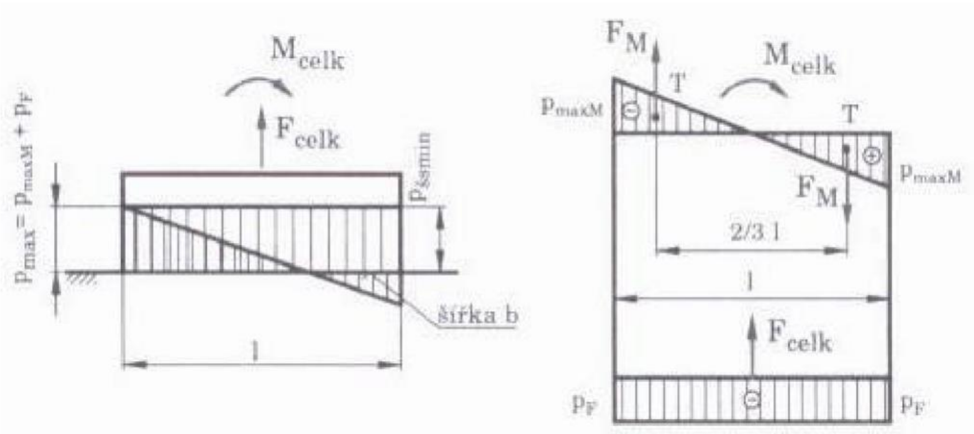


200

Legend: celk. - total, šířka - width

Planar load from F_{celk} and M_{celk}:

simply:



$M_{total\,celk} = F_M \cdot \frac{2}{3} l \Rightarrow F_M = \frac{M_{total}}{\frac{2}{3} l}$ (5.1 - 3)
$F_M = \frac{1}{2} \cdot \frac{1}{2} p_{maxM} \cdot b \Rightarrow p_{maxM} = \frac{M_{total}}{\frac{1}{6} \cdot l^2 \cdot b} = \frac{M_{total}}{W_o}$ (5.1 - 4)
$p_F = \frac{F_{celk}}{l \cdot}$; $p_{max} = p_F + p_{maxM}$ (5.1 - 5)
$F_{SJr} \Leftarrow p_m(F_{total}, M_{total}) = p_{SJr} = \frac{n_{SJ} \cdot F_{SJr}}{l \cdot b}$ (5.1 - 6)

Spatial load by Fcelk and Mcelk

- It is dealt with by analogy as in the plane, but it is also necessary to consider also the third dimension.

Determining the maximum load of the screw and prestressing of the joint (for the maximum load of the screw joint)

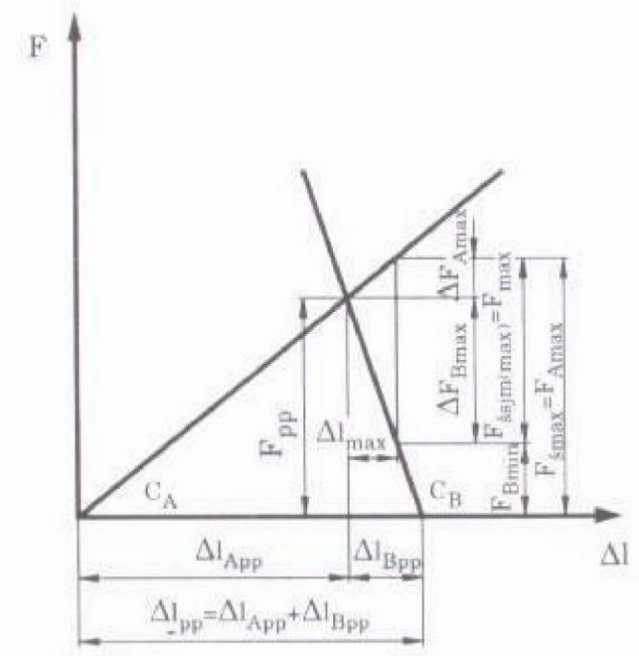
Less important screw joints:

= maximum screw load: F_S size is assumed to be equal to the maximum operating load of the screw joint $F_{\check{S}S}(max)$ increased by safety factor s:
$F_{Smax} = F_S(max) \cdot s$ (5.1 - 7)

where: s □ (1.5 ÷ 2.5)

while the lower values are chosen for larger ø d, higher values are chosen for smaller ø d (for smaller screw diameters, the risk of “breaking” when prestressing is higher). Prestressing of the F_{PP} joint is not determined. It is assumed that in the case of prestressing (“tightening”), the prestressing will be proportional to the size of the screw and therefore sufficient.

Important screw joints (as a prestressed joint - PP)



where: k_A ...stiffness of the stressed arm of the screwed joint

k_B ...stiffness of lightweight arm of screwed joint

The safety of the joint against clogging is expressed by the coefficient of relieving (improperly referred to as „tightness") c_ψ :
$F_{Bmin} = c_\psi \cdot F_{max} > 0$
$c_\psi \in (0.5 \div 1{,}5)$
larger screw ø, smaller screw ø.
⇨ Maximum screw load:
$F_{Smax} = F_{Amax} = F_{Bmin} + F_{max} = (1 + c_\psi) \cdot F_{max}$
Cpp = 1.5÷2,5
⇨ Joint prestressing (for the given non-relief coefficient of the joint c_ψ):
$FPP=FBmin+\Delta FBmax=c\psi\cdot Fmax+kBkA+kB\cdot Fmax=(c\psi+kBkA1+kBkA)\cdot Fmax$

Strength at maximum load

Tension in the screw core

$\sigma t=FsmaxSJmin$ (5.1 - 8)

where: usually S_{Jmin} is a minimum thread core cross section: $SJmin=\pi\cdot dSmin24$ (5.1 - 9)
! The table says (due to the section through the thread area):
S_{Jr} for $dSr=d2+d32>d3$

Specific pressure in threads

If the standardized heights of nuts are used and the recommended thread lengths are observed (article 5.1.1), it is not necessary to assess the pressure in the threads.

(mean)=$FSmaxnz \cdot S1Z = FSmaxnz \cdot \pi \cdot (d2 - D12)4 \cong FSmaxnz \cdot \pi \cdot d2 \cdot H1 \leq pDZ$
Simply (article 5.1.2)

Production, assembly

- Simple design, structural changes of the parts to be connected are simple, the connecting parts are mostly purchased as standardized parts.

- The least suitable elements are threads in connected parts, especially if the hole axes are not perpendicular to the surfaces and if the holes are not walk-through (risk of breakage of tools).

CHARACTERISTICS OF TIME PROPERTIES

Processes speed

- Relatively fast design, production (and purchase), assembly and dismantling.

CHARACTERISTICS OF ECONOMIC / "COST" PROPERTIES

Processes economy

- With an appropriate manufacturing design it is a relatively inexpensive joint.
- Zero operating costs.
- Minimum dismantling costs (if the joint is not corroded).

5. DOWEL, RIVET AND PIN JOINTS – STRUCTURAL ARRANGEMENTS, DESIGN AND CONTROL

5.1. Pin joints

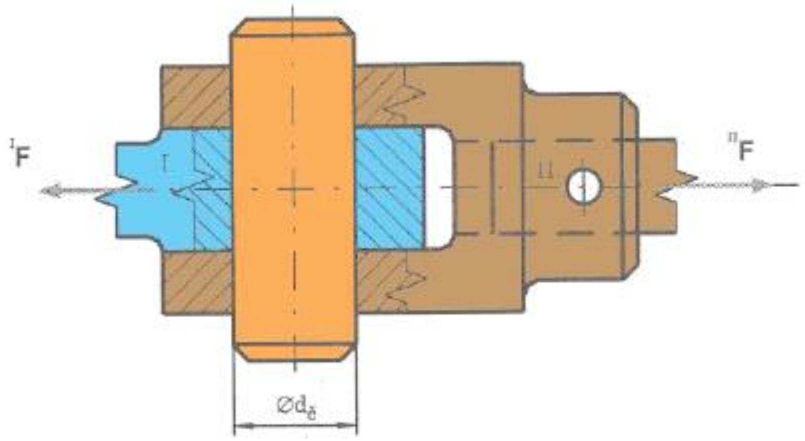
5.1.1. Characteristics

Easily dismountable connections by means of cylindrical pin inserted with movable bearing in the holes in the parts connected so that the connected TS parts are pivoted around the pin axle.

5.1.2. Structure

(basic construction properties)

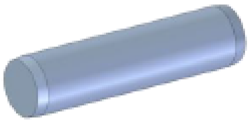
TYPICAL EXAMPLE



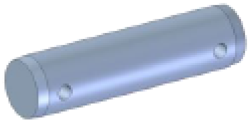
SHAPES

Standardized pins

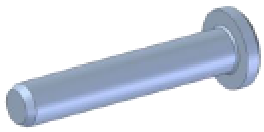
- without a head
    - without holes (ČSN EN 22340)



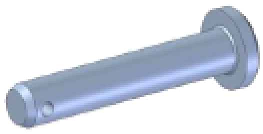
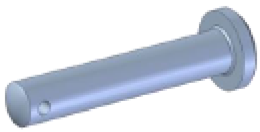
    - with holes for cotters (ČSN EN 22340)



- with a head
    - without holes (ČSN EN 22341)

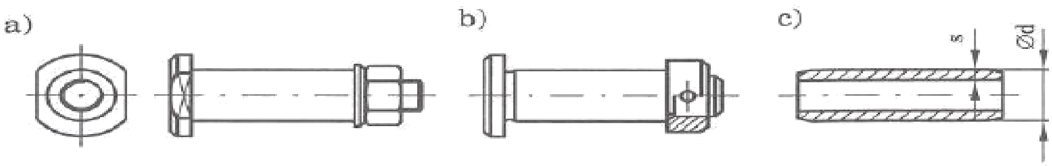


    - with a hole for a cotter (ČSN EN 22341)

Non-standardized pins

Examples:



DIMENSIONS, TOLERANCE AND MOUNTING

Dimensions

Standardized pins according to the relevant ČSN: *ø d*: 1 – 200 mm
l : in allocated rows

Tolerance and mounting

Typically H11/h11 (or H10/h8 or H8/f8)

Material
Standardized pins: steel class 11 100 (11 103, 11 110)
11 300 (11 341, 11 373)
11 400 (11 423)

Non-standardized pins: steel class 11 500
11 600 91

5.1.3. Properties

UTILITY CHARACTERISTIC PROPERTIES

Operation, maintenance, repairs

- Transmission of forces perpendicular on the pin axis with the possibility of turning the connected parts (such as joints).
- Clearance in the connection is a problem in dynamic loading.
- During operation, the joint shall be lubricated (in case it is not equipped with a self-lubricating sleeve etc.).
- Dismounting capability depends on the method of axial locking of the pin, mostly a simple one.
- Protection against loosening also depends on the method of axial locking of the pin; it is most high.
- Protection against failure is determined mostly by the adjacent zones (parts) of the connected parts than by the pin itself.

Production, mounting

- Very simple production, structural modifications of the connected parts are simple (face alignment and reaming), pins and elements for ensuring the position of the pin are mostly purchased as standardized parts (components). Production of non-standardized pins is (generally) also very simple.

5.2. Dowel joints

5.2.1. Characteristics (construction)

Fixed (i.e. immobile) dismountable connection by means of (cylindrical or conical) dowels inserted tightly into the (crosswise) holes in the parts being connected or into the (lengthwise) holes between the parts being connected.

Notes:

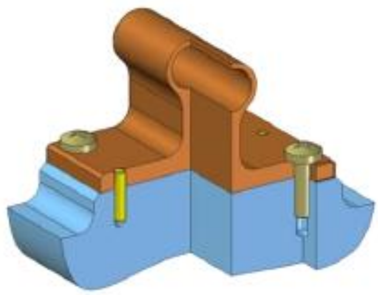
- Dowel joints are mostly used **combined with other types of joints** (or bearing) in order to achieve the desired properties of the resulting joint.
- Given that the adjacent zones (parts) of machines connected by means of dowels (also in combination with other types of joints) are usually difficult to deform due to their structure, such joints shall be placed so that their load is statically determined (or at least solvable with acceptable simplification).

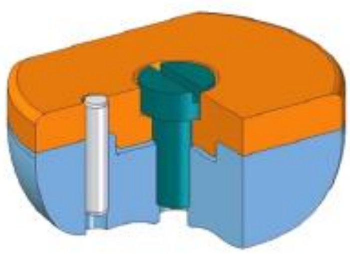
5.2.2. Structure

(basic construction properties)

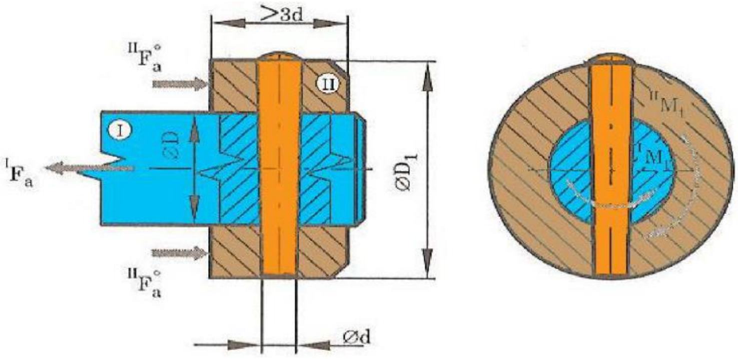
TYPICAL DESIGNS

- **To ensure position** (the main function)





- **To transfer load** (the main function)



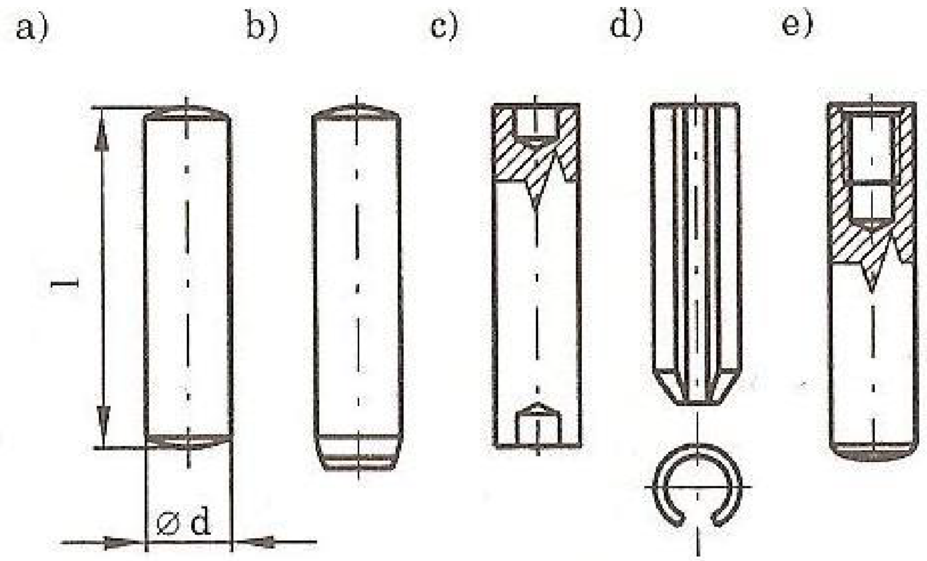
$Fa\ I = Fa\ II = Fa$
$Mt\ I = Mt\ II = Mt$

SHAPES

Standardized dowels

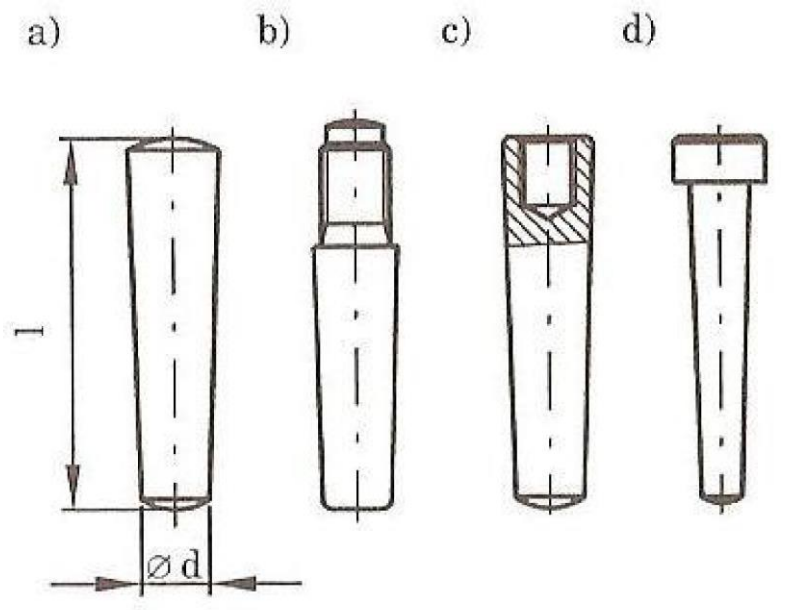
cylindrical (plain / smooth)

- cylindrical non-hardened (standard) (ČSN EN 22338+AC) a)
- cylindrical hardened (ČSN EN 28734) b)
- cylindrical with riveting ends (ČSN 02 2140) c)
- cylindrical flexible with gap (ČSN EN 28752) d)
- cylindrical with inner thread, hardened (ČSN EN 28735) e)
- cylindrical with inner thread, non-hardened (ČSN EN 28733) e)



conical (smooth / plain) (conicity 1 : 50)

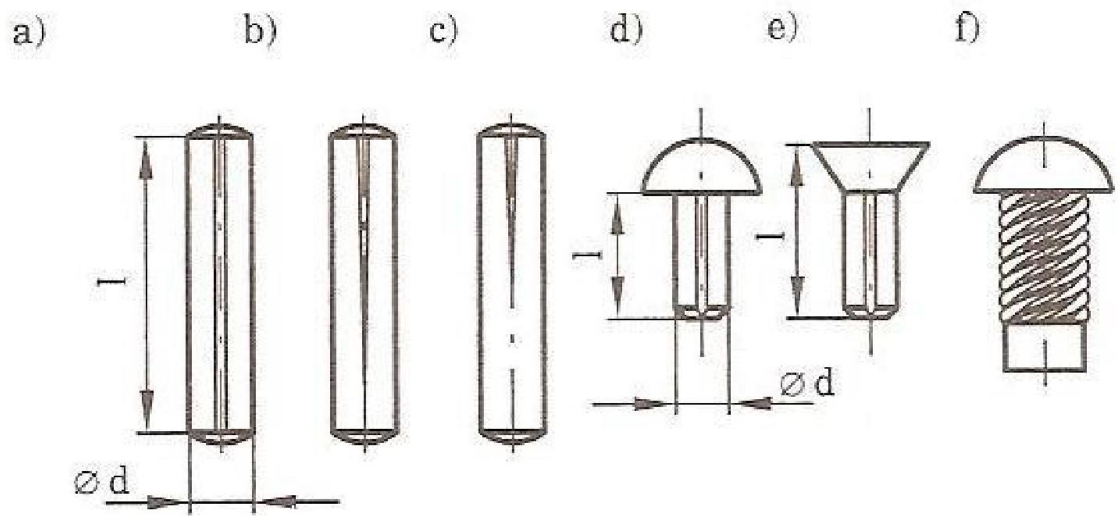
- conical non-hardened (standard) (ČSN EN 22339) a)
- conical with outer thread, non-hardened (ČSN EN 28737) b)
- conical with inner thread, non-hardened (ČSN EN 28736) c)
- conical with head (ČSN 02 2157) d)



Grooved

Without a head a) ÷ c), with a head (referred to as nails d) ÷ f)

- with a guide pin (ČSN EN 28739) a)
- with a chamfer (ČSN EN 28740)
- with grooving in the middle third of the length (ČSN EN 28742) b)
- with grooving in the middle of half length (ČSN EN 28743)
- taper grooved (ČSN EN 28744)
- taper grooved from half-length (ČSN EN 28741) c)
- taper grooved to half-length (ČSN EN 28745)
- grooved nails with ball head (ČSN EN 28746) d)
- grooved nails with countersunk head (ČSN EN 28747) e)
- screw nails (ČSN 02 2195) f)



DIMENSIONS, TOLERANCE AND MOUNTING

Dimensions
According to the relevant standard ČSN ø d: (0.6 ÷ 50) mm
l: in assigned rows

Tolerance and mounting
Cylindrical smooth usually: H7/n6 (for riveting H11/h11)

Material
Cylindrical and conical dowels: steel class 11100 (11107, 11109)
11300 (11323, 11373)
11400 (11423)
11600
Cylindrical flexible and hardened dowels: steel class 11700
Cylindrical hardened dowels: steel class 19400 (19421)

5.2.3. Properties

UTILITY CHARACTERISTIC PROPERTIES

Operation, maintenance, repairs

- Transfer of forces perpendicular to the dowel axis in order to:
    - ensure mutual relation of the connected parts
    - ensure transfer of the load between the parts connected

One of the functions is usually the main one (see TYPICAL JOINT CONSTRUCTION), but they can also be equal.

- Conical and grooved dowels are suitable for zero-backlash couplings (however, the grooved ones only for a minimum load).
- Positioning dowels are positioned as far apart as possible but in such a way that do not allow faulty connection (e.g. turning the connected parts etc.) during reassembly.
- The capability of dismounting and protection against loosening must be ensured by the choice of the dowel and joint construction.
- The reliability of the joint against failure (especially in dynamic stress) is influenced mainly by adjacent zones (areas) of the connected parts in which the dowel holes have adverse notch effects.

Production, assembly

- Very easy production (only drilling and reaming during the assembly), dowels are almost exclusively purchased.
- During assembly, it must be secured against loosening based on the type of the dowel (conical and grooved ones “thrusting”, etc.).

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

- fast design, production (and purchase), assembling and dismantling

COST CHARACTERISTICS OF PROPERTIES

Processes economy

- economical connection
- operating costs arise only from the necessity of lubricating
- minimum dismantling costs

6. FROM SHAFT-HUB JOINTS – BY MEANS OF SPRINGS, WEDGES AND SLOTTING

6.1. Spring and wedge joints

6.1.1. Characteristics (construction features)

Easy-to-dismount connections by means of springs or wedges of a prism shape (for wedges with a chamfered surface) inserted into longitudinal or exceptionally transverse holes corresponding to the shapes in the connected parts.

Notes:

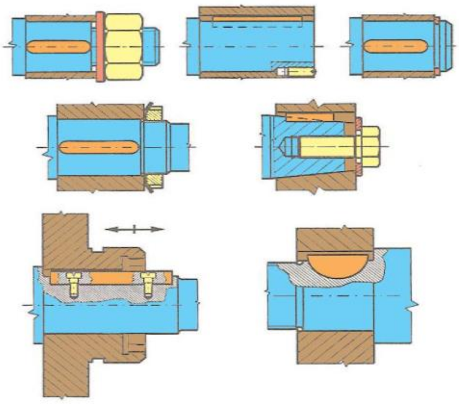
- Spring and wedge joints are almost exclusively used for the cylindrical areas. Therefore, from now on, we will consider only this case.
- Spring and wedge joints are mostly used combined with other types of joints and bearings so that all the desired properties of the resulting connection are achieved (relative axial position, alignment of connected parts, etc.).
- Since the adjacent zones (areas) of the machine components connected by means of springs and wedges (as well as their combination with other joint types) are usually difficult to deform due to their structure, it is recommended to place the joints so that **their loading was statically determined** (or at least solvable under a reasonable simplification).

6.2. Structure

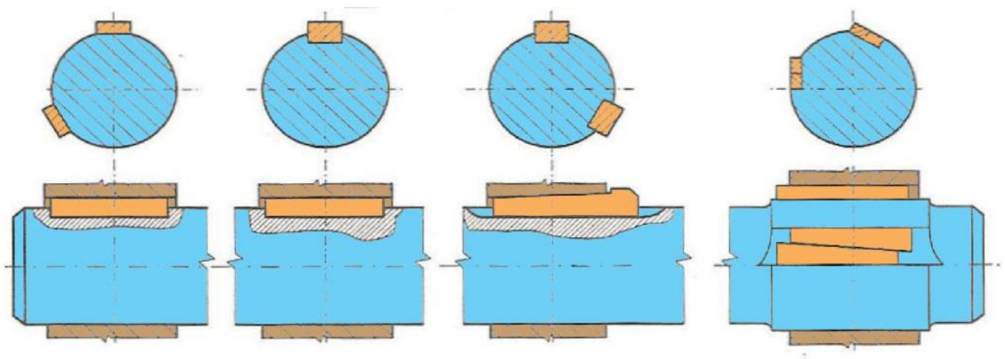
(basic construction properties)

TYPICAL DESIGN

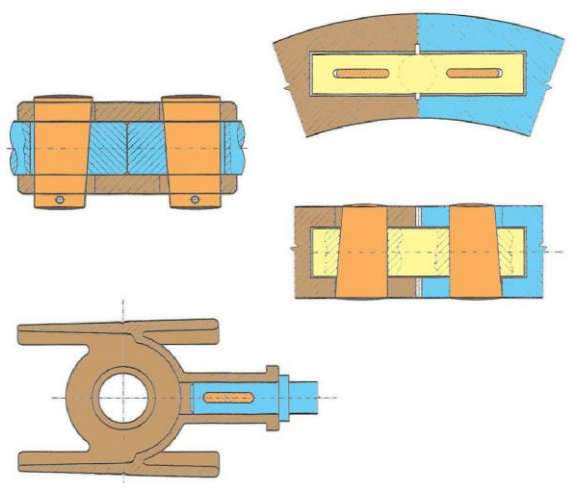
Spring joints (including the method of ensuring connected parts against shift)



Longitudinal wedge joints (chamfered ”upper“ surface of the wedge 1:100)



Transverse wedge joints (chamfered “lateral“ surface of the wedge 1:25 - 1:10)



Notes:

Longitudinal wedge joints are used for connecting the hub and the shaft. They differ from the analogous connection with a spring in **transmitting the load by the friction force** caused by thrusting the wedge into a groove with the opposite chamfer (or onto the second wedge so that the bottoms of both grooves do not have to be chamfered). The lateral areas of the wedge in the groove or other support areas serve as an anti-slip protection. Longitudinal wedge joints are thus suitable for transmitting large loads, including impact loading.

- Their main disadvantages include:

= **normal force (pressure) created by thrusting the wedge** and thus tangential friction forces ensuring the load-bearing capacity of the joint **cannot be identified.**

= due to the wedging, **transverse clearances in the joint are in one direction** only, which is a defect in their most frequent use between the hub (belt pulley, spur gear, flywheel, etc.) and the shaft.

- Longitudinal wedge joints are therefore practically not used; if yes, their lateral areas are designed and assessed for the transmission of the full load, as in the case of the key joints. In the recommended literature there is detailed information for their solution.

- Transverse wedge joints were used mostly for **large crank mechanisms, flywheels, drawbars, etc.** Currently they are only rarely used. The recommended literature provides detailed information for their solution.

- **From now on,** only commonly used longitudinal spring joints will be considered.

SHAPES, DIMENSIONS, TOLERANCE AND MOUNTING

Types according to the ČSN (non-standardized keys are practically not used)

tight – for sliding joints

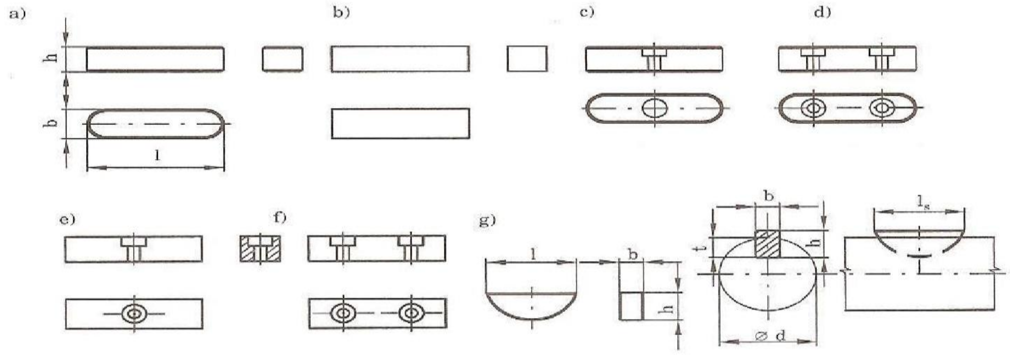
- round ends (ČSN 02 2562) a)
- straight ends (rarely used) (ČSN 30 1382) b)

Replaceable and loose – for sliding joints

- round ends ("replaceable") (ČSN 02 2570) 1 sc. c)
  (ČSN 02 2575) 2 šr. d)
- straight ends ("loose") (ČSN 30 1383) 1 sc. e)
  (ČSN 30 1385) 2 šr. f)

Woodruff – for non-sliding joints
(only *d* ≤ 50 mm) g)
(ČSN 30 1385)

other shapes (slots, or thread holes, etc.) – according to the relevant ČSN



Dimensions

- according to the relevant ČSN for *ø d* : (6 ÷ 500) mm

l : in assigned rows

- assigning the cross-section of the KEYS to the shaft dimensions according to the ČSN

(ČSN 02 2507, ČSN 30 1036, ČSN 30 1037)

Notes:

- assigning the cross-section does not mean that it is not necessary to design and assess the key by loading. The differences are in the contact length of the key.
- usual key length: 1 ÷ 1,5 d for steel components

1,5 ÷ 2,5 d for cast components

Tolerance and mounting

Cylindrical part of the joint:

- on-sliding joints (conventional): H8/h7 (or H8/k7)

(higher requirements: provisional H8/m7, H8/p7)
(high requirements: moulded H7/r6, H7/

Material

conventionally: steel 11 600
for increased loading: steel 14 240

6.2.1. Properties

UTILITY PROPERTIES CHARACTERISTICS

Operation, maintenance, repairs

- Transfer of forces transverse to the longitudinal axis of the key. If the slide along the key axis is not desired, it is necessary to secure the joint in any other way (see TYPICAL DESIGN). With small axial forces, itis possible to use bearing of cylindrical surfaces with allowance uložení válcových ploch s přesahem.
- Clearance in joint is a defect in the case of dynamic loading.
- Dismounting capacity depends on the method of securing in the axial direction; simple usually.
- Protection against loosening also depends on the method of securing in the axial direction; usually high
- Failure reliability is given mainly by the adjacent zones (areas) of the parts connected, where the slots for the key have adverse notch effects.

Production, assembly

- to manufacture the slots requires a special tool, keys are purchased
- during the assembly it is necessary to secure or reduce the axial displacement of the connected parts

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

- Fast design, relatively slow production (if there are no special tools available). Not suitable for mass production.
- The speed of assembling and dismounting depends on the overall design; usually fast

COST CHARACTERISTICS OF PROPERTIES

Processes economy

- medium-expensive joint
- zero operating costs
- relatively low dismounting costs

6.3. Spline joints

6.3.1. Characteristics

(typical structure properties)

Easily dismountable joints by means of co-working slots (teeth, keys) created on the parts connected.

Notes:

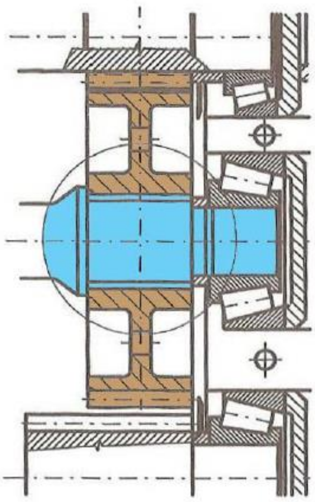
- **Spline joints** are used exclusively with the slots created on the axially symmetrical surface. The slots can thus be **parallel, oblique and perpendicular** to the joint axis. **From now on**, only the most commonly used spline joints working on the principle of co-mating outer and inner slots (teeth) on **cylindrical surface** (i.e. parallel to the axis /centre/ of the joint symmetry).

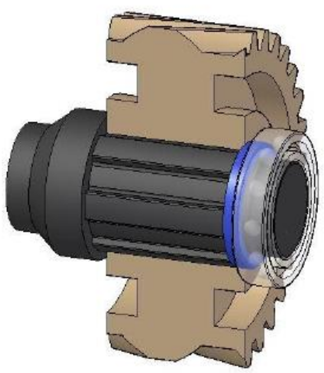
- Spline joints with slots on the cylindrical surface are mostly used in combination with other types of joints (or bearings) so that all desired joint properties are achieved (relative axial position, sometimes more precise alignment of connected parts, etc.).

6.3.2. Structure

(basic construction properties)

TYPICAL DESIGN (including the methods of securing against axial displacement)

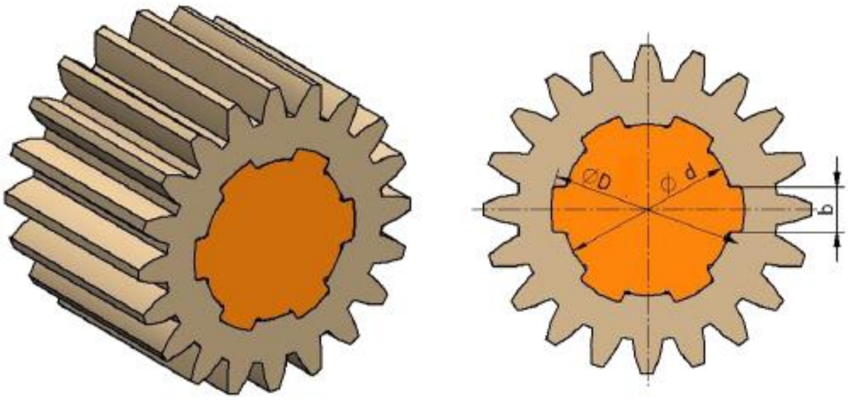




SHAPES, DIMENSIONS A TOLERANCE

I. PARALLEL GROOVING (ČSN 01 4942)

Basic shape of cross-section

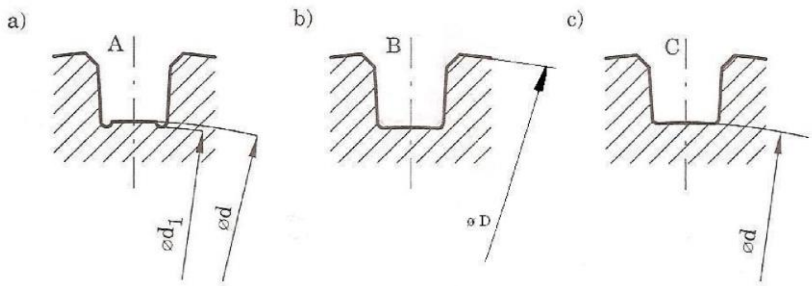


Types according to the number and dimensions of grooves / keys

- light series
- medium series
- heavy series

Note:

All three series have the same grading of ø d according to ČSN.
Types (designs) by the method of centering and manufacturing
A centering on the inner ø d in manufacturing by means of hob a)
B centering on the outer ø d or sides b)
C centering on the inner ø d c)



Dimensions

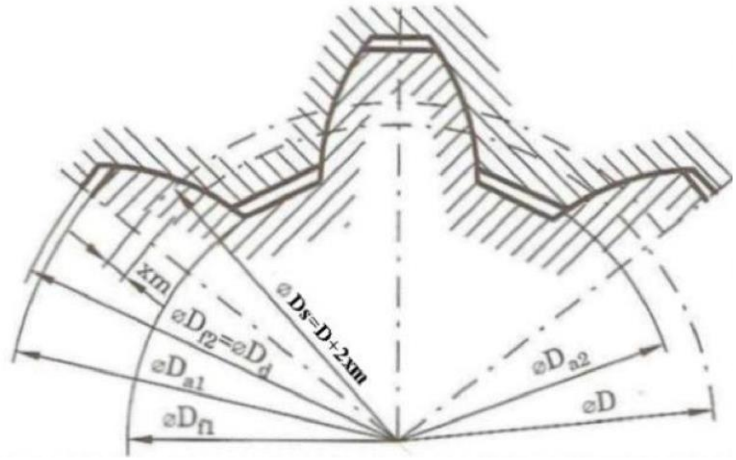
According to ČSN (01 4942) rated *ø d*: (23 ÷ 112) mm (in a series), contact length lst (1 ÷ 1,5) *d stř*

Tolerance and mounting

According to ČSN (01 4949)

II. INVOLUTE GROOVING (ČSN 01 4952 - 01 4955)

Basic shape of cross-section



Toothing

Shape of groove sides: involute
Meshing angle: α = 30°
modules : m = (0,5 ÷ 10) mm
positive and negative correction: xm < 0
xm > 0
number of teeth: z = 6 ÷ 20

Types according to the method of centering and shape (design) of grooves:

- centering on the sides of teeth, flat bottom
- centering on the sides of teeth, convex bottom
- centering on the head of the shaft teeth, flat bottom

Note:

- Most commonly, **centering on the teeth sides** is used; centering on the head of the shaft teeth (outer centering) is used only in the case of required accuracy of the shaft and hub alignment.

Dimensions

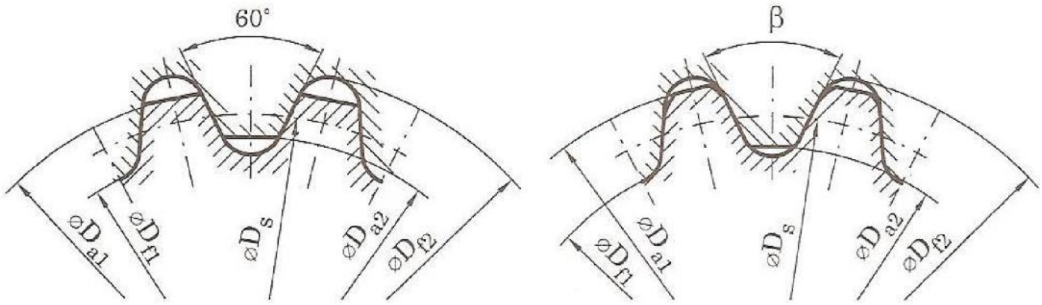
According to ČSN (01 4952 - 01 4955), rated *Dd* = (4 ÷ 500) mm, contact length *lst* (1 ÷ 1,5) *dstř*

Tolerance and mounting

According to ČSN (01 4953)

III. FINE GROOVING

Basic shape of cross-section



Toothing

Pro ⌀D_{a1} ≤ 60mm:	
tvar boků zubů na hřídeli i náboji:	rovinný
sklon boků drážek:	β = 60°
Pro ⌀D_{a1} > 60mm:	
tvar boků zubů na hřídeli:	evolventní
modul:	m = 1,5 mm
úhel záběru:	α = 27° 30'
tvar boků zubů v náboji:	rovinný
sklon boků drážek (podle ⌀D_{a1}):	β ≅ 60° (57° ÷ 63°)
počty zubů:	z = 6 ÷ 20

Legend: pro – for, tvar boků zubů na hřídeli i náboji – shape of teeth sides on the shaft and hub, rovinný – flat, sklon boků drážek – gradient of slot sides, tvar boků zubů na hřídeli – shape of teeth sides on shaft, evolventní – involute, modul – module, úhel záběru – meshing angle, tvar boků zubů v náboji – shape of teeth sides in hub, počty zubů –number of teeth

Dimensions

According to ČSN (01 4933) rated *ø Da1* = (8 ÷ 120) mm, contact length *lst* (1 ÷ 1,5) *dstř*

Tolerance and mounting

According to ČSN (01 4933)

MATERIAL

Quality steel for both connected parts:
min. compressive strength: $\sigma Pt \geq 500$ MPa
min. hardness of sides for sliding joints: HRC ≥ 55

6.3.3. Properties

I. and II. PARALLEL AND INVOLUTE GROOVING

UTILITY PROPERTIES CHARACTERISTICS

Operation, maintenance, repairs

- Transmission of high torques under alternating and impact loading, clearance in slots can be a defect.
- Requirements for precise alignment must be secured by either (more expensive) type of toothing or other method of centring
- Suitable for axial displacement of the connected parts without loading or with torque loading; otherwise it is necessary to secure axially.
- Dismounting depends on the method of securing in the axial direction; usually simple
- Failure reliability (especially in the case of dynamic loading) is affected by notch effect of slots and their run-outs

Production, assembly

- Production requires special tools and machinery
- Relatively easy assembly

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

- Fast design (using data in the ČSN tables)
- Relatively fast production only when using a suitable equipment, fast assembly and dismounting.

COST CHARACTERISTICS OF PROPERTIES

Economy of processes

- Expensive joint, economical only in the case of mass production – in this case more economical than key joints, etc.
- Operating costs in the case of movable joints only due to lubrication, except for this – zero costs
- Minimum dismounting costs.

5.2.3 - III. FINE GROOVING

UTILITY CHARACTERISTICS OF PROPERTIES

Operation, maintenance, repairs

- Transmission of torques, compared to key joints shorter joints with the same loading
- Must be secured against axial displacement of the connected parts.
- Dismounting depends on the method of securing in the axial direction, usually easy
- Failure reliability affected by the notch effect of the slots and their run-outs, weakening of shaft is lower than in the case of parallel and involute grooving

Production, assembly

- As in the case of parallel and involute grooving

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

- As in the case of parallel and involute grooving.

COST CHARACTERISTICS

Economy of processes

- As in the case of parallel and involute grooving.

7. POWER SHAFT-HUB JOINTS OF SHAFT AND HUB – CRIMPING AND CLAMP-ING

7.1. Crimp joints

7.1.1. Characteristic

(typical structure properties)
Rigid (ie. Immovable connected in operation) joints that are difficult to dismantle, working on the principle of permanent flexible pre-stressing of the connected parts by means of allowance in their contact surface (of any shape).
From now on, only the most common crimping joint with a cylindrical (or slightly conical 1 : 50) contact surface.

7.1.2. Structure

(basic construction properties)

Outer part ("hub")

Rotational symmetrical part (gear, ring gear, clutch disc, flywheel, etc.), or its deformation-active part (see below), whose inner (functional) cylindrical hole is made with a determined tolerance and quality of the surface.

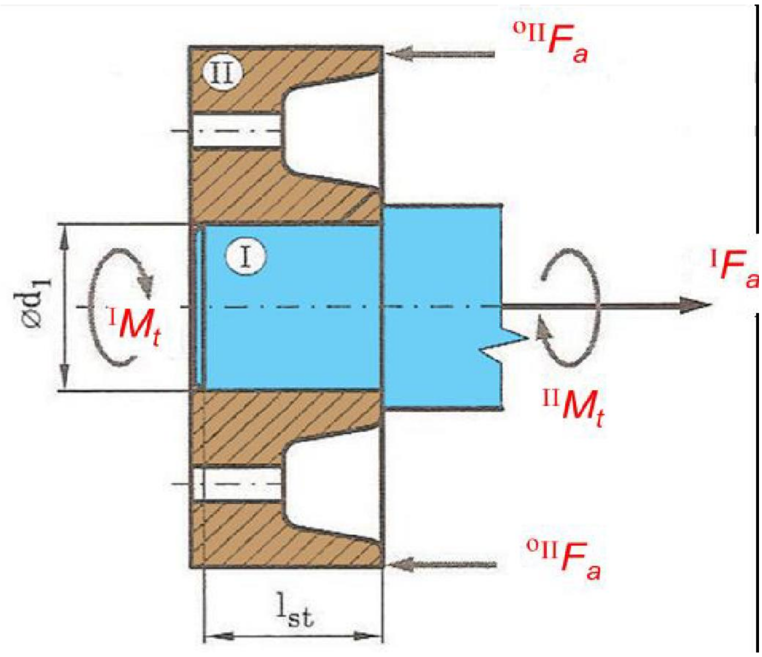
Inner part ("pin")

Rotational, symmetrical, full or hollow part (ring gear disc, full or hollow shaft, etc.) whose outer (functional) cylindrical surface is made within the dimension tolerance with determined allowance to the dimensions of the relevant cylindrical hole of the outer part and with determined quality of surface.

Note:

- allowance can be determined in the reverse order (outer part ⇨ inner part), the above mentioned alternative is significantly more suitable in terms of production, and is therefore more common

TYPICAL DESIGN



MtI=MtII=Mt
FI=FII=F
Symbol ° means acting in all circumference

7.1.3. Properties

UTILITY CHARACTERISTICS OF PROPERTIES

Operation, maintenance, repairs

- Transmission of torque and / or axial friction force generated in the contact area by permanent prestressing and friction coefficient. The joint can also capture the bending moment.
- Suitable also for large loading (alternating, impact), as there is no clearance in the joint.
- High accuracy of alignment and perpendicularity of the connection
- High reliability of all properties of joint.
- No maintenance required x in the case of dismounting (replacement, repairs of the connected parts) dismounting is very difficult, sometimes even impossible.

Production, assembly

- High requirements for accuracy of the production tolerance.
- Relatively difficult assembly:
    - cold pressing (press equipment)
    - hot drawing (not pressing!) (equipment for uniform heat and safe manipulation with outer part) with a possible cooling of the inner part (cooling equipment).
    - In both cases, axial trip on the parts is necessary in order to fix the axial position (ie. support, most often annular area perpendicular to the axis).
- Suitable for all types of production when using appropriate production facilities (piece production, small batch production, ...).

Other aspects

- Relatively dangerous assembly – pressing or manipulation with a hot part during hot drawing.
- Relatively safe in operation – smooth shapes.
- Tolerance of bearing must be pursuant to ČSN.

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

- The joint is suitable for fast design and implementation, does not require any special measures (material, semi-products, tools), if there is suitable pressing or heating (cooling) device at disposal
- Not suitable for fast repairs and dismounting

COST CHARACTERISTICS

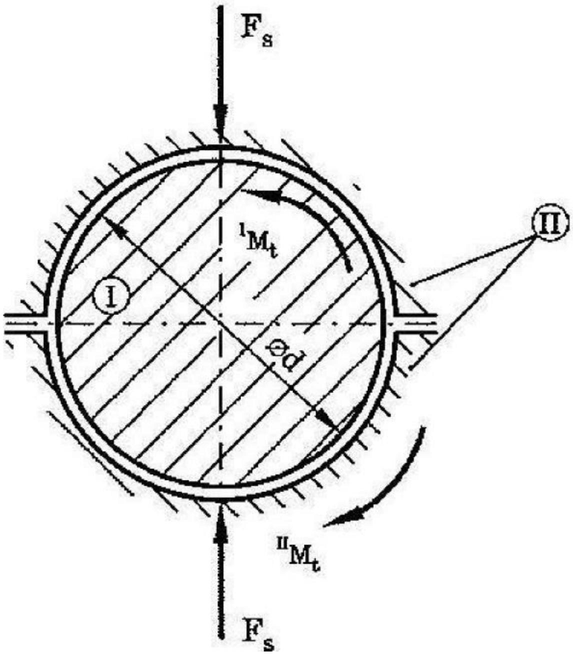
Economy of processes

- Medium production costs
- Zero operating costs.
- High dismount costs

7.2. Clamping joints

7.2.1. Characteristic

(typical structure properties)
Rigid, easy to dismount connections on the principle of clamping (or bracing) of the connected parts in their contact areas (of any shape) by means of elements that do not participate in transmitting the loading. From now on, only the most common clamping joints with a rotationally symmetrical contact area



Contact length: *l*st
$MtI=MtII=Mt$

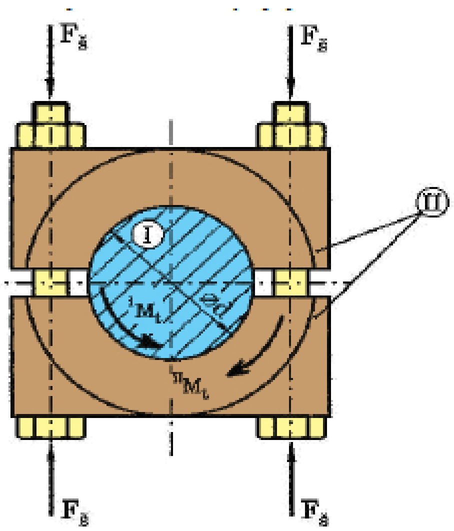
7.2.2. Structure

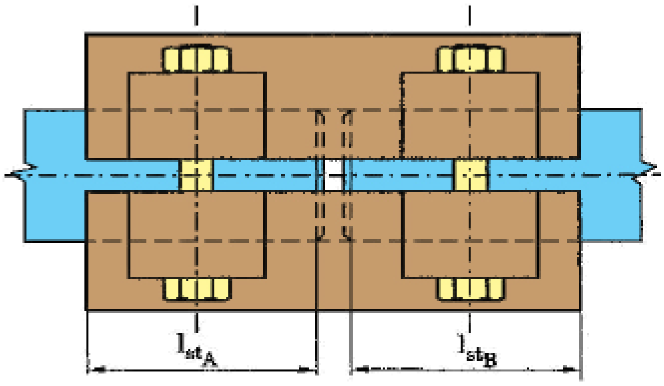
(basic construction properties)

I. CLAMPING JOINTS WITH CYLINDRICAL CONTACT AREA

A) WITH A DIVIDED OUTER PART

Usually clamp couplings of shafts:

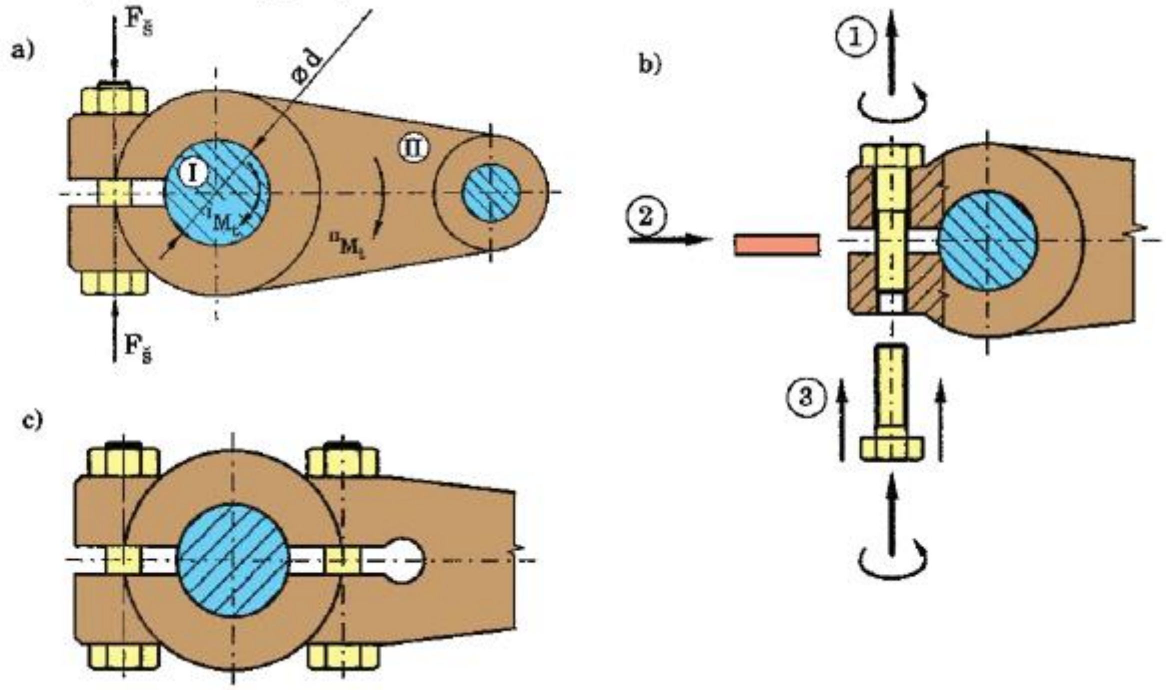




$MtI=MtII=Mt$

B) WITH A PARTLY DIVIDED OUTER PART

Usually clamp couplings of levers with shaft:

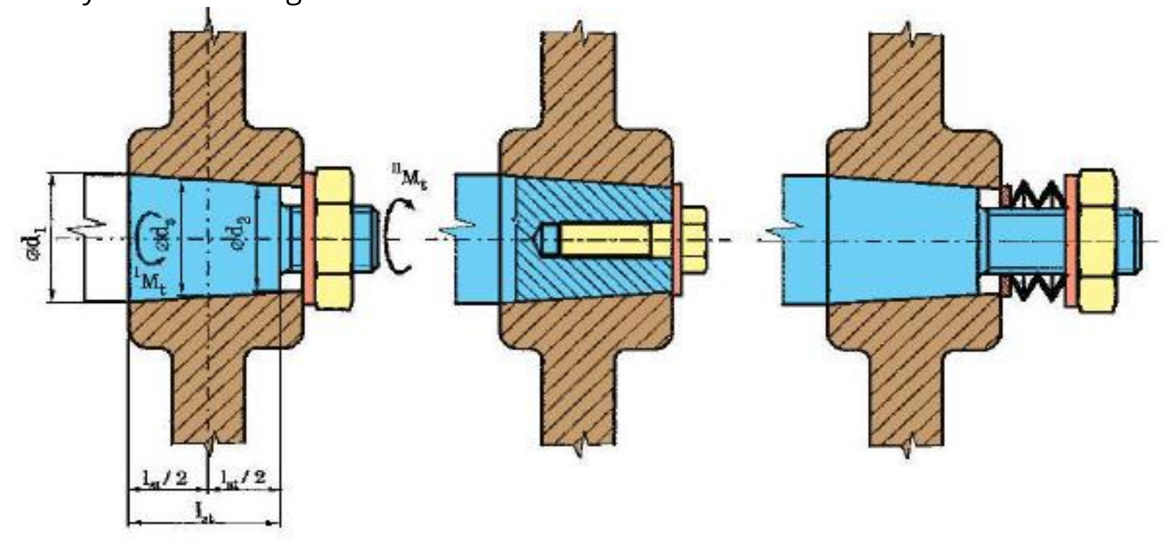


Mounting of inner and outer part:

A), B) a) b) – temporary B) c) – with overlap (small A)
Either H8/j7 or H8/k7 H8/n7 or H8/p7
or H7/j6 or H7/k6 H7/n6 or H7/p6
C) WITH A NON-DIVIDED OUTER PART (for small ø and small *M*t)

II. CLAMP JOINTS WITH CONICAL CONTACT AREA

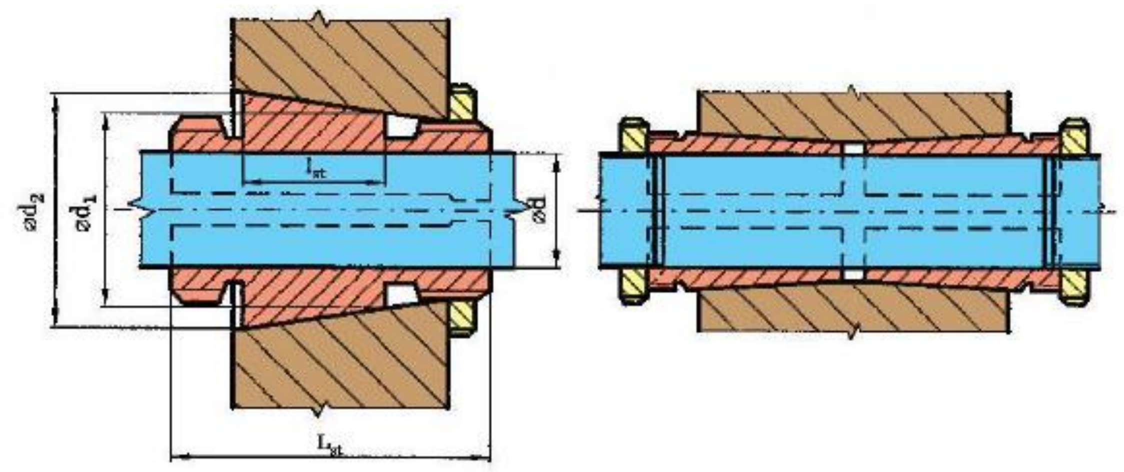
(only with non-divided outer part)
Usually for connecting hubs with shaft on its ends:



$MtI=MtII=Mt$
$ds=d1+d22$
Conicity: 1:5 - 1:10

III. CLAMP JOINTS WITH CONICAL SLEEVE

(only with non-divided outer part)
Usually for connecting ("hubs") inner bearing rings etc. with the shaft anywhere of its length:



Conicity: 1:10 - 1:15
Mounting of sleeves on the shaft - temporary: H8/j7
Those joints are not used for transmitting large loads, therefore they will not be further considered.

7.2.3. Properties

UTILITY CHARACTERISTICS OF PROPERTIES

Operation, maintenance, repairs

- Transmission of torque and axial force (friction force generated in the contact area by clamping) by bracing and friction coefficient). The joint can capture bending moment.
- Easy assembly, replacement and re-setting of relative position of the connected parts (except for the axial position of the joints with the conical contact area)
- Joint reliability significantly depends on the reliability of securing clamping elements against loosening.
- High reliability against fatigue fraction (no notches on the shaft).

Production, assembly

- Relatively easy production and assembly
- Divided parts shall be machined simultaneously
- Easy assembly and setting relative position of the connected parts (except for the axial position of the joints with the conical contact area).

Other aspects

Relatively dangerous for the service in the case of rotating due to outer non-rotational shapes (sometimes has to be covered).

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

fast design, assembly, maintenance, dismantling.

COST CHARACTERISTICS

Economy of processes

- relatively low production costs
- zero operating costs.
- minimal dismantling costs.

8.FLEXIBLE JOINTS

8.1. Basic information

8.1.1. Characteristic

(typical construction properties)
Machine parts (organs), whose main function is to receive, preserve and re-release mechanic energy on the principle of elastic deflection of the material.

Notes:

- The basic part of each spring is “an individual spring”. In the case of compound springs, it is necessary to determine the loading of the individual springs on the basis of force (e.g. moment) and deformation conditions. The loading of the individual springs is dealt with separately. The properties of the compound spring are obtained by the reverse procedure. In majority of cases, springs are used on the principle of flexible shapes or malleable materials. Springs based on ductile materials (pneumatic, hydropneumatic, etc.) are used only in special cases and therefore they are used only in the introductory part of this chapter.

8.1.2. Structure

(basic construction properties)

PERFORMANCE CHARACTERISTIC AND SPRING DIAGRAM

Shifting and rotating due to deformation deflection deformace: $u = f\,(k, F\,[N])$ [mm], $\varphi = f\,(k\varphi, Mt\,[Nmm])$ [rad]

Stiffness and torsion rigidity: $k{=}dF[N]du[mm][N.mm{-}1]$
,$k\varphi{=}dMt[Nmm]d\varphi[rad][N.mm.rad{-}1]$

Types of performance characteristics:

- **by deformation deflection dependence on loading:**

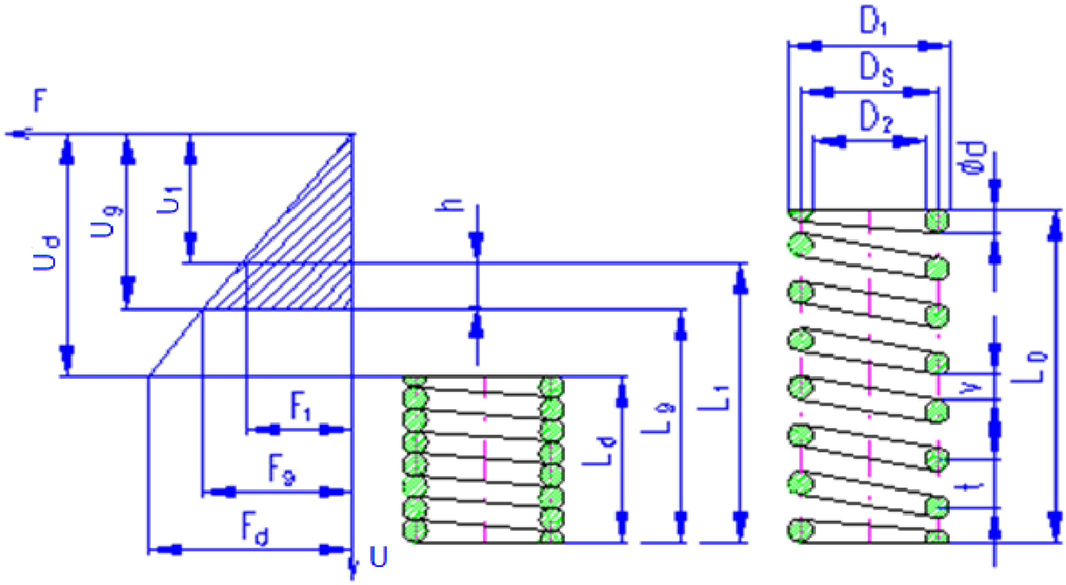
= linear
= non-linear (continuous and broken)
 progressive
 degressive

- **by internal losses:**

= without hysteresis a)
= with hysteresis b)

Working spring diagram

Examples of linear helical spring:



Structure
(basic construction properties)

TYPES OF MATERIAL

A) Metallic

Steels

For high stress load, including dynamic load. Quality heat-treated steel with high flexibility, strength, fatigue and toughness:

Steel of all classes: 11 000 (min 11 800) - 19 000.

Strength of wires used for springs is increased by their mechanical strengthening (drawing) during the manufacturing. The influence of strengthening is smaller with the larger diameter of wire.

Therefore, when determining the strength of wire material is necessary to consider not only the type of material (including the heat treatment) but also the wire diameter /see the following examples).

B) Non-metallic material

Rubber

For low stress and special requirements (high internal attenuation, non-conductivity of electricity, heat insulation, etc.)
The disadvantage is low resistance to low and high temperatures (-35° C < t < 50° C), shorter lifetime especially in the case of dynamic load, and low chemical resistance to oil and petrol.

Plastics

For low stress and special requirements (as in the case of rubber; compared to rubber, plastics show higher resistance to higher temperatures (-40° C < t < 120° C) and higher chemical resistance to oil and petrol.

C) Special material ("media")

Besides the aforementioned metallic and non-metallic materials, liquids and gases in special springing elements are also used as flexible material, usually with a necessary help of hydraulic or hydropneumatic systems.

CRITERIA FOR SELECTION OF MATERIAL

- spring type (structure etc.)
- use (function, parameters, ...)
- stress and deformation (types, size, ...)
- environment (heat, aggressiveness, ...)
- special requirements (electricity conductivity, magneticity, ...)

8.1.3. Basic properties

Properties of mechanical energy accumulators are used in propulsion systems and reverse mechanisms:

- for capturing static and dynamic forces or torques
- for changing the frequencies and oscillation shapes of mechanical systems
- for measuring and regulating forces and moments

Operating costs are usually zero.

Other operating, time, cost properties etc. are affected significantly by the structure of the spring, that is by:

- construction elements and their arrangement/organisation uspořádáním
- Shapes
- dimensions
- Material
- type of production
- state of surface
- difference from rated values in assembled state.

8.1.4. Design and evaluation

(for achieving desired properties and prediction of achieved reflective and reactive properties.)
Due to relatively low stiffness and weight of springs to high stiffness and weight of adjacent machine parts, the frequencies of oscillating system (simply: $\Omega = \sqrt{k/m_{red}}$ [rad.· s-1]) generally significantly lower than in the case of other common machine parts. It follows that in the case of common low-frequency dynamic operating load, it is necessary to deal with the design and evaluation of springs in terms of dynamic; the design and evaluation cannot be simplified and dealt with as static load increased only by operating (dynamic) coefficient *cdyn* as in the case of other common machine parts.
In some cases, it is possible to use more precise procedures as I the case of shaft couplings. Due to higher variability of spring use, this is only an exception. For these reasons, from now on only the information referring to design and evaluation of springs under static load are given.
The information relevant to design and evaluation of dynamically stressed springs need to be sought in professional literature.

Notes:

- When designing statically stressed spring: load(max), def(max) => Shapes, dimensions, material ...
- When designing statically stressed spring: safety, def(max) <= load(max), Shapes, dimensions, material ...

9. MATERIAL JOINTS – WELDED, SOLDERED, BONDED

9.1. Welded joints

9.1.1. Characteristic

(typical construction properties)
Rigid non-dismountable connections based on the principle of melting connected parts using heat and / or pressure, using / without using filler material.

9.1.2. Structure

(basic construction properties)

METHODS OF MANUFACTURING (TYPES OF WELDING)

A) Melting: connecting by means of melting the material (of connected parts and / or filler) using heat, without pressure.

Types (according to the heat input)

- arcing: between metal (alternating or direct current) or carbon (direct current) electrode and original material:

- by hand with a metal electrode
- automatic with welding wire and flux
- automatic with tungsten electrode under modified atmosphere
- automatic with carbon electrode

- flame: combustion of gases – acetylene or propane-butane and oxygen
- electroslag: no arc. Heat source is the current passing through conductive slag and hot wire
- plasma: two arcs – basic and carrier generating plasma
- electron. beam: metals with high melting point - W, Mo …
- termite: mixture of iron oxide with aluminium powder
- foundry: liquid metal – castings repairs

B) Pressure: connecting by melting the material (of the connected parts and/or filler material) using heat and pressure.

Types (by method)

- by resistance: melting using low-voltage and intensive electrical current
- by contact: melting or upsetting (melting off, stamping)
- by points: two electrodes, usually cooled by water (thin sheets)
- by seams: between two disc electrodes or disc electrode and other component (in tight containers)
- by protrusions: one part - protrusions. It is clamped between flat electrodes (in mass production, otherwise rather costly)
- by friction (dry): melting by friction (for rotating parts)
- induction: melting using induced current (for producing seam tubes)
- ultrasound: melting using high frequency
- explosion: using explosives, spark discharge, magnetic wave
- from now on, only more common melt welding joints (connections by welds) are considered

Types of welded joints

Types by cross-section shape

Given by standards: ČSN 05 0025 ÷ 05 0028
ČSN 13 1075 (for pipelines)

CONNECTED AND FILLER MATERIALS

A) Connected material

Basic rule:

To use only material with guaranteed weldability (given in steel quality standards (material data sheets) ČSN 41 0000 ÷ 41 9858).

Degrees of weldability

zaručená (vždy)	1a	pouze t > 0° C	i dynamicky namáhané svary
zaručená podmíněně	1b	za urč. podm. zaruč.	staticky namáhané svary
dobrá	2	nezaručuje, ale lze	podřadné svary
obtížná	3	nevyhovující svary	nedoporučuje se

Legend: zaručená (vždy) - guaranteed always, zaručená podmíněně - guaranteed conditionally, dobrá - good, obtížná - difficult, pouze - only, za urč. podmínek zaručená - guaranteed under certain conditions, nezaručuje x lze - not guaranteed x possible, nevyhovující tvary - inconvenient shapes, i dynamicky namáhané svary - including dynamically stressed welds, staticky namáhané svary - statically stressed welds, podřadné svary - inferior welds, nedoporučuje se - not recommended

Notes for individual material types:

- for steel in general: electric arc welding C ≤ 0.2%, P,S ≤ 0.1%
- steel classes 10 -17 : special types with guaranteed weldability (see in Table)
- hardened steel : hard to weld (must be pre-heated)
- casting steel (higher C): hard to weld (cracking)
- grey cast iron (higher C): hard to weld (pre-heated to 650° C)
- cast iron (422530,35,40): good weldability.
- non-ferrous metals: hard to weld (high heat conductivity (copper, bronze, brass) and low melting temperature)

B) Filler material

Types (by shape and modifications)

- coated electrodes: for arc hand-welding
- by the type of the material welded
- by the type of the coating (alkaline, acidic, ...)
- by the diameter: (1,6 ÷ 8) and length: (200 ÷ 500)
- bare wires: for welding without air supply

(submerged or under modified atmosphere)

- by the type of the material welded
- by the diameter: (1,6 ÷ 5) in meters
- by the diameter: (5 ÷ 20)

9.1.3. Properties

(properties)

UTILITY CHARACTERISTICS OF PROPERTIES

Operation, maintenance, repairs

- transmission of all load types
- not dismountable
- reliability affected by susceptibility to internal stress and notch effects

Production, assembly

- difficult to manufacture.
- possible to manufacture large machines and their parts (not possible by means of castings and forgings).

TIME CHARACTERISTICS OF PROPERTIES

Processes speed

- relatively fast design and manufacturing
- in the case of complex products, ignition or aging necessary in order to remove internal stress (can be done also by means of vibrations), which extends the production time

CHARACTERISTICS

Processes economy

- In the case of piece production it is less expensive than castings, forgings, etc. (savings of material, less work); the necessity to remove the internal stress in the case of complex weldments increases the costs.
- Zero operating costs if the impossibility of dismounting is not a problem.
- High costs of "dismounting" (flaming, etc.).

9.2. Soldered joints

9.2.1. Characteristics

(typical construction properties)
Solid (immovable) not dismountable connection of two (usually) metal parts by means of metal which is melted during the connecting process and by means of diffusion adheres to the connected parts without melting them.
Soldered joints are used in various industries (precision mechanics, goldsmiths, plumbing, canning, vehicle construction, etc.).

9.2.2. Structure

(basic construction properties)

TYPES OF PRODUCTION *(MANUFACTURING)*

By the melting temperature (always lower than the melting temperature of the connected parts)

- soldering (to 450° C)
- brazing (over 450° C)

Preparation of metallic clean surface

- mechanically (scraping, brushing)
- by ultrasound
- chemically (using flux)

Heating up to desired temperature

- locally (by electric solder, solder lamp, burner, electric resistance, high frequency, etc.)
- overall (in a furnace using modified atmosphere, in vacuum using high frequency, submerging in salts melt, using melted solder)

CONNECTED MATERIAL, SOLDERS, FLUX

A) Soldering

Connected materials:

- copper, zinc, steel, lead and their alloys (usual materials)
- grey cast, aluminium, glass, metal-ceramic alloys (spec.)

Solders: (ČSN 05 5612 ÷ 50)

- tin
- special

Flux:

- resin, tallow, stearin, rosin
- chlorides (cause corrosion)

B) Brazing

Connected materials:

- steel, grey cast
- copper, nickel and their alloys

Solders:

- brass (ČSN 05 5680 ÷ 86)
- silver (ČSN 05 5660 ÷ 76)
- for aluminium (ČSN 05 5700 ÷ 80)

Flux: (ČSN 05 5700 ÷ 80)

- borax, boric acid
- chlorides, soda, potash, silica

SHAPES OF SOLDERED JOINTS

Basic types:

- butt-welding
- with sloping surface
- with bent sheet
- with overlapping
- with contact element

9.2.3. Properties

UTILITY CHARACTERISTICS

Operation, maintenance, repairs

- transmission of all small load types, most suitable in case of shearing stress.
- soldering used especially for the joints with tightness requirement or conductivity requirements in the case of not big tightness and in the cases where the material cannot be heated up to high temperatures.
- brazing where tightness, toughness, fatigue resistance, corrosion resistance, higher temperatures.
- they can be repaired using heat.

Production, assembly

- high demands on design (cleaning surfaces, small and even gap, even heating to the necessary temperature).

Other aspects

- degreasers and flux may be unsuitable (in terms of hygiene or possible allergies)
- impossible recycling

TIME CHARACTERISTICS

Processes speed

- relatively fast design and manufacturing

COST CHARACTERISTICS

Economy of processes

- relatively cheap in production in small batches
- zero operating costs, if the impossibility to dismount the connection is not a problem
- disposal of solders

9.3. Bonded joints

9.3.1. Characteristic

(typical construction properties)
Solid (immovable) connections by means of a liquid material (glue) that adheres to the connected parts (creating a thin layer of about 0.1 mm).

Bonded joints are used when the conventional connecting methods are not suitable or possible. They are used also for machine repairs.

9.3.2. Structure

(basic construction properties)

MANUFACTURING METHODS

By temperature and pressure necessary for solidification of adhesive:

- normal temperature – about 20° C
- higher temperature 20° ÷ 200° C
- high temperature – about 200° C
- high temperature – about 200° C and pressure

Preparation of clean surface:

- mechanically
- chemically
- removing impurities, fats, oxides

CONNECTED MATERIALS AND GLUES

Connected materials

Types:

- Metallic: in aeronautics or mechanical engineering for connecting tins, containers, frames, pipelines, hubs on shafts, etc.
- Non-metallic: in all fields for connecting wood, PVC, ceramic parts, thermosets, glass, etc.

Druh	teplota tuhnutí	tlak při tuhnutí	pevnost τ_{Pt} [MPa]
Polyester	norm.	ne	až 20
Polyvinylacetát	norm.– zvýš.	ne	až 30
Epoxid. pryskyřice	norm.– zvýš.	ne	až 30
Syntetický kaučuk	zvýš.– vysoká	ano	až 30
Fenolové pryskyřice	zvýš.– vysoká	ano	až 30
Fenolformaldehyd	zvýš.– vysoká	ano	až 30

Legend: druh – type, teplota tuhnutí – solidification point (temperature), tlak při tuhnutí – pressure on solidification, pevnost – strength, polyester – polyester, polyvinylacetát – polyvinyl acetate, epoxid. pryskyřice – epoxy resins, syntetický kaučuk – synthetic rubber, fenolové pryskyřice – phenolic resins, fenolformaldehyd – phenol formaldehyde, ne – no, ano – yes, normální –normal, zvýšená – higher, vysoká – high

Choosing by:

- type and dimensions of connected materials.
- method (drawing, shearing, bending) and type (static, dynamic) of load.
- operating temperature and chemical influence of environment.
- butt-welding – not suitable
- with sloping surface - better
- with bent sheet - suitable
- with contact element – suitable
- with adjusted surface – very good but expensive

9.3.3. Properties

UTILITY CHARACTERISTICS

Operation, maintenance, repairs

- suitable for transmitting relatively small loads in shearing stress, while even distribution of load is ensured (in the case of solid connected parts) compared to riveted or welded joints
- suitable for joints with tightness requirement
- suitable for joints with electric insulation requirements
- suitable for joints requiring vibration and noise attenuation
- not suitable for normal and dynamic loading
- not suitable for higher operation temperatures
- not suitable in aggressive environment
- do not require maintenance; impossible to dismount

Production, assembly

- suitable for connecting materials that cannot be heated up
- suitable for connecting materials that cannot be welded
- suitable for connecting thin sheets that cannot be welded or riveted
- suitable for connecting materials of different properties
- easy manufacturing
- relatively complicated preparation (cleaning of surfaces)
- requirement of necessary technical tools in the case of heat and pressure gluing

Other aspects

- degreasers can be inconvenient in terms of eco-friendliness and hygiene
- recycling almost impossible.

TIME CHARACTERISTICS

Speed of processes

- fast design
- simple structure enables fast connection of the parts
- solidification time can extend the production time (of seconds to hours)

COST CHARACTERISTICS

Economy of processes

- simple design reduces the costs of labour and material
- possible special technical tools for curing heat require additional costs
- zero operating costs if the impossibility to dismount the connection is not a problem

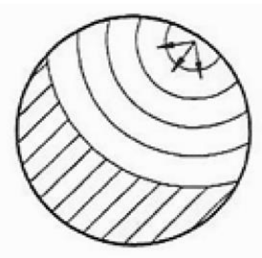
10. DYNAMIC (VARIABLE) LOAD AND STRESSING MACHINE PARTS TS – DYNAMIC (FATIGUE) STRENGTH

10.1. Basic information

Manifestations of dynamic (variable) load on the strength of machine parts:

- failures at stress σ<<σ D
- brittle fractures of parts even in the case of tough materials

Example of a typical fracture of a machine part (shaft, pivot, etc.) caused by fatigue
(the upper part of the section shows smoothed initial area of the disruption caused by material fatigue, the lower shaded parts shows the final classical granular static fracture



Dynamic load and stress is caused by:

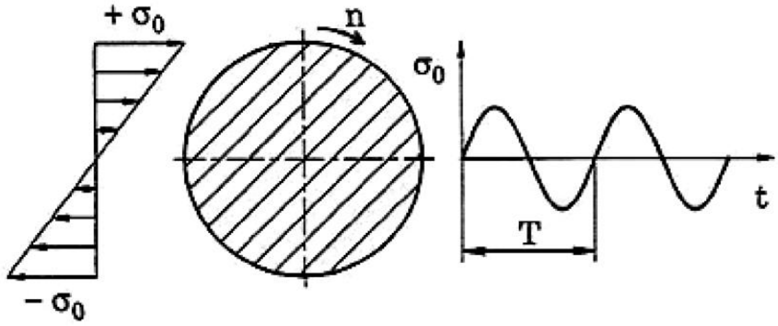
a) changes of external load:

Example: $Mo=Momax \cdot \sin(\omega \cdot t), n=0$

b) changes in the position of the part to constant (not variable) loading:

Example: $Mo=Momax´, n\neq 0$

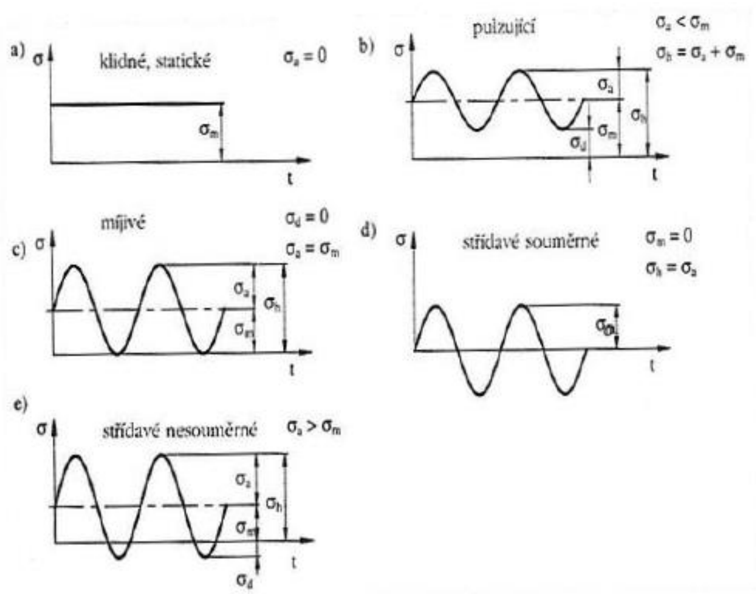
Dynamic load caused by rotation of the part to external static (constant) loading



Courses of variable load and stress:

- **general course:**
  = stochastic
  = periodic

- **harmonic course:**
  = sine/cosine with one or more harmonic components (usual also as an equivalent substitution of general periodic course for calculations and experiments)



Legend: klidné - still, statické – static, pulzující – pulsing, míjivé – fleeting, střídavé souměrné – alternating regular, střídavé nesouměrné – alternating irregular

Typical types of harmonic voltage – diagrams of curves

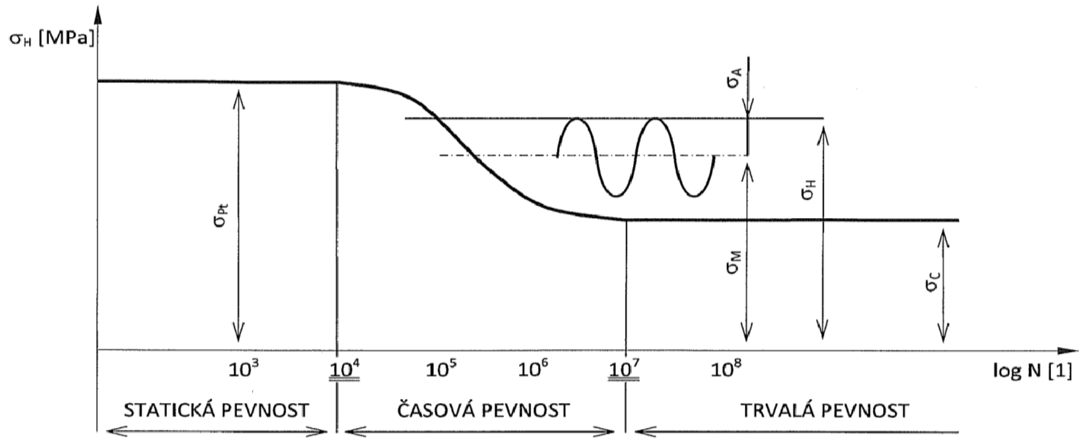
where: σ_m – medium voltage of the oscillation, σ_a – voltage of the oscillation amplitude, σ_h – oscillation upper voltage,
σ_d – low voltage of the oscillation

Lifetime (durability) of machine parts at harmonic stress:
Lifetime (durability) of a component is given by the number of oscillations at which a fatigue failure occurs.

10.2. Material fatigue limit

Fatigue time limit (time limit for fatigue of common machine part):
$\sigma N=\sigma M+\sigma AN$ ... oscillating voltage (□*M*, □*A*), at which the service life at the given mounting of the machine part is *N* cycles

Fatigue limit („"permanent" fatigue for common machine part):
$\sigma C=\sigma C=\sigma M+\sigma AN$... pulsating harmonic voltage, ($\sigma M\neq 0$, $\sigma A\neq 0$, tj. $\sigma H=\sigma M+\sigma A$, at which the lifetime of the given machine part *N* = □ cycles

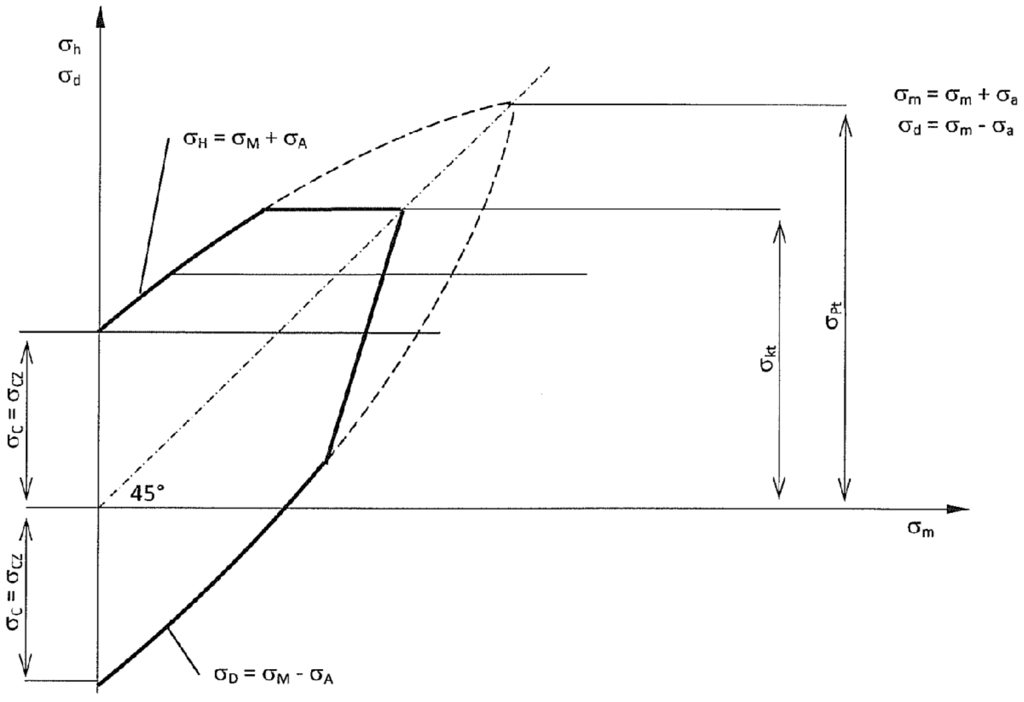


Legend: statická pevnost – static strength, časová pevnost – time strength, trvalá pevnost – time strength

10.3. Material fatigue limit at common harmonically changing voltage

Basic Smith chart:

Smith chart defines the limit parameters of harmonic voltage, i.e. the limiting medium voltage of the oscillation and limiting voltage of the oscillation amplitude at which the fatigue fractures of a smooth polished rod (generally a certain point on a common machine part). The chart must be experimentally determined for each material type (and point on a machine part) separately.



10.4. Factors influencing material fatigue

σC = σCZ … **(basic) fatigue limit** for smooth polished rod
σC= σCZ** … **lower (basic) fatigue limit** for a **point** on a component, i.e. **not for a component as a whole**) due to the factors given below

10.4.1. Notch effect – notch coefficient β

Notches are sudden changes in shape on components that cause local increase (concentration) of a "proper" load at the given point, causing:

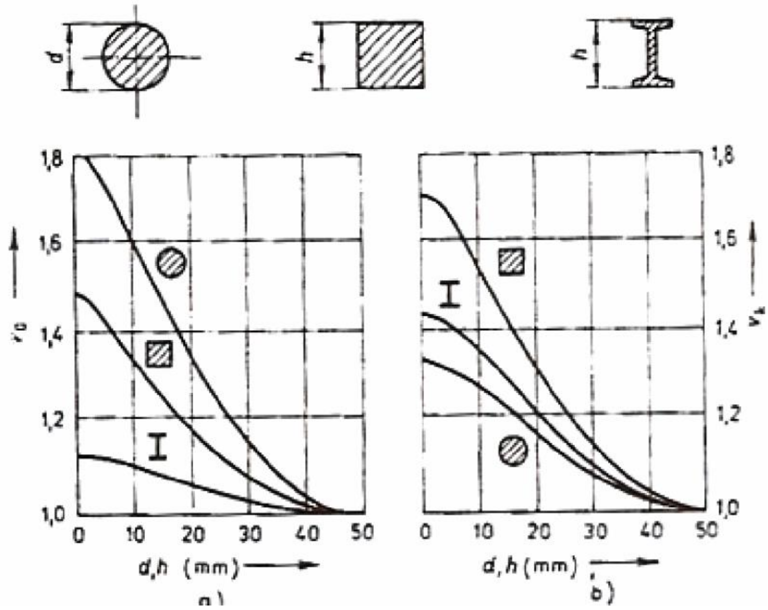
- reduction of strength
- reduction of material toughness

10.4.2. Component size effect – coefficient of component size ν

For basic types of stress:

$\sigma C*=\nu\cdot\sigma C$ … for tension – compression
$\sigma Co*=\nu\cdot\sigma Co$ … for bending
$\tau Ck*=\nu k\cdot\tau Ck$ … for torsion

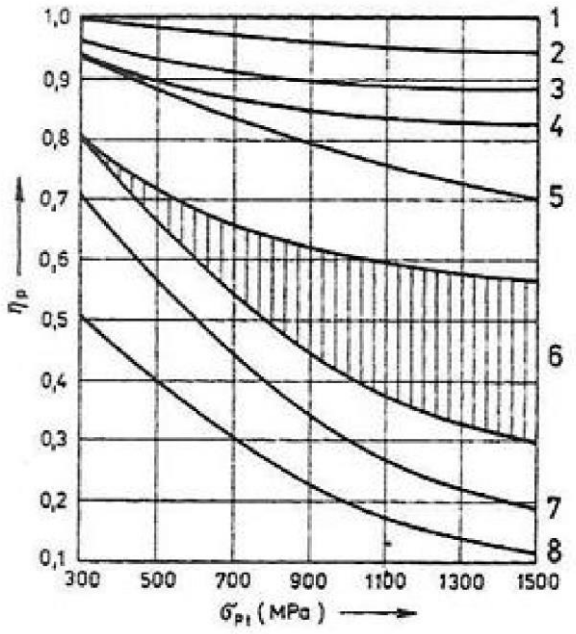
Examples of diagrams for determining the size component coefficient value ν



10.4.3. Surface quality effect – surface quality coefficient ηP

$\sigma C* = \eta p \cdot \sigma C$ … for tension – compression
$\sigma Co* = \eta po \cdot \sigma Co$ … for bending
$\tau Ck* = \eta pk \cdot \tau Ck$ … for torsion
$\eta po = \eta p$
$\eta pk = 0{,}5 \cdot (1 + \eta p)$

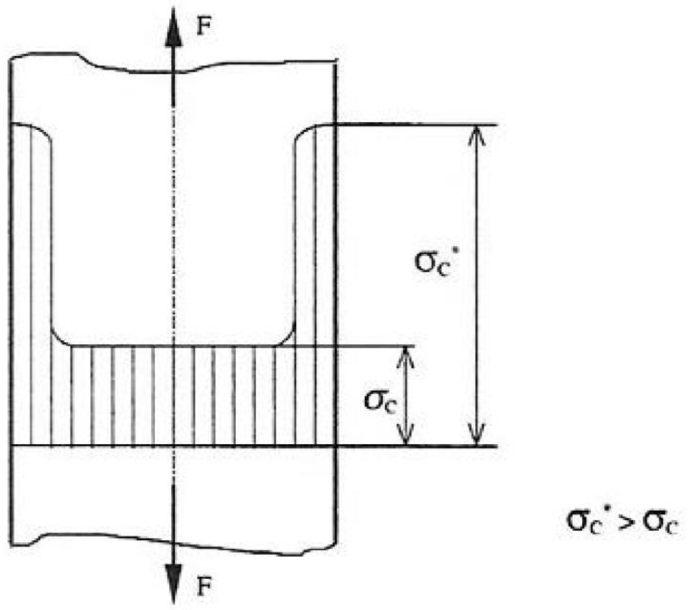
Diagram for determining the surface quality coefficient value *ηP*



10.4.4. Influence of surface reinforcement - coefficient of surface reinforcement k

$\sigma C{*}=k{\cdot}\sigma C$ … pro tah – tlak
$\sigma Co{*}=ko{\cdot}\sigma Co$ … pro ohyb
$\tau Ck{*}=kk{\cdot}\tau Ck$ … pro krut

Effect of surface-hardening on increasing the fatigue limit (critical for fatigue failures)



The values of coefficient *k* for the individual types of stress and typical hardening types must be sought in special professional literature. For a vast majority of non-hardened surfaces it holds true that:

$k = k_{ko} = k_k = 1$

11. SHAFTS

Shaft is a machine component of a cylindrical shape used for transferring rotating movement and mechanical work. On shaft, gear wheels, sprockets, pulleys, belt pulleys, castors, clutches, stop brakes, and other rotating and non-rotating parts, such as cams. Shafts can be divided into two groups by the function and stress: axles and transmission shafts.

Axles (machine shafts)

Axles (machine shafts) do not transmit any torque (performance). They are stressed only by bending. Axles bear gear wheels, belt pulleys, castors and other rotating machine parts that are mounted on them either rotating or fixed. Typical examples of machine shafts are railway machines axles.

Transmission shafts

Transmission shafts are also called drive shafts. They are more commonly used than the machine shafts. They are stressed mainly by torque, which they transmit from the point of drive to the point of work. Unlike the machine shafts, transmission shafts are stressed by torsion combined with bending. Shafts are pivoted in bearings. A typical example of transmission shafts is shaft in gearboxes, that is, all shafts that are powered.

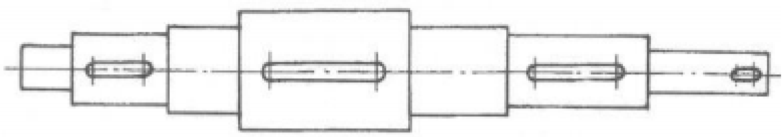
Types of transmission shafts

By shape and method of using:

- normal
- hollow
- slotted
- crankshafts
- flexible shafts

Normal transmission shaft

It is manufactured by turning, since the shaft stress varies over its length, as well as its diameter. The stress is lowest at the ends of the shaft, therefore their diameter is smallest. Changes in the shaft diameter cause various fittings facilitating mounting of the rotating parts on the shaft.



Hollow transmission shaft

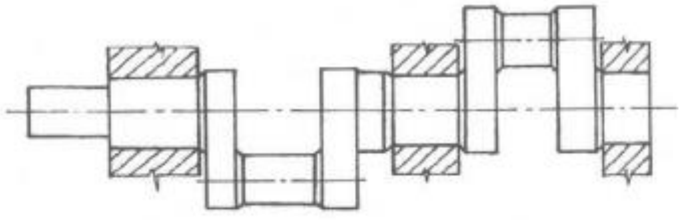
It uses material much more economically. It can transmit more load than a full shaft at the same weight. This is due to the fact that when subjected to torsion and bending, the center of the shaft is much less stressed than its outer part.

Slotted transmission shaft

It has longitudinal grooves on its length, actually producing several springs. Slotted shaft thus has the same function as keyed joint. It is used where we need to ensure axial displacement of rotating parts on (mostly) gear wheels on the shaft.

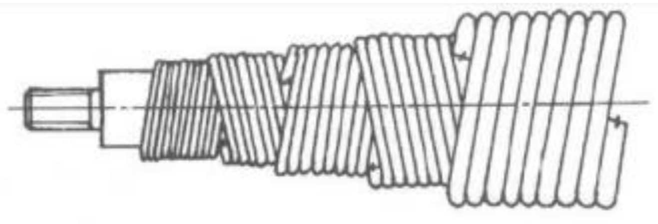
Crankshaft

It is a part of a crank mechanism changing the direct reciprocating movement to rotating and vice versa. Crankshafts are manufactured of forget blanks and then finished by machine tools.

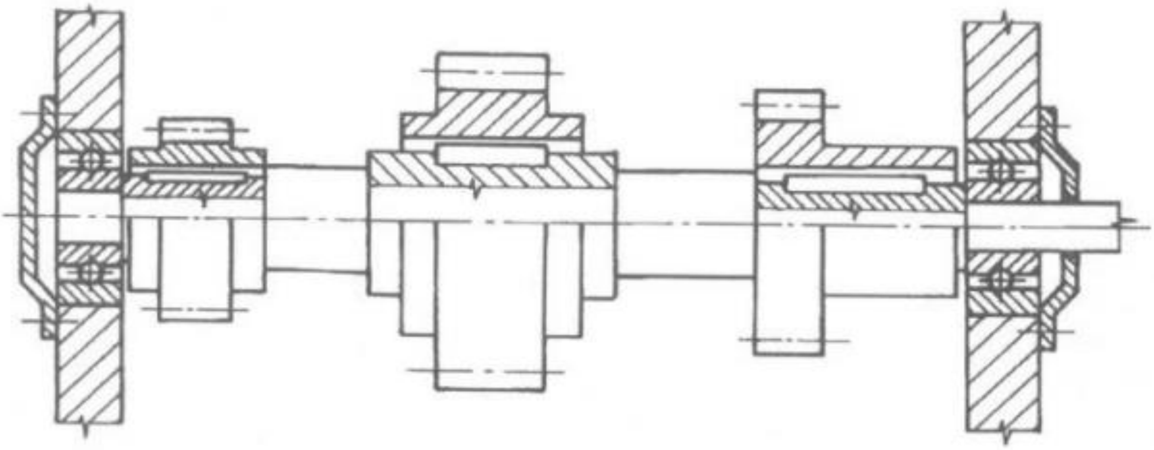


Flexible shaft

It is used where it is necessary to change the position of the driving shaft to driven shaft during the rotation. To ensure the necessary flexibility, the shaft is manufactured of wire in several layers. The individual layers are wound in opposite directions so that the shaft does not tend to unwind. E.g. hand grinder.



Placing of transmission shafts



Example of placing transmission shaft on two rolling bar bearings

12. PLAN BERARINGS

Characteristic

(typical construction properties)
Rotating bearings on the principle of surface contact with sliding friction (of different type).

Notes:

- Types of sliding friction (by the lubrication intensity):
  = static friction: without lubricant or with solid lubricant (graphite, etc.), friction surface areas are in full contact
  = limiting friction: with insufficient layer of lubricant, friction surface areas are in partial contact
  = fluid friction: dostatečná vrstva maziva (kapalina, plyn, příp. plast. mazivo), třecí plochy se nedotýkají
- The related effect is the wear condition of sliding surfaces depending on the intensity of lubrication.

12.1. Bearing with hydrodynamic bearings

12.1.1. Characteristic

(typical construction properties)
Sliding rotary bearings where the layer of lubricant (so called hydrodynamic wedge) is generated by the relative movement of sliding surfaces (creating wedge gap). Therefore, the so-called limiting friction with the beginning or end of movement under static friction during the acceleration and deceleration.

SHAPES, DIMENSIONS, SURFACE ROUGHNESS AND TOLERANCE

A) Sliding surfaces

Geometrical shape

It is achieved by machining (drilling, turning, grinding) without additional scratching (it affects the geometrical shape).
At higher parameters: geometrical shape accuracy is prescribed.

Surface roughness

Operating conditions - roughness Ra: of the bearing pin [μm]

- high parameters 0,2 0,4
- medium parameters 0,4 0,8
- low parameters 0,8 1,6

Tolerance

Accuracy at radial plain bearings IT5 ÷ IT7

B) Lubricant inlet

Shapes and dimensions:

Lubrication holes, slots, pockets according to ČSN 01 5906 (always shallowe with rounded shapes)

Position of lubrication grooves at radial bearings:

In an unloaded area (perpendicular to the direction of the motion, never to the edges)

C) Bearing housing and bearing case (radial bearings components)

Notes:

- Housing: plain bearing insert in the shape of a hollow cylinder.
- Case: a part of split sleeve, or the whole but split sleeve.

Types of housing and cases:

by the thickness of sleeve/case, diameter of the pin d:

- thin-walled: thickness *s* (0.02 ÷ 0.1)·*d*

(it is machined: finished before mounting – accuracy depends on the accuracy of boring in the bearing housing)

- thick-walled: thickness *s* (0.1 ÷ 0.2)·*d*

(machined: finished as the thin-walled, with additional machining)

by the number of layers:

- single-layer ("massive"): from bearing materials, only exceptional (it is costly)
- double-layer ("bimetallic"): with liner, of bearing materials (thickness 0.2 mm),

lifetime of bearing increases with decreasing thickness of liner

- three-layer: with additional galvanic coating of a soft composition (Pb - Sn, etc.), which enables to use non-hardened pins.

Position of cases and housings (in the body of bearings)

With an overlap ensuring reliable transmission of a friction moment in the bearing are used only to ensure the proper position during the assembly)
Usual position: H7/p6, H7/r6, H7/s6 (in the case of thin-walled it is given by the measuring on the circumference)

MATERIAL

Types of bearings materials

Material class $p \cdot v$ [MPa· m· s-1]

- tin and lead alloys (compound) 20 ÷ 100
- copper alloys with tin, lead, etc.(bronze) 20 ÷ 100
- aluminium alloys 20 ÷ 100
- other metals (grey cast, porous metals) 10
- plastics 10 ÷ 30
- other non-metallic material (graphite, rubber, wood)

Choosing bearing material

Choosing bearing material, as well as the construction and lubrication properties, is a key factor for reliability and lifetime of bearings.

Main criteria:

Outer bearing properties (required):

= type and size of load, sliding speed, lifetime
= operating temperature, type of lubricant, environment
= price

Bearing construction properties (recommended):

= type and hardness of the pin material (at least 100 HB higher than the hardness of the bearing material)
= roughness of sliding surfaces (by the recommendation above)
= type and quantity of lubricant (sufficient quantity of quality lubricant (without impurities) – except for oiliness and oilless bearings)

Sliding, mechanical and physical properties of bearing materials (optional):

= galling resistance (compatibility with the pin material), hard particles adaptability and JÍMAVOST, friction coefficient.
= load (characterized by coefficient $p \cdot v$), fatigue strength, ...
= corrosion resistance, abrasion resistance, hardness, ...

12.1.2. Properties

Operation, maintenance, repairs

- capturing radial or axial displacements and forces; however, both functions can be ensured by proper construction within one unit (see above)
- suitable for impact and dynamic load (high attenuation)
- very quite and smooth operation without vibrations
- clearance in the bearings ("float") can be a defect
- especially suitable for permanent operation (at the beginning and end of movement there is no hydrodynamic lubricant layer – static and limiting friction with high wear, can be improved by pressure lubrication x it is more expensive)
- wider than at roller bearings
- smaller outer diameter than at roller bearings
- Easy dismounting is given by the structure of the bearing
- higher requirements for maintenance and purity (lubrication and oil purity)

Production, assembly

- high requirements for precision of manufacturing and cleanliness of environment
- easy assembly is influenced by the structure of load-bearing part

TIME CHARACTERISTICS

Processes speed

- time-consuming design, manufacturing, maintenance, repairs, etc.

COST CHARACTERISTICS

Economy of processes

- relatively costly design and manufacturing
- relatively costly operation, maintenance and repairs

13. BALL BEARINGS

Characteristics

(typical construction properties)
Rotating bearings on the principle of rolling contact with rolling friction usually using separately manufactured component – rolling bearing.

SHAPES (TYPES) OF BALL BEARINGS (ČSN 02 4629)

By the direction of the captured forces (and movements)

(A) **radial** (outer and inner ring, cage, rolling body)
(B) **axial** (rings, cage, rolling body)

By structure (the basis is the shape of rolling body)

(A) **Standard bearings**

- Single row ball bearings a)

= purely radial 1 ÷ 6
= with angular contact 7 ÷ 9

- Double row ball bearings b)

= with angular contact 1
= tilting 2 ÷ 4

- Roller bearings c)

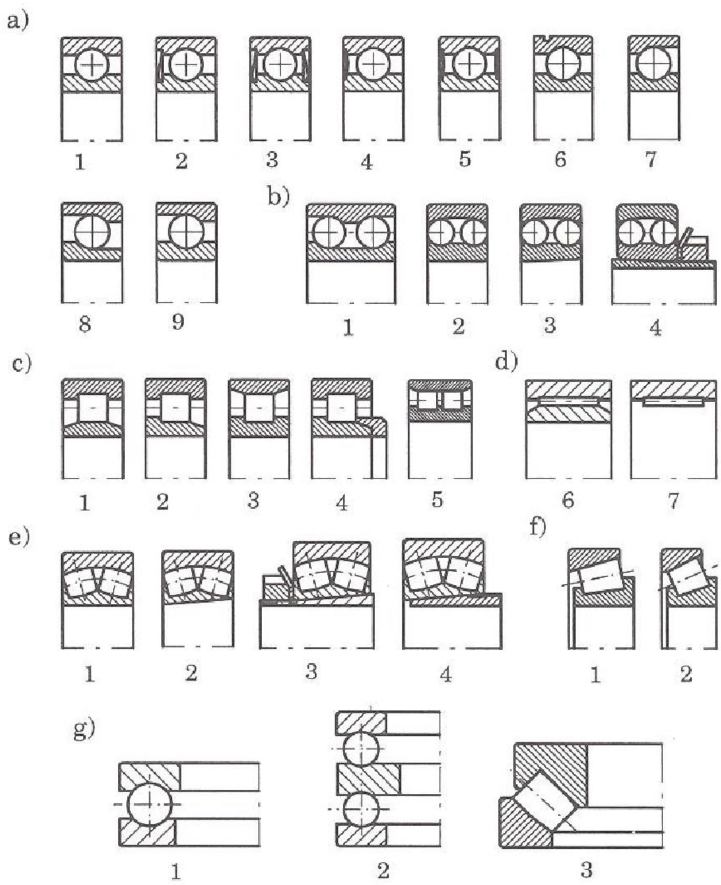
= single row(NU, NJ, N) 1 ÷ 4
= double row (NN with conical hole) 5

- Needle bearings d)

= single row 1
= single row without inner ring 2

- Double row spherical e) … 1 ÷ 4
- Roller f) ….1 ÷ 2
- Axial g)

= ball one-directional 1
= ball bi-directional 2
= roler 3



(B) **Special bearings**

- Ball bearings a)

= with a four-point contact 2

- Roller b)

= multi-row 1

- Needle c)

= cage with needles 1

= case with needles 2

- Axial d)

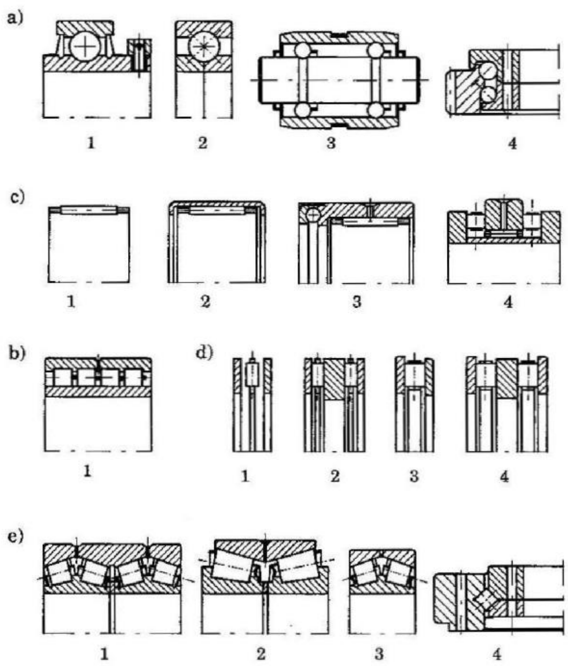
= needle 1 a 2

= roller 3 a 4

- Tapered e)

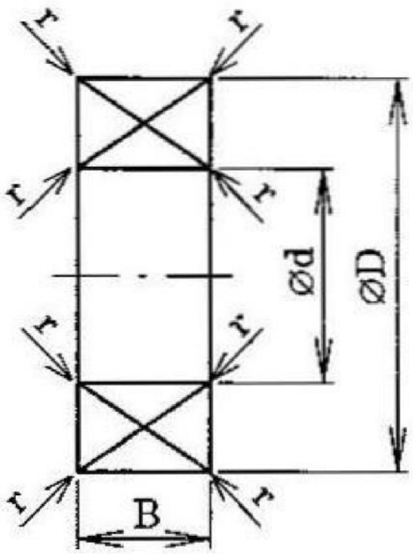
= multi-row 1, 2, 3

= cross 4



DIMENSIONS OF ROLLING BEARINGS (ČSN 02 4629)

Basic dimensions:



ød … inner diameter
øD … outer diameter
B … width
r … radius of curvatore

Dimensional series

Individual types of bearings in dimensional series: *d* ⇨ *D, B, …*⇨

Notes:

- for *d: 20 ÷ 480 mm:*

d = (last two digits in the marking according to ČSN) x 5
e.g.: 6220 ⇨ d = 20 x 5 = 100 mm

ACCURACY OF DIMENSION AND RUNNING OF BALL BEARINGS
(ČSN 02 4612) (ČSN ISO 492)

Tolerance:

- dimensions
- throwing at turning:

= radial for radial bearings
= axial for axial bearings

POSITION OF BALL BEARINGS

Important for lifetime of ball bearings.

Factors influencing the position choice:

- size and type of load
- material and toughness of parts
- heat conditions in bearings
- dilatation of components
- precision requirements
- assembly and dismounting requirements

Rules and recommended mounting:

- Ring rotating in the loading direction (circumferential loading) must be fixed (to prevent rolling):
    - (J7, K7)/ j6, k6
    - (outer ring hole – more common / pin for inner ring – more common

- Ring not rotating in the loading direction can be mounted freely / with clearance (point load)

- H7, H8 (G7)/(h6, g6)
- (outer ring hole – more common, pin for inner ring)

MATERIAL OF BALL BEARINGS

Rings and rolling bodies

High requirements (local alternating voltage); therefore besides high static strength and exact composition, there are high homogeneity requirements.
Usually: chrome steel class 14, hardened and tempered to min. hardness 59 HRC

Cages

Usually pressed from steel sheet.
Quality bearings have brass or ceramic material cages.

UTILITY CHARACTERISTICS

Operation, maintenance, repairs

- Capturing radial and axial displacements and forces by the type of bearings and its mounting on / in both parts of the machine (usually on the shaft and in the case) at high revolutions and temperatures.
- Not suitable for impact loading.
- Clearance in bearing can be a defect.
- Low losses, efficiency η 0,98.
- Small longitudinal dimensions compared to other types of bearings.
- Larger diameters compared to other types of bearings.
- Simplicity or complexity of replacing bearings is influenced by the structure of the load-bearing and mounted part; usually simple.
- Low maintenance requirements (lubrication by grease or oil for toothing lubrication).

Production, assembly

- Manufacturing requires precision, bearings are purchased.
- Simplicity or complexity of assembly is influenced by the structure of the load-bearing and mounted part; usually simple.

TIME CHARACTERISTICS

Processes speed

- Relatively fast design, production (and purchase), assembly and dismounting.

COST CHARACTERISTICS

Economy of processes

- With a suitable design, manufacturing is relatively cheap (much cheaper in case of mass production).
- Low operating costs (lubricants).
- Low dismounting costs.

14. SHAFT COUPLINGS

14.1. Characteristic

(typical construction properties)
Machine parts enabling the transmission of torque and movement between two adjacent rotating parts of a technical equipment (system), with their axles being:

- parallel
- slightly concurrent
- slightly skew

This function is often combined with other functions (those usually being the main functions):

- to reduce the transmitted torque
- to dampen torsional oscillations
- to enable manufacturing of large part
- to enable assembly and dismounting
- to eliminate changes in position of the parts connected (due to geometric inaccuracies, malleability, thermal expansion, etc.)

Based on the principle and method of transmitting torque and rotation (i.e. by functioning / working principle and method), coupling can be divided into:

14.1.1. Mechanical couplings

Non-disconnected (permanently connected in the operation):

- (non-flexible) rigid (tubular, trough, flange/disc, with spur)
- (non-flexible) leveling (tubular, pin, toothed, with cross disc, with joints, toothed)
- flexible (disc, with integrated flexible bodies, with inserted flexible bodies, ring and disc, with metal springs, membrane)

Controlled (mechanically, hydraulically, pneumatically, electromagnetically) with changes in connection controlled from the coupling neighbourhood:

- toothed (front, cylindrical)
- friction (disc, vanes)

Automatic / **semi-automatic**, with changes in connection directed fully / partly by the coupling

- insurance (destructive, sliding, sliping)
- starting (powder, segment)
- idle (axial principle, radial principle)

14.1.2. Hydraulic couplings

Hydrodynamic

- with closed ring (uncontrolled, self-controlled, controlled)
- with open ring

Hydrostatic

14.1.3. Electric couplings

Asynchronous

- with swirl armature
- with cage armature

Synchronous

14.1.4. Magnetic couplings

Notes:

- The classification is embedded in ČSN 02 6400, in the case of mechanical couplings a more suitable functional structure and labelling is used.

By ensuring sub-functions, couplings consist of the following parts:

- **driving (propulsion) part** (connected with driving part of the technical system)
- **driven part** (connected with driven part of the technical system)
- **connecting part** (connection between the driving and driven part of the coupling)

If the coupling is "symmetrical" (in terms of dimensions, weight, function), the division of the shaft into driven and driving part is determined only by the selected orientation in the technical system. However, in the case of many types of "non-mechanical" couplings, the right distinguishing between the driving and driven part of the coupling (to driving and driven part of the technical system) a necessary condition for ensuring their proper functioning).

Notes:

Due to their easy classification, couplings are most designed, manufactured and delivered as components. This applies to all types of mechanical, “non-mechanically” (= electromagnetically, hydraulically and pneumatically) controlled couplings and partly also for hydraulic, electric and magnetic couplings used in special cases.

Information for using mass-produced couplings shall be sought in the manufacturer´s catalogue or in professional literature. From now on, only commonly used mechanical couplings are considered, with a focus on the individually designed and manufactured types.

14.2. Fixed (rigid) couplings

14.2.1. Fixed (rigid) couplings in general

Characteristic

(typical construction properties)
Couplings on the principle of fixed connections preventing all relative movements of connected rotating parts (usually shafts).

Properties of common couplings

UTILITY CHARACTERISTICS

Operation, maintenance, repairs

- Transmission even of periodically changing torques
- Possibility of transmission of bending moments
- In operation, non-alignment of connected parts can generate additional loads leading to coupling damage

Production, assembly

- Relatively easy production
- Assembly is relatively complex, precise alignment of the connected part is always necessary; some types also require the possibility of axial displacement of (at least one) connected parts

TIME CHARACTERISTICS

Processes speed

- Fast design and production (purchase)
- Assembly and dismounting can be slow (time-consuming, complicated)

COST CHARACTERISTICS

Economy of processes

- Relatively cheap
- Zero operating costs

14.3. Levelling (rigid dumping)

14.3.1. Levelling (rigid dumping in general

Characteristic

Typical construction properties
Couplings on the principle of (rigid) kinematic pairs enabling changes in relative position of connected parts.

Properties of common couplings
(properties)

UTILITY CHARACTERISTICS

Operation, maintenance, repairs

- Transmission of torque when enabling axial, radial angular or combined deviation of axles of connected rotating parts
- Usually require lubricating

Production, assembly

- Simplicity or complexity of production depends on the type of coupling
- Usually relatively easy assembly

TIME CHARACTERISTICS

Processes speed

- it depends on the type of coupling; usually fast assembly and dismounting

COST CHARACTERISTICS

Economy of processes

- Production costs depend on the type of coupling
- Operating costs are given by the necessity of maintenance, especially lubricating

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