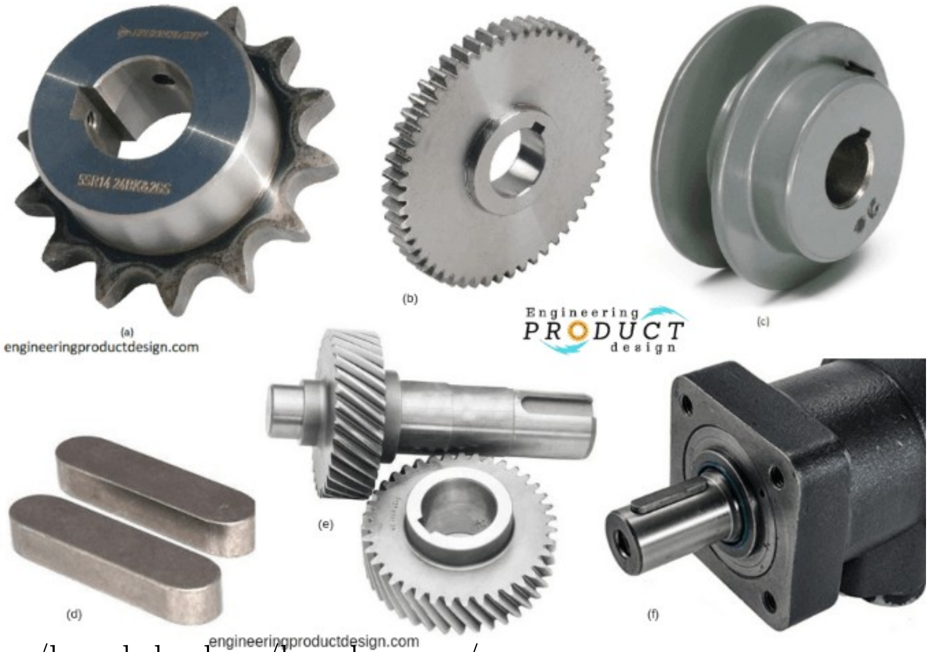
Miscellaneous Components - Keys

- Keys - Keys are used on shafts to secure rotating elements, such as gears, pulleys, or other wheels. They enable the transmission of torque from the shaft to the shaft-supported elements

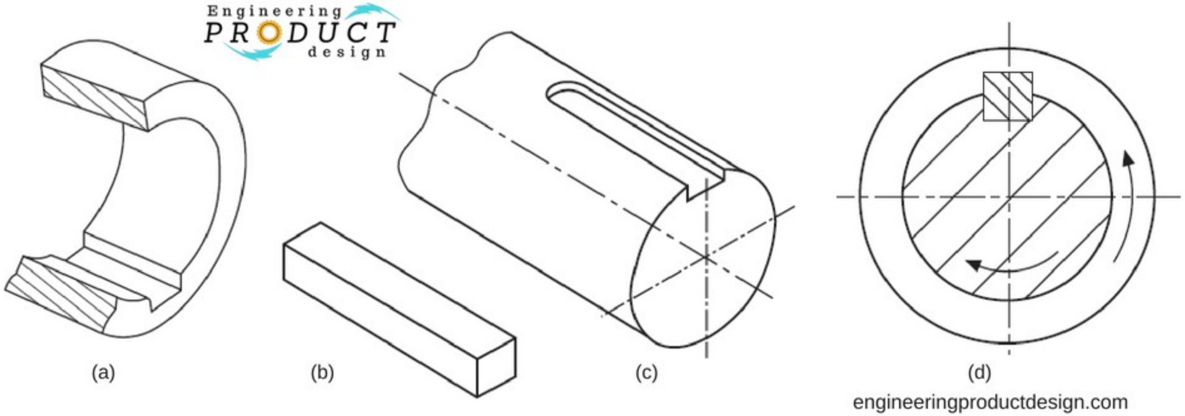
- The ASME defines a key as "a demountable machinery part which, when assembled into keyseats, provides a positive means for transmitting torque between the shaft and hub."



https://engineeringproductdesign.com/knowledge-base/keys-keyways/

Keyed Joint

Nomenclature



Keyway Key Keyseat Keyed joint

Advantages

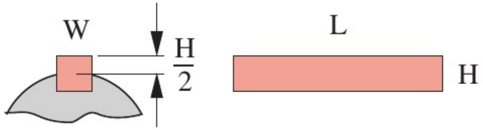
- Cheap manufacturing cost
- Well-standardized
- Medium to high torque transmission
- Reusable

Disadvantages

- Not suitable for alternating directional loads and shocks
- Possible axial displacement of hub unless locked by an extra component such as a set screw or retainer rings
- Over time keyed joints might become very difficult to dismantle
- Keyways introduce stress points due to the notch effect and reduce shaft strength
- Introduces shaft imbalance

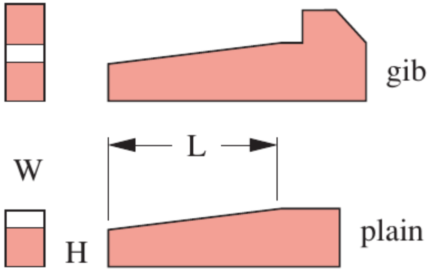
https://engineeringproductdesign.com/knowledge-base/keys-keyways/

Types of Sunk Keys



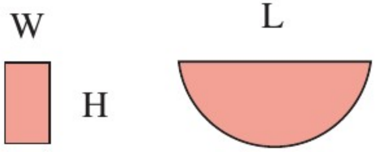
(a) Parallel key

A **parallel** key is square or rectangular in cross section and of constant height and width over its length. The parallel key is placed with half of its height in the shaft and half in the hub.



(b) Tapered keys

A **tapered** key is of constant width but its height varies with a linear taper of 1/8 in per foot, and it is driven into a tapered slot in the hub until it locks. It may either have no head or have a gib head to facilitate removal.



(c) Woodruff key

A **Woodruff** key is semicircular in plan and of constant width. It fits in a semi-circular keyseat milled in the shaft with a standard circular cutter. Woodruff keys are used on smaller shafts. The penetration of a Woodruff key into the hub is the same as that of a square key, i.e., half the key width.

Norton, Machine Design – An Integrated Approach

Dimensions of Keys

Parallel Key

Shaft Diameter (mm)	Key Width x Height (mm)
$8 < d \leq 10$	3 x 3
$10 < d \leq 12$	4 x 4
$12 < d \leq 17$	5 x 5
$17 < d \leq 22$	6 x 6
$22 < d \leq 30$	8 x 7
$30 < d \leq 38$	10 x 8
$38 < d \leq 44$	12 x 8
$44 < d \leq 50$	14 x 9
$50 < d \leq 58$	16 x 10
$58 < d \leq 65$	18 x 11
$65 < d \leq 75$	20 x 12
$75 < d \leq 85$	22 x 14
$85 < d \leq 95$	25 x 14

Square keys

Key length should be less than about 1.5 times the shaft diameter to avoid excessive twisting with shaft

The width of a tapered key for a given shaft diameter is the same as for a parallel key as shown in the table. The taper and gib-head size are defined in the standard.

Woodruff keys width as a function of shaft diameter are essentially the same as those for square keys shown in the table. The other dimensions of the Woodruff keys are defined in the standard.

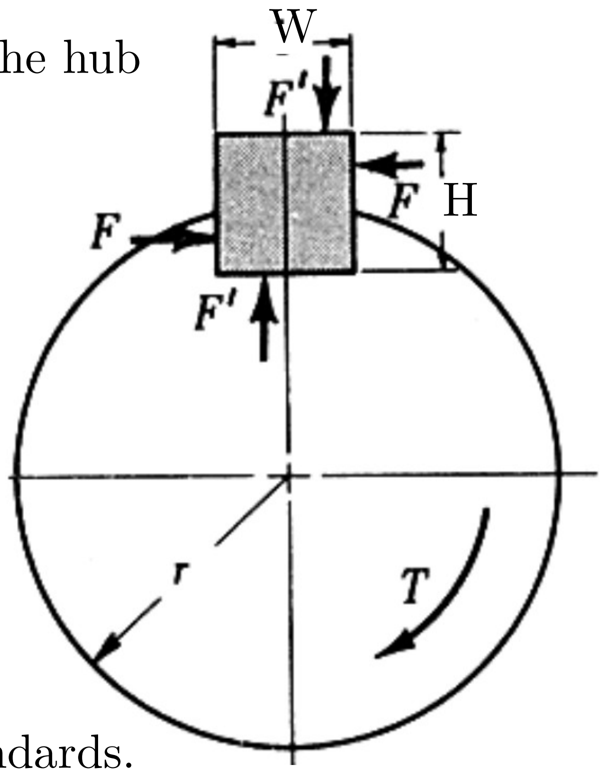
Norton, Machine Design – An Integrated Approach

Design of Keys

Failure Modes of Keys

Shear Failure – key is sheared across its width at the interface of the hub and the shaft

Crushing Failure – crushing of either side in compression



F – applied force acting on the key. $F \sim T/r$

T – torque transmitted by the shaft

r – radius of the shaft

F' – responsible for creating a resisting couple

L – length of the key

W – width of the key

H – height of the key

<u>W and H are chosen as per the diameter of the shaft – from the standards.</u>

<u>The design variables are: L and the number of keys.</u>

<u>Key materials</u>: Because keys are loaded in shear, ductile materials such as low carbon steel are used

Design of Keys

Square/Rectangular keys

Shear Failure: The average shear stress due to direct shear is

$$\tau = \frac{F}{A_{shear}} = \frac{F}{LW} = \frac{T}{rLW}$$

Crushing Failure: The average compressive stress due to compressive load is

$$\sigma_c = \frac{F}{A_{crush}} = \frac{F}{L(H/2)} = \frac{2T}{rLH}$$

Torque carrying capacity from shear failure point of view:

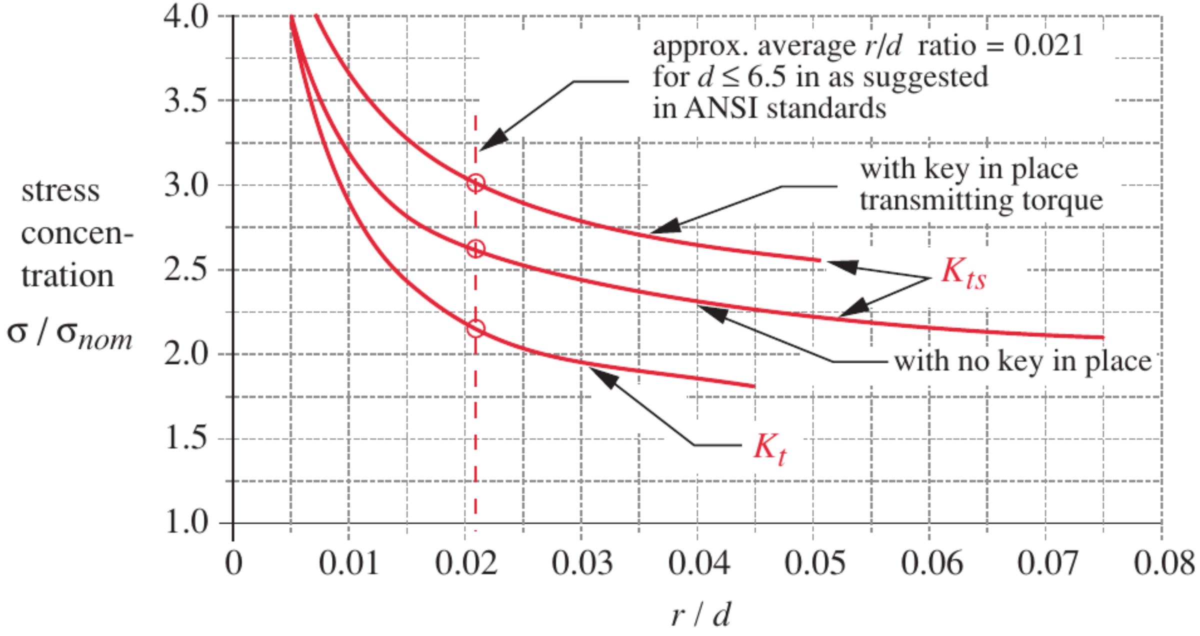
$$T_s = \tau_y rLW = \frac{\sigma_y}{\sqrt{3}} rLW$$

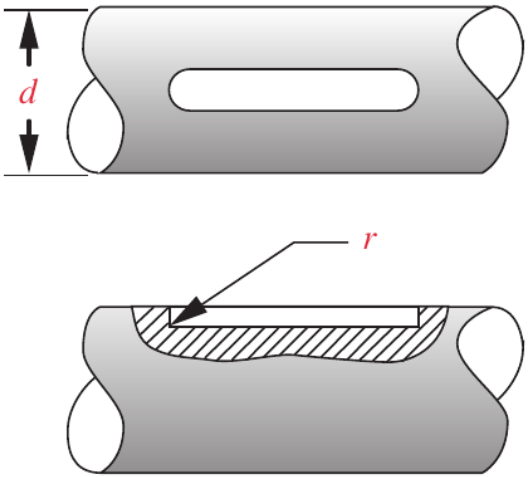
Torque carrying capacity from crushing failure point of view:

$$T_c = \frac{1}{2}\sigma_y rLH$$

Torque carrying capacity $= \min(T_s, T_c)$

Stress-Concentration Factors for an End-Milled Keyseat in Bending (K_t) and Torsion (K_{ts})





Norton, Machine Design – An Integrated Approach

Design of Keys

A steel shaft with yield strength of 517 MPa, has a diameter of 36.0 mm. The shaft rotates at 600 rpm and transmits 30 kW through a gear. Select an appropriate key for the gear, with a factor of safety of 1.5.

Material Selected: Low carbon steel with yield strength of 372 MPa (softer than than the shaft material)

From the table: For d = 36.0 mm, $W = 10$ mm, $H = 8$ mm, FOS = 1.5

Transmitted torque $T = P/\omega = 477.5$ Nm

Shear failure:

$$L_s = \frac{2\sqrt{3}T \times FOS}{dW\sigma_y} = 18.6 \text{ mm}$$

Crushing failure:

$$L_c = \frac{4T \times FOS}{dH\sigma_y} = 26.8 \text{ mm}$$

Length of the key $L = \max(L_s, L_c) = 26.8$ mm

Steps in Keyed Joint Design

- **Determine Load Requirements**:
  Calculate the torque and power the key needs to transmit.
- **Select Key Type**:
  Choose the appropriate key type based on the application requirements and load conditions.
- **Material Selection**:
  Select a material with adequate strength and wear resistance
- **Dimension Calculation**:
  Use standard dimensions for key width and height based on shaft diameter.
  Ensure the key length is sufficient to transmit the required torque without shearing and crushing
- **Keyway Design**:
  Design the keyway in both the shaft and the hub to match the key dimensions.
  Ensure proper fit and alignment.
  - Use appropriate machining methods like milling or broaching to create the keyways.
- **Stress Analysis**:
  - Perform a stress analysis to ensure the key can handle the operational loads without failure.
- **Prototype and Testing**:

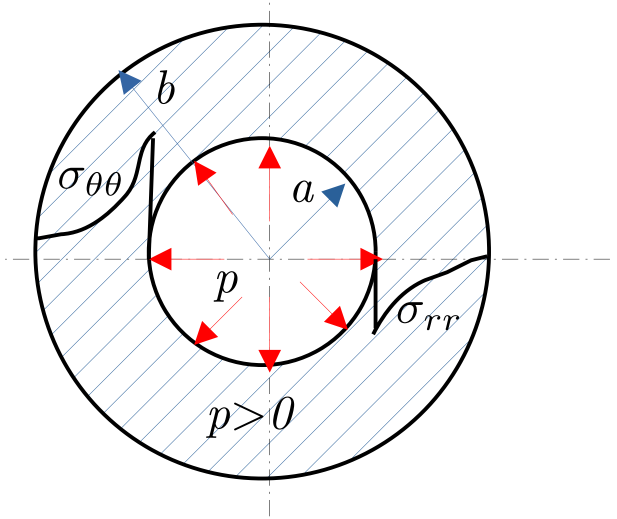
Types of Keys and Usage

Key type		Shaft key usage
Sunk keys	Rectangular keys	A rectangular key is generally used for shaft diameter between 1″ (25 mm) and 20″ (500 mm)
		Generally, these have a reduced effect on the shaft due to its shallow keyway depth
	Square keys	A square key is used if the deeper key depth is required to transmit torque. But ensure the weakened shaft can support the load.
		A square key is used for shafts diameter up to and including 1″ (25 mm)
	Parallel sunk keys	Parallel sunk keys are widely available and are one of the easiest to install
		If possible, use set screws in the hub to hold it down to stop it from sliding out during operation
	Gib head sunk keys	These are very similar to rectangular/parallel keys, but it is easier to remove due to the head
	Feather keys	Feather keys allow the hub to move axially while transmitting the rotational torque
	Woodruff keys	Use it for lower loads and can accommodate any tapered shafts/hub connection.
Saddle keys		Only use it for very light unidirectional loads
Tangent keys		Can be used on slow bi-directional large torque applications.
		Not recommended for high frequency directional change
Round / Circular Keys		Used only for very low torque and speeds
		It can be fitted by drilling and reaming the shaft and hub assembly together
		Key diameter to be approximately sixth of the shaft diameter

https://engineeringproductdesign.com/knowledge-base/keys-keyways/

Preliminaries – Press and Shrink Fits

Thick hollow cylinder subjected to internal pressure p

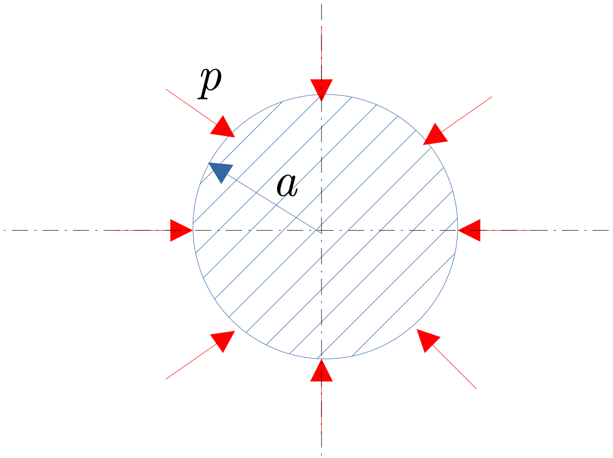


$$u_r = \frac{1}{2\mu}\left((1-2\nu)\frac{pa^2}{b^2-a^2}a + \frac{pa^2b^2}{b^2-a^2}\frac{1}{a}\right)$$

$$\sigma_{rr} = \frac{pa^2}{b^2-a^2}\left(1-\frac{b^2}{r^2}\right)$$

$$\sigma_{\theta\theta} = \frac{pa^2}{b^2-a^2}\left(1+\frac{b^2}{r^2}\right)$$ Since $\frac{b^2+a^2}{b^2-a^2} > 1,\ (\sigma_{\theta\theta})_{max} > p$

Solid cylinder subjected to external pressure p

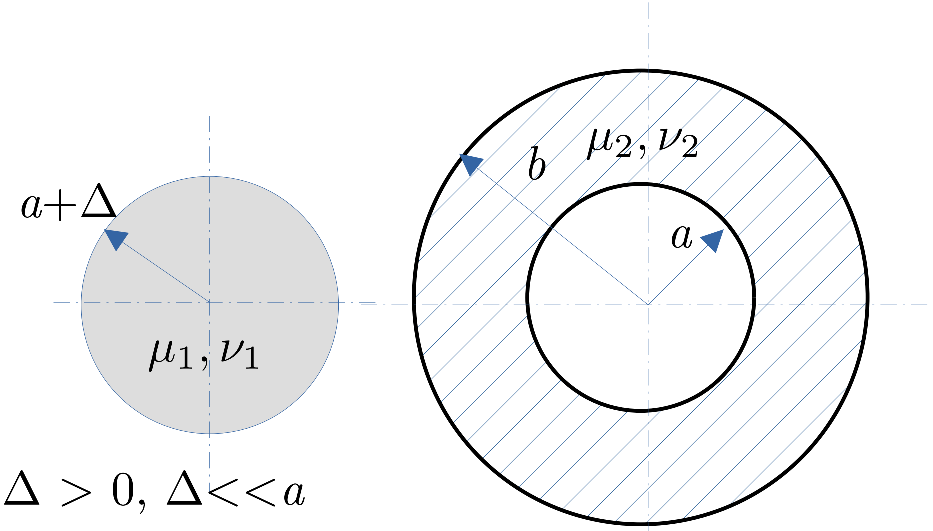


$$u_r = -\left(\frac{1-2\nu}{2\mu}\right)pr$$

$$\sigma_{rr} = \sigma_{\theta\theta} = -p$$

Press/Shrink/Interference Fits

- **Press Fits**: When two cylindrical parts are assembled by shrinking or press fitting one part upon another
- Can sometimes be used effectively to minimize the need for shoulders and keyways.
- The stresses due to an interference fit can be obtained by treating the shaft as a cylinder with a uniform external pressure, and the hub as a cylindrical part with uniform internal pressure
- The pressure is a function of interference, material properties and geometric properties
- From the results presented in the previous slide and the compatibility equation $a + \Delta + u_{r1} = a + u_{r2}$ or $\Delta = u_{r2} - u_{r1}$ the expression for the interface pressure is given by



$\Delta > 0,\ \Delta << a$

$\delta = 2\Delta$ – diametrical interference

Interface pressure

$$\tilde{p} = \frac{\mu_1 \delta / a}{(1 - 2\nu_1) + \frac{\mu_1}{\mu_2}\left(\frac{1+(a/b)^2}{1-(a/b)^2} - 2\nu_2 \frac{(a/b)^2}{1-(a/b)^2}\right)}$$

Torque carrying capacity of press or shrink fit

$$\begin{aligned} T &= F_f a \\ &= f(2\pi a L \tilde{p}) a \end{aligned}$$

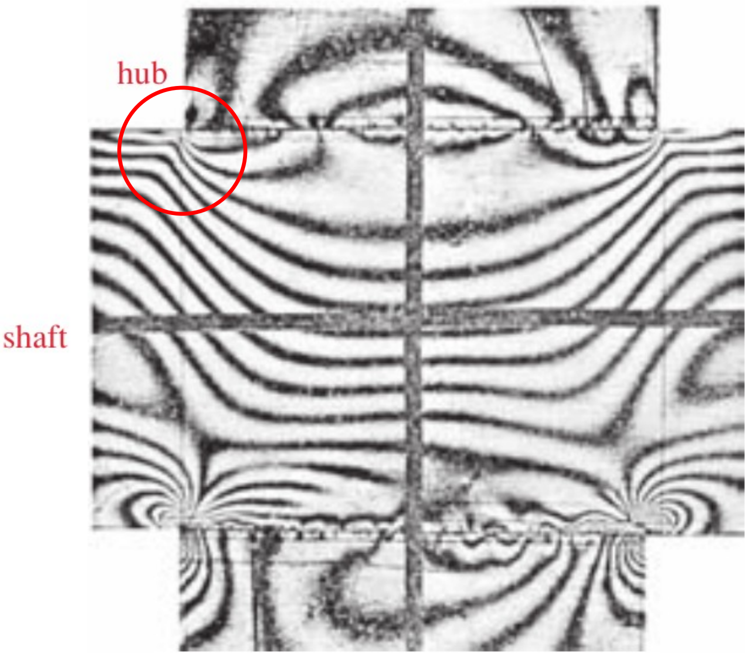
$$T = 2\pi f \tilde{p} L a^2$$

Typical values of the friction coefficient f $\quad 0.15 \leq f \leq 0.20$

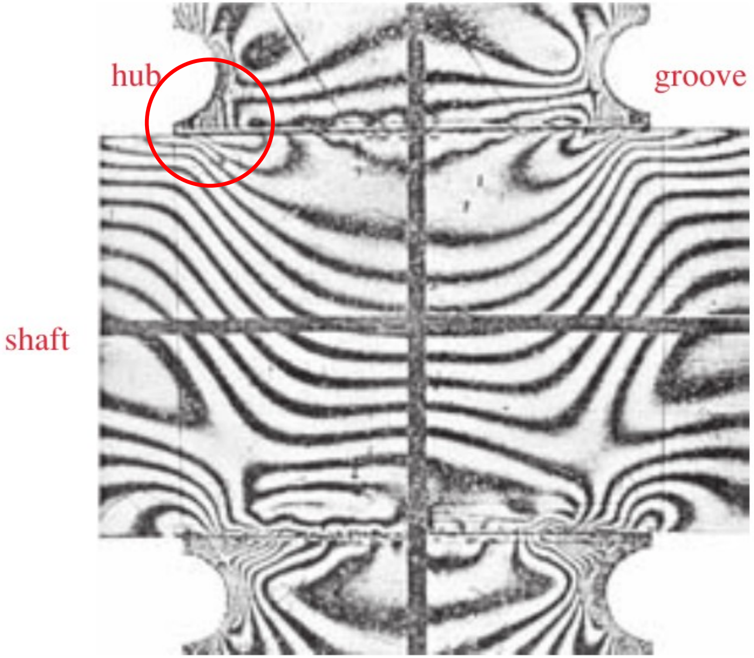
L – length of the hub

Press/Shrink/Interference Fits – Stress Concentration Effects

A press fit creates stress concentrations in the shaft and hub at the ends of the hub due to the abrupt transition from uncompressed to compressed material.



A Plain Press-fit Assembly



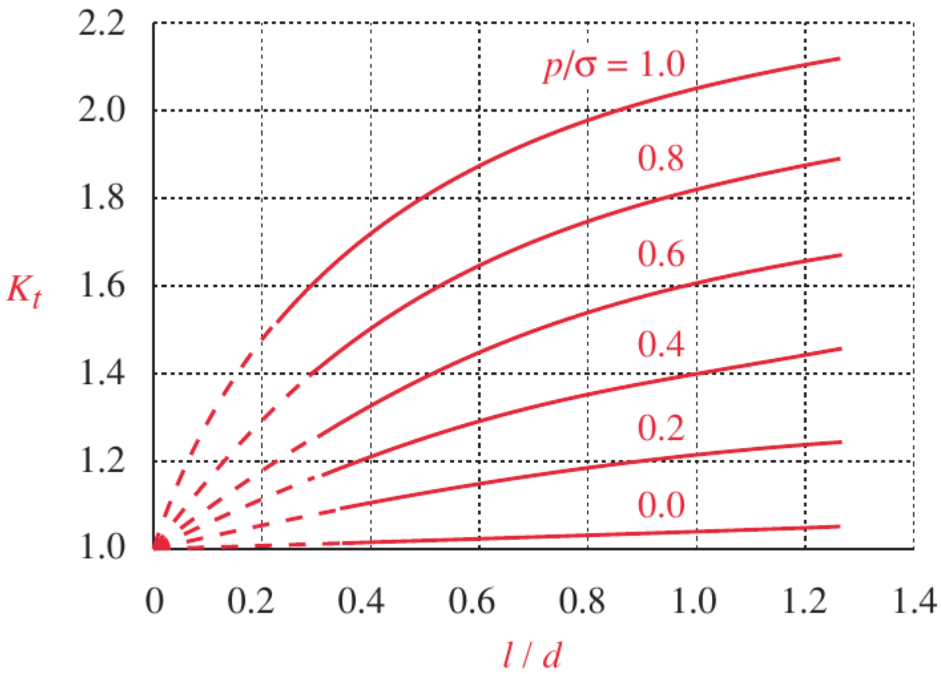
A Grooved-Hub Press-fit Assembly (reduction in stress concentration)

Norton, Machine Design – An Integrated Approach

Press Fits – Geometric Stress Concentration Factors

$$p/\sigma = \frac{\text{nominal press-fit pressure}}{\text{nominal bending stress}}$$

$$l\,/\,d = \frac{\text{length of hub}}{\text{diameter of shaft}}$$

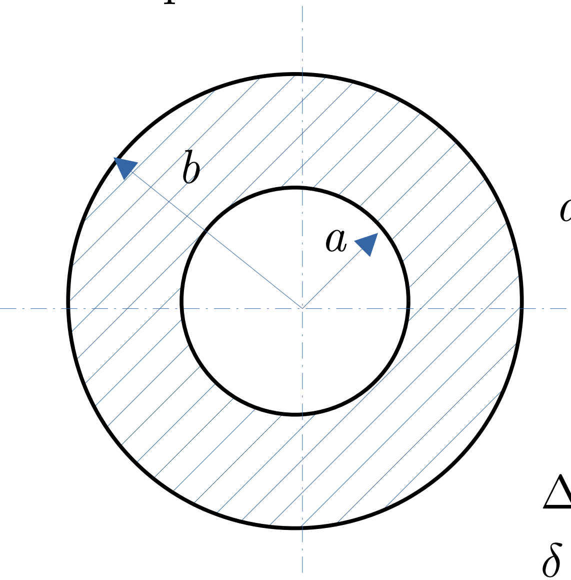


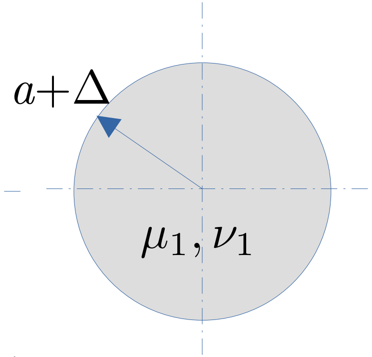
Norton, Machine Design – An Integrated Approach

End

Press and Shrink Fits

- **Press and Shrink Fits**: When two cylindrical parts are assembled by shrinking or press fitting one part upon another
- Can sometimes be used effectively to minimize the need for shoulders and keyways.
- The stresses due to an interference fit can be obtained by treating the shaft as a cylinder with a uniform external pressure, and the hub as a cylindrical part with uniform internal pressure
- The pressure is a function of interference, material properties and geometric properties





$$\tilde{p} = \frac{2\mu_1 \Delta / a}{(1 - 2\nu_1) + \frac{\mu_1}{\mu_2}\left(\frac{1+(a/b)^2}{1-(a/b)^2} - 2\nu_2 \frac{(a/b)^2}{1-(a/b)^2}\right)}$$

$\Delta > 0$

$\delta = 2\Delta$ – diametrical interference

Advantages of Woodruff key.

The Woodruff key is simple and easily adjustable.

Due to the exact fit of the key, there is no gap between the shaft & key. It reduces stress concentration & improves the reliability of the shaft.

Mostly used in the tapered shaft where all others key fails.

It is typically useful in high-speed applications.

It can tilt and align according to the movement of the shaft.

Easy to remove.

Disadvantages of Woodruff Key

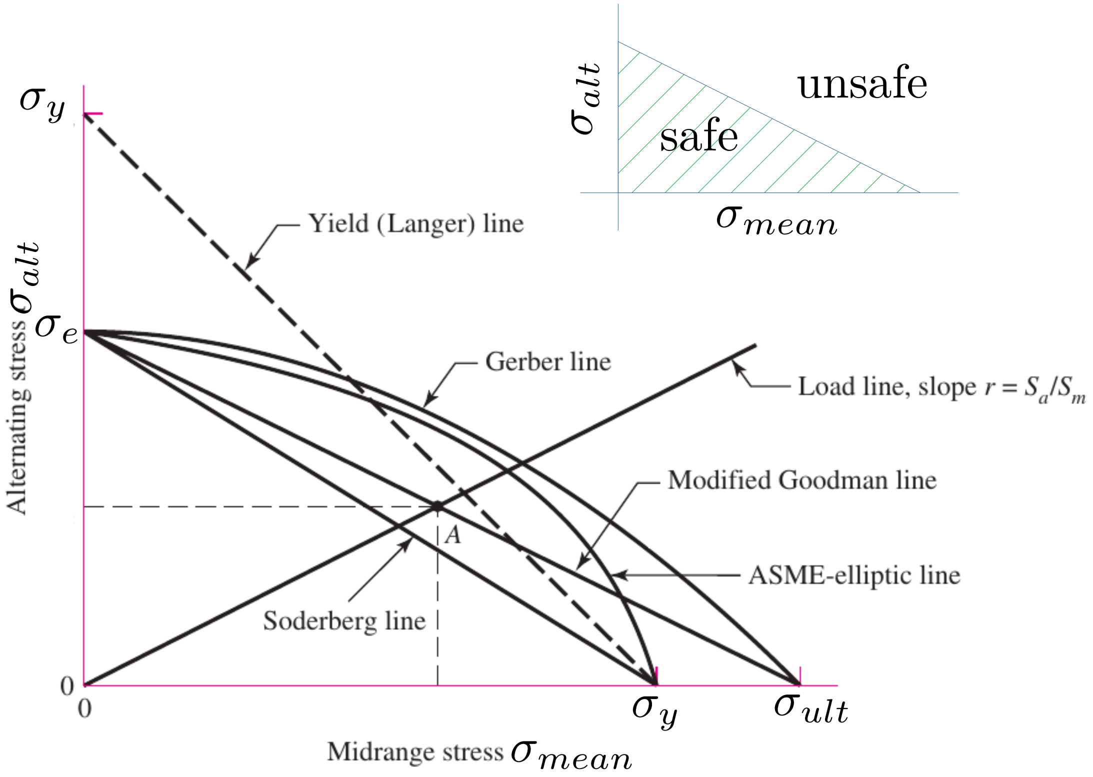
Woodruff key is difficult to install because of its groove.

Due to high depths, there are chances of reduction of strength in the shaft.

It is not suitable to carry a high load.

No axial movement between shaft and mating part.

Fatigue Criteria in Presence of Mean Stress



Soderberg line $\dfrac{\sigma_a}{\sigma_e} + \dfrac{\sigma_m}{\sigma_y} = 1$

Modified Goodman line $\dfrac{\sigma_a}{\sigma_e} + \dfrac{\sigma_m}{\sigma_{ult}} = 1$

Gerber line $\dfrac{\sigma_a}{\sigma_e} + \left(\dfrac{\sigma_m}{\sigma_{ult}}\right)^2 = 1$

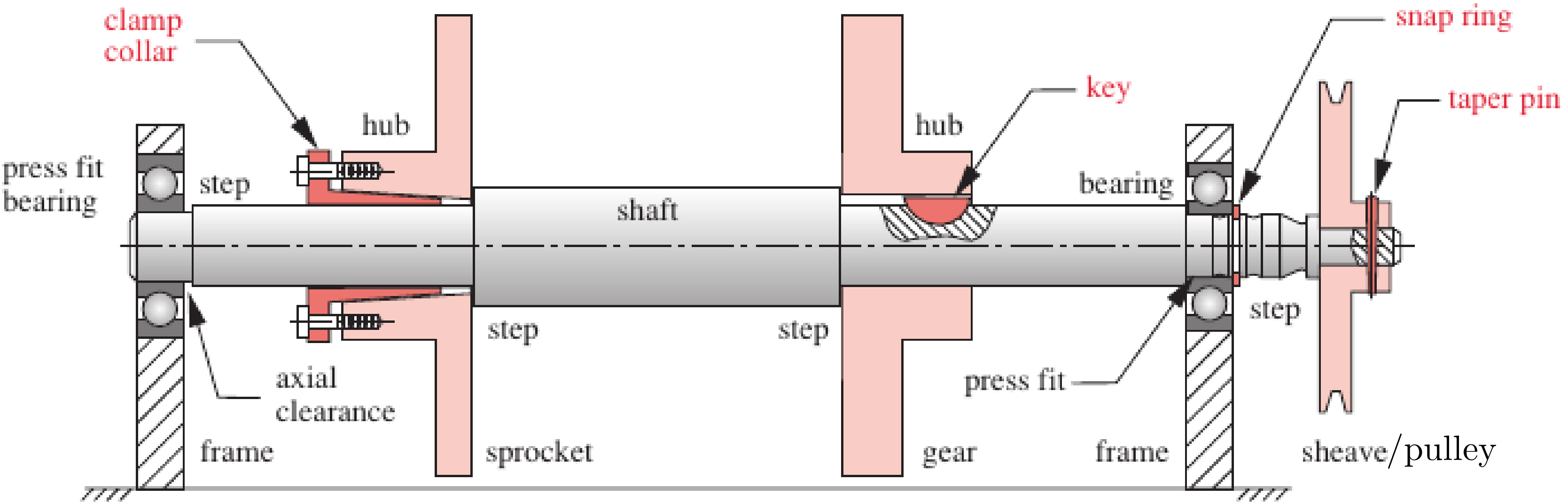
SME-elliptic line $\left(\dfrac{\sigma_a}{\sigma_e}\right)^2 + \left(\dfrac{\sigma_m}{\sigma_y}\right)^2 = 1$

Yield (Langer) line $\sigma_a + \sigma_m = \sigma_y$

σ_e is the modified/corrected endurance limit

If N is the factor of safety then replace σ_m and σ_a with $N\sigma_m$ and $N\sigma_a$, respectively

Typical Shaft Layout



Mounted parts
- Bearings
- Sprocket
- Gear
- Sheave/pulley

Torque transfer methods
- Press fit
- Clamp collar
- Key
- Taper pin

Axial Location
- Shoulder/Step
- Snap ring
- Taper pin