Machine Components: Shafts, Keys, and Couplings

ME 72 Engineering Design Laboratory

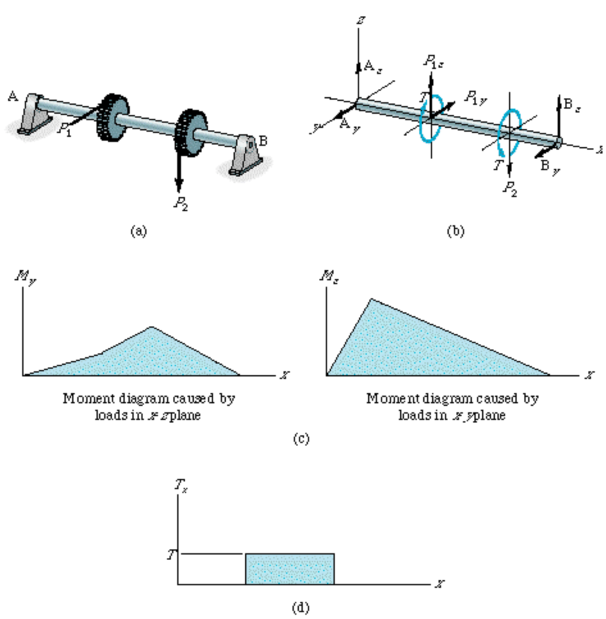
Shafts

- Shaft Functions
  - Provide an axis of rotation
  - Used to transmit power
  - Used to position/mount gears, pulleys, bearings, etc.
- Shaft Design Issues
  - Geometry (stepped cylindrical geometry)
  - Loading
  - Stress and Deflection (Strength and Rigidity)

Shaft Design Procedure

- Develop a static free-body diagram.
- Draw a bending moment diagram in two planes.
- Develop a torque diagram.
- Establish the location of the critical cross section.
- Perform a Stress Analysis for sizing.

Shaft Assembly



Shaft Assembly.

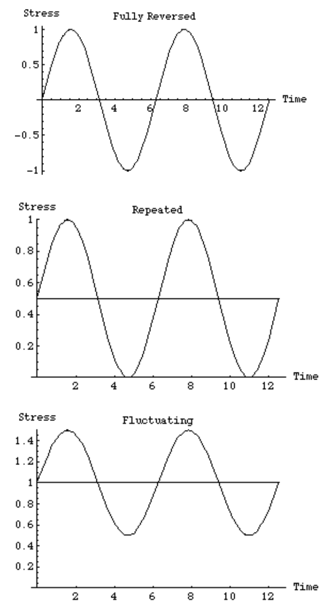
(a) Shaft with two bearings at A and B and two gears with resulting forces P_1 and P_2;

(b) free-body diagram of torque and forces resulting from assembly drawing;

(c) moment diagram in x-z and x-y planes;

(d) torque diagram.

Loads



- Static Loading
  - Radial
  - Tangential
  - Axial (Thrust)
- Dynamic (Cyclic) Loads
  - Fully reversed
  - Repeated
  - Fluctuating

Stresses

- Stress due to Axial Loading

$$\sigma_x = \frac{4F}{\pi d^2}$$

- Stress due to Bending

$$\sigma_x = \frac{My}{I} \qquad \sigma_{\max} = \frac{32M}{\pi d^3}$$

- Stress due to Torsion

$$\tau_{xy} = \frac{16T}{\pi d^3}$$

Stress Concentrations

- Stress caused by a sudden change in form
  - Fillets (on shoulders)
  - Holes (for pins)
  - Grooves (for snap rings)

$$K = \frac{\text{highest value of stress on "feature"}}{\text{nominal stress on mininum cross section}}$$

TABLE A-15

Charts of Theoretical Stress-Concentration Factors K_t *(Continued)*

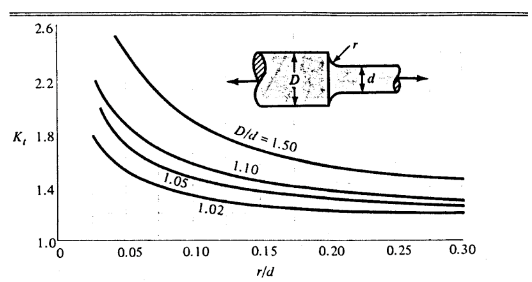


FIGURE A-15-7

Round shaft with shoulder fillet in tension. $\sigma_0 = F/A$, where $A = \pi d^2/4$.

$$\sigma_{\max} = K\,\sigma_d$$

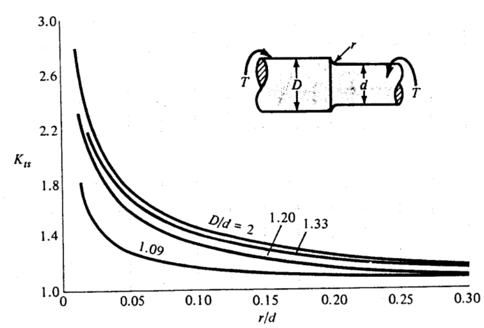


FIGURE A-15-8

Round shaft with shoulder fillet in torsion. $\tau_0 = Tc/J$, where $c = d/2$ and $J = \pi d^4/32$.

Shaft Design Guidelines

- Keep shafts short and minimize cantilever designs.
- Hollow shafts have better stiffness/mass ratios, but are more expensive.
- Configure shaft geometry to reduce stress concentrations.
- Remember that gears can produce radial, tangential, and axial loads.
- Be aware of maximum shaft deflection requirements of bearings.
- Shaft natural frequency should be as high as practical.

Constraining Parts on Shafts

- For Torque Transfer
  - Keys
  - Set screws
  - Pins
  - Splines
  - Tapered fits
  - Press or shrink fits
- For Axial Location
  - Nut and cotter pins
  - Sleeves
  - Shoulders
  - Ring and groove
  - Collar and set screw
  - Split hub

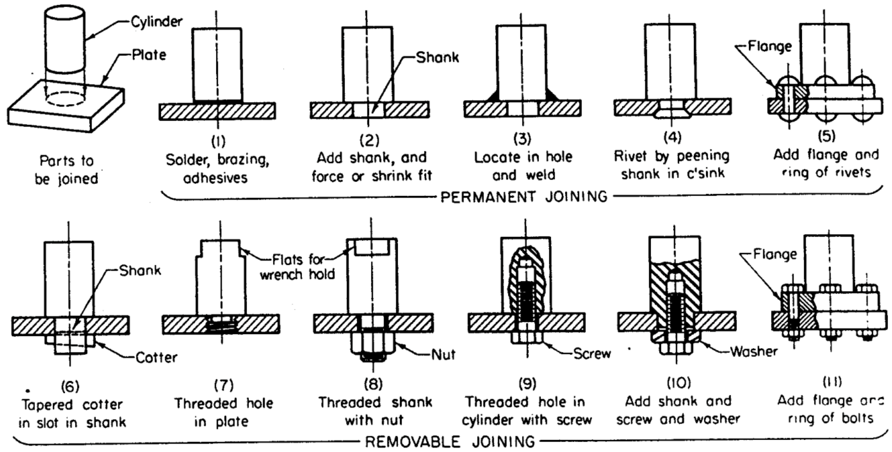


Fig. 21.23. Various ways to join a cylinder to a flat plate.

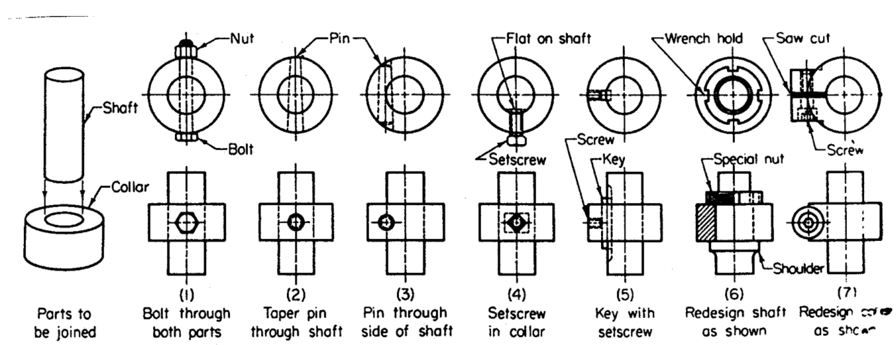


Fig. 21.24. Various ways to fasten a removable cylindrical part on a shaft.

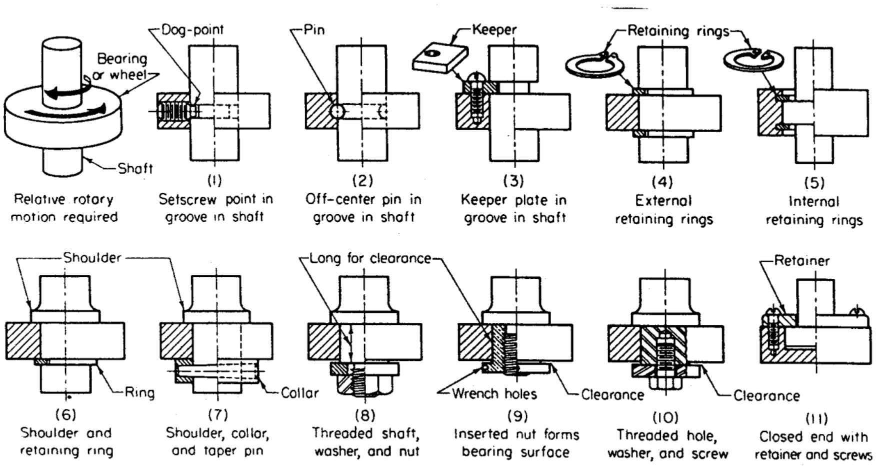


Fig. 21.25. Various ways to join movable parts with freedom to rotate.

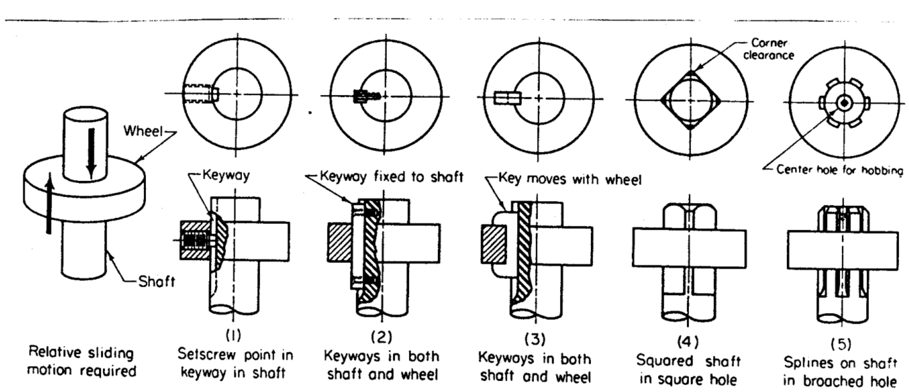
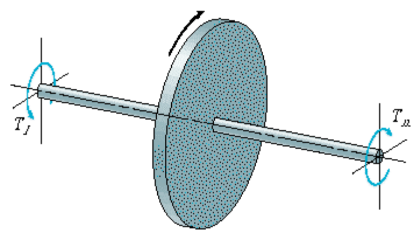


Fig. 21.26. Various ways to join rotating parts with freedom to slide.

Flywheels

- Uses of flywheels
  - To reduce amplitude of speed fluctuation
  - To reduce maximum torque required
  - To allow energy to be stored and released when needed.



Flywheel Design

- Procedure
  - Plot the load torque vs angle for one cycle
  - Determine the average over 1 cycle
  - Find angles with min and max angular velocity
  - Determine the kinetic energy by integrating the torque curve
  - Determine ω_{avg}
  - Determine I_m
  - Find the dimensions of the flywheel.

Couplings

- Couplings transmit torque and motion between shafts in the presence of various types of misalignment

- Types of Misalignment
  - Angular
  - Parallel
  - Torsional
  - Axial

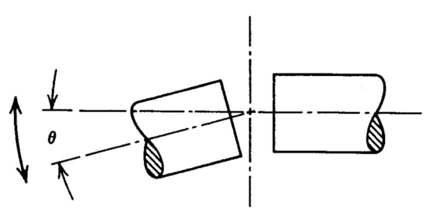


Figure 10-3 Angular misalignment is present when the shafts' axes are inclined one to the other. Its magnitude can be measured at the coupling faces.

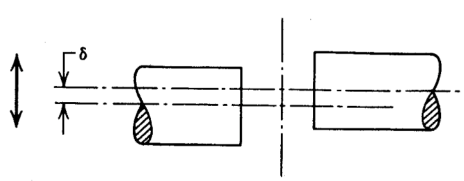


Figure 10-4 Axial or parallel-offset misalignment is present when the axes of the driving and driven shafts are parallel, but laterally displaced.

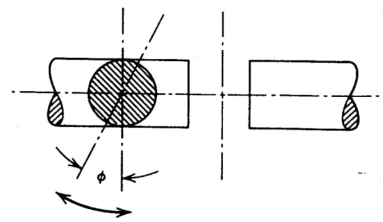


Figure 10-5 Torsional misalignment is present when the two shafts undergo angular displacements during operation.

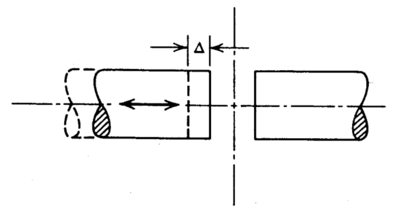


Figure 10-6 End float is present when the two shafts move axially relative to each other.

Types of Couplings

- Rigid Couplings
  - Set-screw
  - Keyed
  - Clamped
- Flexible Couplings
  - Jaw type
  - Gear, spline, grid, chain
  - Helical and bellows
  - Linkages
  - Universal Joints
    - Used in pairs
- Basic Specs Include: nominal and peak torque, misalignment tolerances, shaft size, operating temp, speed range, and backlash.

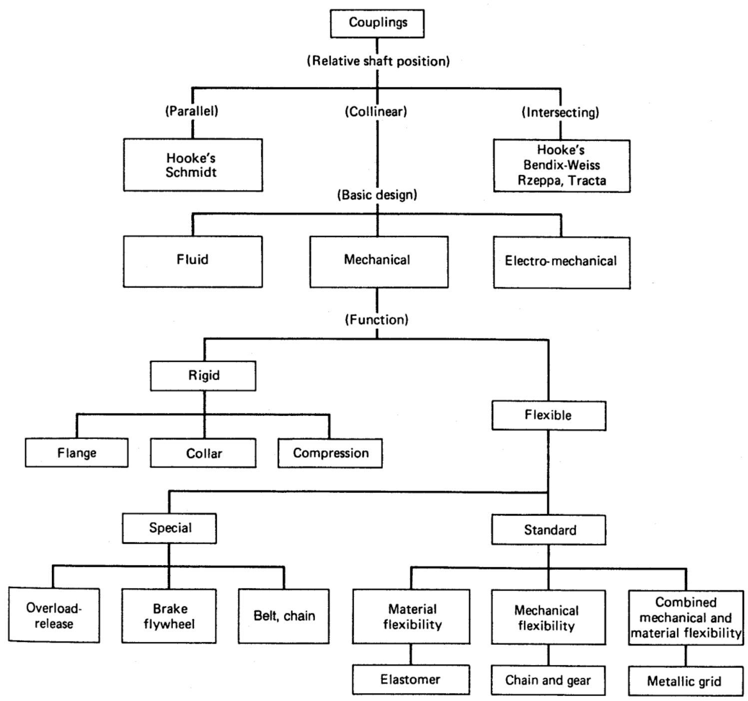


Table 9-7 Characteristics of Various Types of Couplings

Class	Misalignment Tolerated: Axial	Angular	Parallel	Torsional	Comments
Rigid	large	none	none	none	requires accurate alignment
Jaw	slight	slight (<2°)	slight (3% *d*)	moderate	shock absorption—significant backlash
Gear	large	slight (<5°)	slight (<1/2% *d*)	none	slight backlash—large torque capacity
Spline	large	none	none	none	slight backlash—large torque capacity
Helical	slight	large (20°)	slight (<1% *d*)	none	one piece - compact—no backlash
Bellows	slight	large (17°)	moderate (20% *d*)	none	subject to fatigue failure
Flexible disc	slight	slight (3°)	slight (2% *d*)	slight to none	shock absorption—no backlash
Linkage (Schmidt)	none	slight (5°)	large (200% *d*)	none	no backlash—no sideloads on shaft
Hooke	none	large	large (in pairs)	none	slight backlash—speed variation unless used in pairs
Rzeppa	none	large	none	none	constant velocity

Summary

- Shafts transmit rotary power.
- Shafts are typically designed for maximum stiffness and minimum deflection.
- Keys and similar elements are used to attach parts and align components along a shaft.
- Couplings are used to transmit power between two misaligned shafts.

References

- Hindhede, U., Zimmerman, J., Hopkins, B., et al., *Machine Design Fundamentals: A Practical Approach*, Englewood Cliffs: Prentice Hall, 1983.
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