The University of Tennessee at Martin
MARTIN School of Engineering

Keys & Keyways

Lecture 19

Engineering 473
Machine Design

Fundamental Problem in Shaft Design

How do I connect stuff to the shaft?

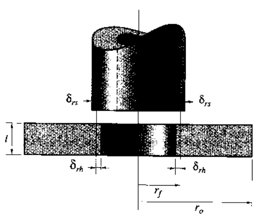
Interference Fits

Keys & Keyseats **Pins** **Hubs/Collars**

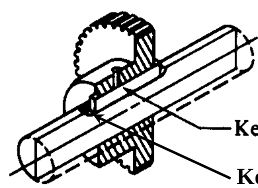
Integral Shaft **Splines/Polygons**

Interference Fits

Interference Fits – Hole is undersized and part is heated to allow it to slide over shaft. Compressive interface pressure develops when part cools. **Reference Lecture 15 Notes**.



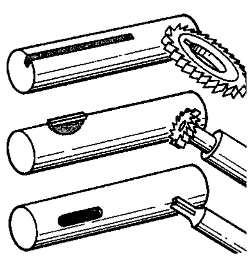
Keys and Keyseats



Keys are used to transmit torque from a component to the shaft.

Mott, Figure 11-1

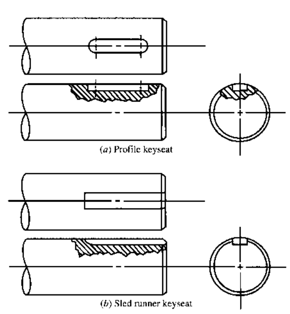
Types of Keyseats

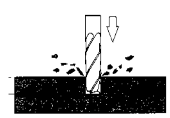


Keyseats are classified according to the process by which they are made.

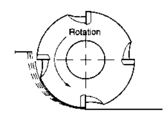
Olivo, Fig. 40-3

Keyway Fabrication Methods





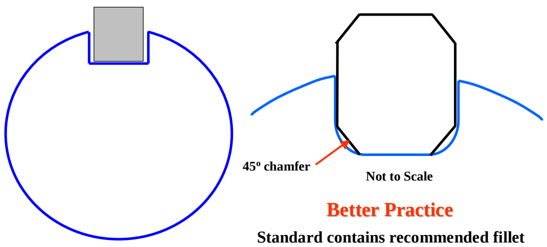
End Mill on Vertical Milling Machine



Key Cutter on Horizontal Milling Machine

Chang, Fig. 5.8, Mott, Fig. 12-6

Fillet Radii and Key Chamfers



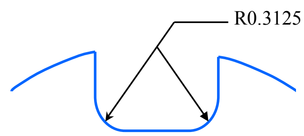
Better Practice

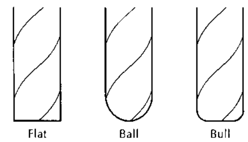
Standard contains recommended fillet radii and key chamfer combinations to provide lower stress concentration factors.

General Practice: Zero root fillet and chamfer

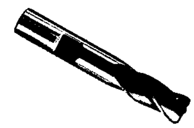
"Keys and Keyseats," ANSI Standard B17.1-1967.

Fillet Radii Fabrication





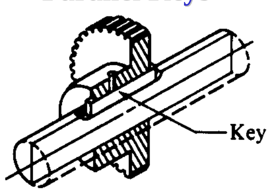
A 'Bull' end mill can be used to machine fillet radii in keyways.



Bull End Mill

MSC Catalog, Fanfara, Figure 3-6

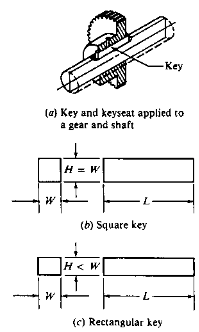
Square and Rectangular Parallel Keys



The hub is slightly larger than the shaft and key to allow it to slide over the shaft during assembly. The set screw is used to take up the slack. The resulting friction is used to provide resistance to axial motion. Thread adhesive may be required to ensure that vibration doesn't cause the set screw to loosen.

Mott, Figure 11-1

Square and Rectangular Key Geometry

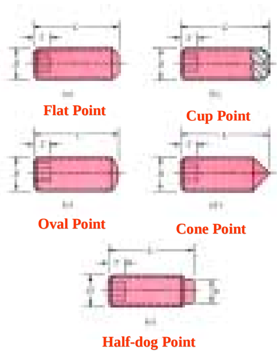


"Keys and Keyseats," ANSI Standard B17.1-1967.

Width is approximately ¼ the diameter of the shaft.

Standard contains tables of recommended key sizes versus shaft diameter.

Set Screws



Holding Power – Resistance to axial or rotary motion of the hub or collar relative to the shaft.

Holding power is a function of friction between contacting portions of hub or collar and shaft and any penetration of the setscrew into the keyway or shaft.

Shigley, Fig. 8-26

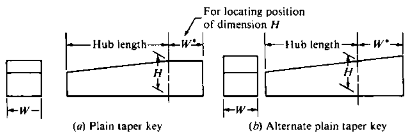
Representative Holding Power Values

SIZE, in	SEATING TORQUE, lb · in	HOLDING POWER, lb
#0	1.0	50
#1	1.8	65
#2	1.8	85
#3	5	120
#4	5	160
#5	10	200
#6	10	250
#8	20	385
#10	36	540
1/4	87	1000
5/16	165	1500
3/8	290	2000
7/16	430	2500
1/2	620	3000
9/16	620	3500
5/8	1325	4000
3/4	2400	5000
7/8	5200	6000
1	7200	7000

Based on alloy steel screw against steel shaft, class 3A coarse or fine threads in class 2B holes, and cup-point socket setscrews.

Shigley, Table 8-13

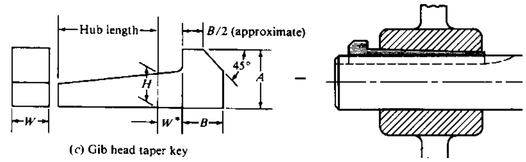
Tapered Keys



Designed to be inserted from the end of the shaft after the hub is in position. The taper will impart a compressive contact pressure between the hub and the shaft. Friction will help transmit torque and provide resistance to axial motion of the hub relative to the shaft. Tapered keys do not require set screws. Access to both ends of tapered keys are required so that the key can be inserted and driven out when the key is being removed.

Mott, Figure 11-3

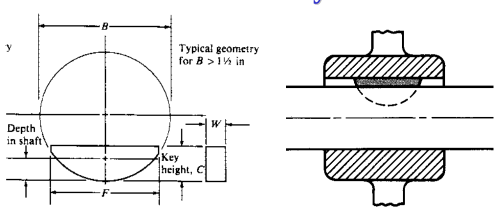
Gib Head Keys



Installation is similar to standard tapered keys. The extended head provides a holding method for removing the key by pulling instead of driving it out.

Mott, Figure 11-3, Shigley, Fig. 8-28

Woodruff Keys

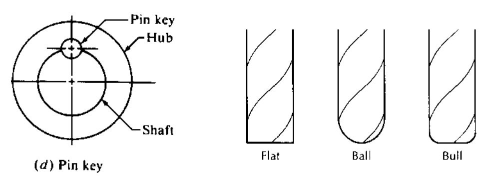


Circular groove in shaft holds the key in place while the hub is slid over the shaft. The Woodruff key will have less shear strength than a rectangular or square key.

ANSI Standard B17.2-1967 lists recommended dimensions for Woodruff Keys.

Mott, Figure 11-3

Circular (Pin) Keys

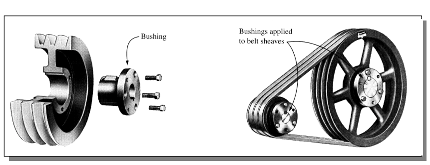


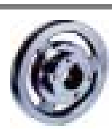
Significantly lower stress concentration factors result from this type of key as compared to parallel or tapered keys. A ball end mill can be used to make the circular key seat.

Fanfara, Figure 3- 6, Mott, Figure 11-3

Tapered Bushings

Tapered hub causes split bushing to be drawn down on shaft. Higher strength alternative to set screws.



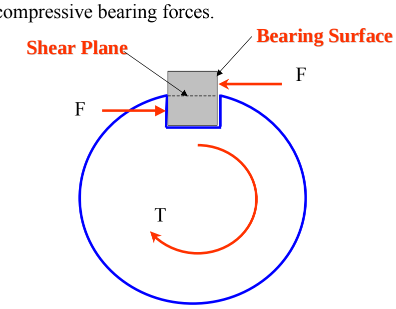


Key is used to transmit torque, friction keeps system from sliding axially along shaft.

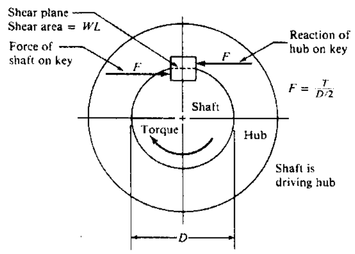
Mott, Fig. 11-10, www.emerson-ept.com

Stress Analysis of Parallel Keys

A key has two failure mechanisms: 1) it can be sheared off, and 2) it can be crushed due to the compressive bearing forces.



Shear Stress Analysis of Square and Rectangular Parallel Keys



$$F = \frac{T}{D/2}$$

$$A_s = WL$$

$$\tau_{ave} = \frac{F}{A_s} = \frac{T}{(D/2)(WL)}$$

$$\tau_{ave} = \frac{2T}{DWL}$$

Mott, Fig. 11-4(b)

Required Key Length

(Shear)

From Maximum Shear Stress Failure Theory, the shear yield strength is given by:

$$S_{ys} = 0.5S_{yt}$$

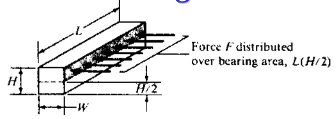
$$\tau_{all} = \frac{0.5S_{yt}}{N_{sf}}$$

The minimum length of the key can be found by setting the average shear stress equal to the allowable shear stress.

$$\tau_{ave} = \frac{2T}{DWL} = \frac{0.5S_{yt}}{N_{fs}}$$

$$L_s = \frac{4TN_{fs}}{S_{yt}DW}$$

Bearing Stress: Square and Rectangular Parallel Keys



$$\sigma_b = \frac{F}{A_b}$$

$$\sigma_{b,all} = \frac{KS_{yc}}{N_{fs}}$$

$$L_b = \frac{4TN_{fs}}{KS_{yc}DH}$$

$$F = \frac{T}{D/2}$$

Triaxial Stress Factor

$$1.0 \le K \le 1.5$$

$$A_b = \frac{HL}{2}$$

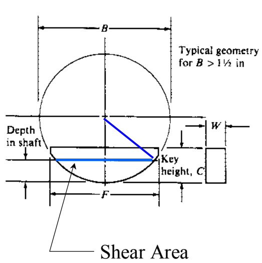
Mott, Fig. 11-4(a)

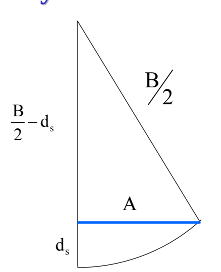
Comparison of Shear and Bearing Length Equations

Minimum Required Length to Prevent Shear Failure	Minimum Required Length to Prevent Bearing Failure
$L_s = \frac{4TN_{fs}}{S_{yt}DW}$	$L_b = \frac{4TN_{fs}}{KS_{yc}DH}$

If K=1, these equations give the same result for a square key. In general K will be greater than 1.0 and more shear failures will be observed in the field. Keys are generally designed to fail before overloads can cause damage to the shaft or attached component. In this respect they act like a mechanical fuse.

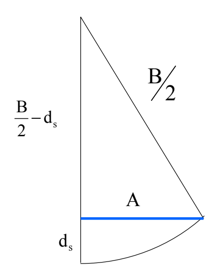
Stress Analysis of Woodruff Keys





$$\left(\frac{B}{2}\right)^2 = \left(\frac{B}{2} - d_s\right)^2 + A^2$$

Shear Analysis of Woodruff Keys



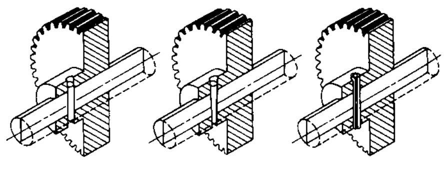
$$\left(\frac{B}{2}\right)^2 = \left(\frac{B}{2} - d_s\right)^2 + A^2$$

$$A = \sqrt{d_s(B - d_s)}$$

$$A_s \equiv \text{Shear Area} = 2W\sqrt{d_s(B - d_s)}$$

$$\tau_{ave} = \frac{2T}{DA_s} \qquad \tau_{s,all} = \frac{0.5S_{yt}}{N_{fs}}$$

Shear Pins



The strength analysis of shear pins is similar to that used to find the strength of a fastener. We'll defer the strength analysis until we cover fasteners.

Mott, Fig. 11-9

Stress Concentration Factors

Key seats create stress concentrations in the shaft. There are different stress concentration factors for bending and torsional loads. Peterson contains a compilation of stress concentration factors that includes key seat geometries. For flat end mills, Peterson gives K_t=2.14 for bending and K_t=2.62 for torsion. These may be reduced by using key seats made with bull end mills. The stress concentration factor for a sled runner key seat is significantly lower than for a profile key seat. A circular key and keyseat will have lower stress concentration factors any other key geometry.

R.E. Peterson, Stress Concentration Factors, Wiley, New York, 1974.

Assignment

1. Determine the length of a parallel key for a gear to be mounted on a shaft with a 2.00 in-diameter shaft. The key is made from AISI 1020 cold-drawn steel. The gear transmits 21,000 lb-in of torque and has a hub length of 4.00 inch.
2. A V-belt sheave transmits 1,112 lb-in of torque to a 1.75 in-diameter shaft. The sheave is made form ASTM class 20 cast iron and has a hub length of 1.75 in. Design a parallel key and key seat. The key material is AISI 1020 cold-drawn steel. Create an AutoCAD drawing that would enable a machinist to make the key seat.