The University of Tennessee at Martin

MARTIN School of Engineering

Splines

Lecture 20

Engineering 473
Machine Design

MARTIN

Fundamental Problem in Shaft Design

How do I connect stuff to the shaft?

Interference Fits

Keys & Keyseats

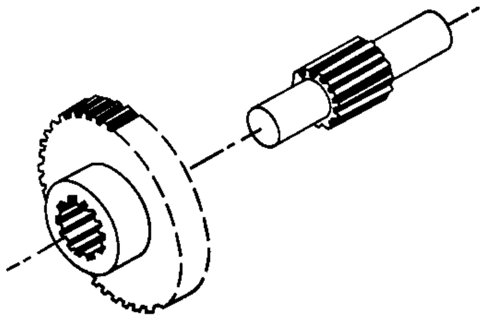
Pins

Hubs/Collars

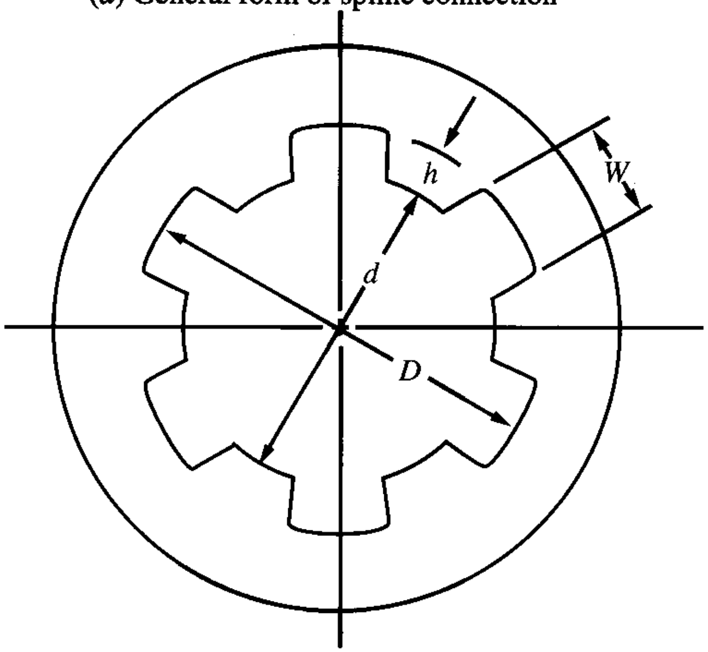
Integral Shaft

Splines/Polygons

Splines



(*a*) General form of spline connection

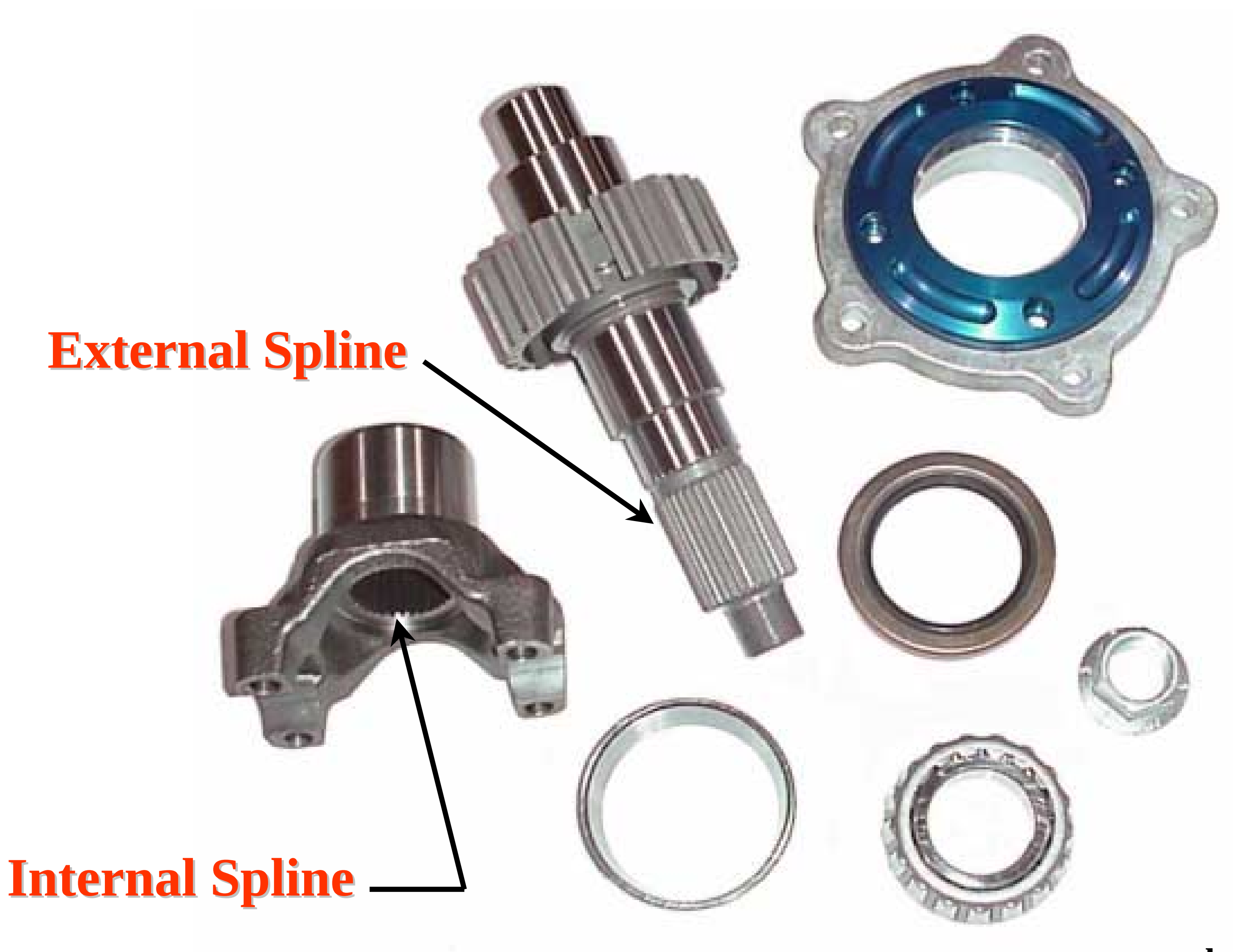


(*b*) Internal spline

- Splines can be thought of as a series of axial keyways with mating keys machined onto a shaft.
- There are two major types of splines used in industry: 1) straight-sided splines, and 2) involute splines.
- Splines provide a more uniform circumferential transfer of torque to the shaft than a key.

Mott, Fig. 11-6

Splined Shaft and Hub



www.advanceadapters.com

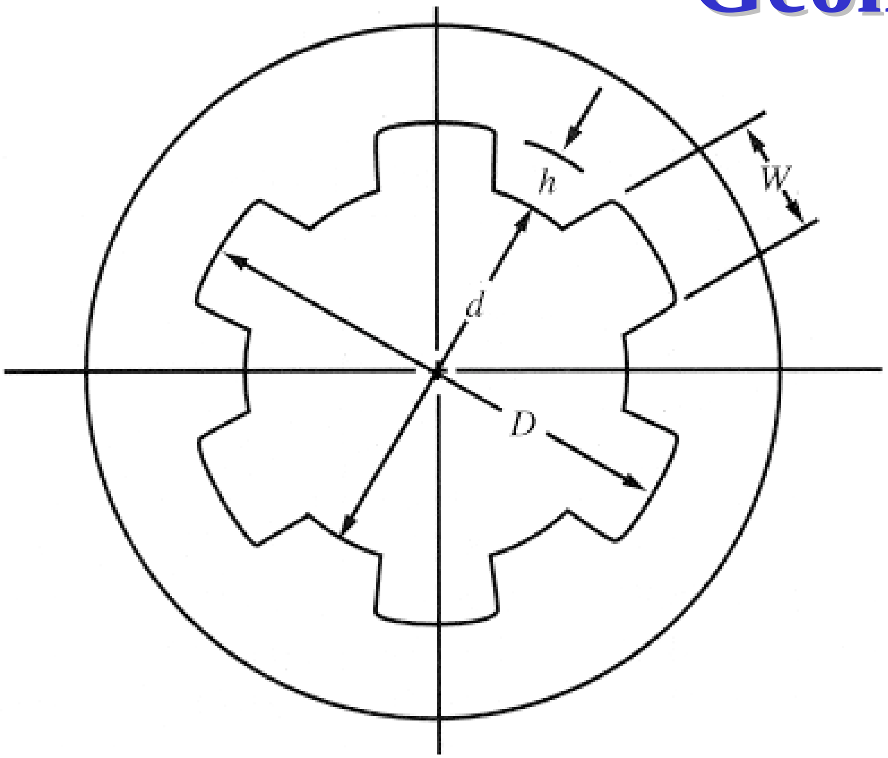
Spline Standards

- ANSI B92.1-1970 (R1982), Involute Splines, American National Standards Institute.

- ANSI B92.2-1980, Metric Module Involute Splines, American National Standards Institute.

- SAE Straight Tooth Splines

Straight-Tooth Spline Geometry

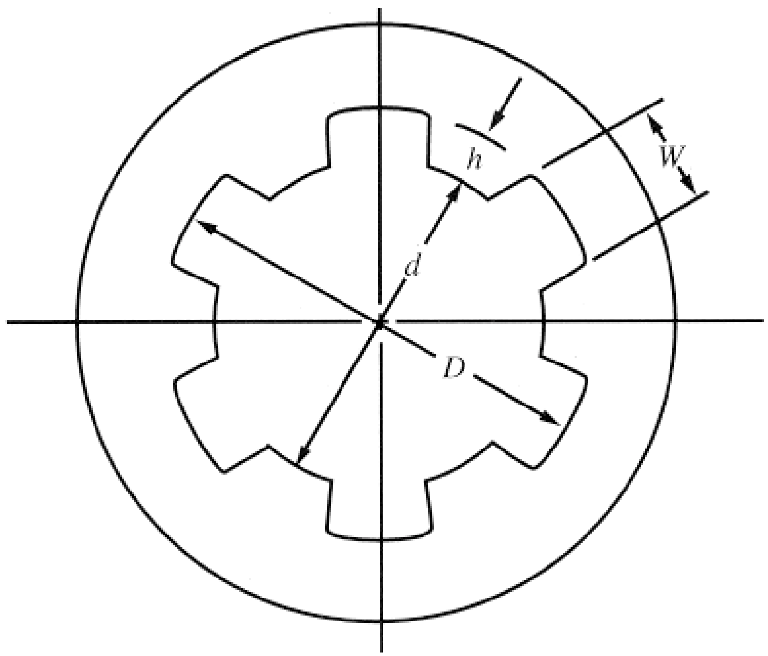


- SAE straight-tooth splines usually contain 4,6,10, or 16 splines.
- Parameter dimensions are controlled by the fit needed for a particular application.

No. of splines	*W*, for all fits	*A:* Permanent fit		*B:* To slide without load		*C:* To slide under load	
		h	*d*	*h*	*d*	*h*	*d*
Four	0.241D	0.075D	0.850D	0.125D	0.750D		
Six	0.250D	0.050D	0.900D	0.075D	0.850D	0.100D	0.800D
Ten	0.156D	0.045D	0.910D	0.070D	0.860D	0.095D	0.810D
Sixteen	0.098D	0.045D	0.910D	0.070D	0.860D	0.095D	0.810D

Mott, Fig. 11-4

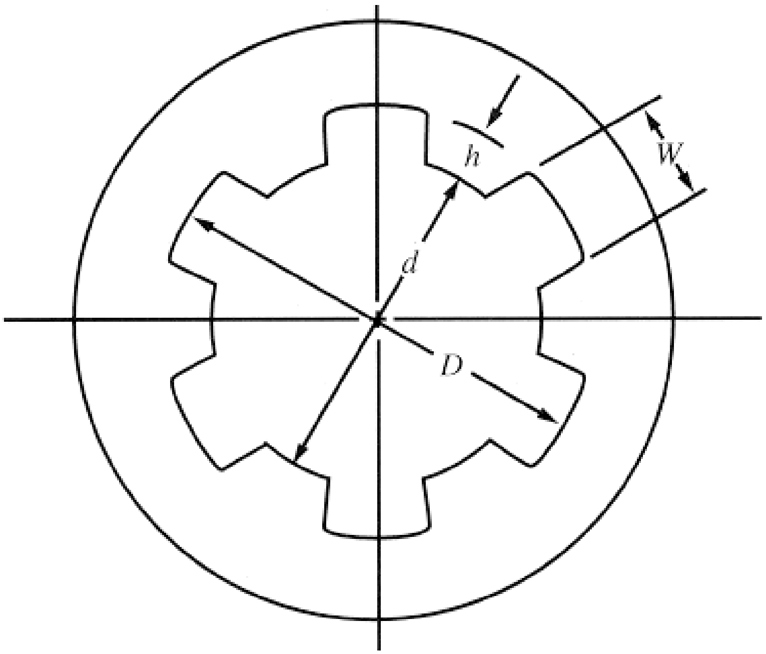
Straight-Tooth Spline Strength



Splines have the same failure mechanisms as keys: 1) shear or 2) bearing.

- The torque capacity per unit length of an SAE spline is based on a 1,000 psi bearing stress on the sides.
- Depending on the class of fit, a spline is able to accommodate axial movement along the shaft and still transmit torque.

Straight-Tooth Spline Strength
(Continued)



$$T = 1{,}000 \cdot N \cdot R \cdot h$$

$$R = \frac{1}{2}\left(\frac{D}{2} + \frac{d}{2}\right) = \frac{D+d}{4}$$

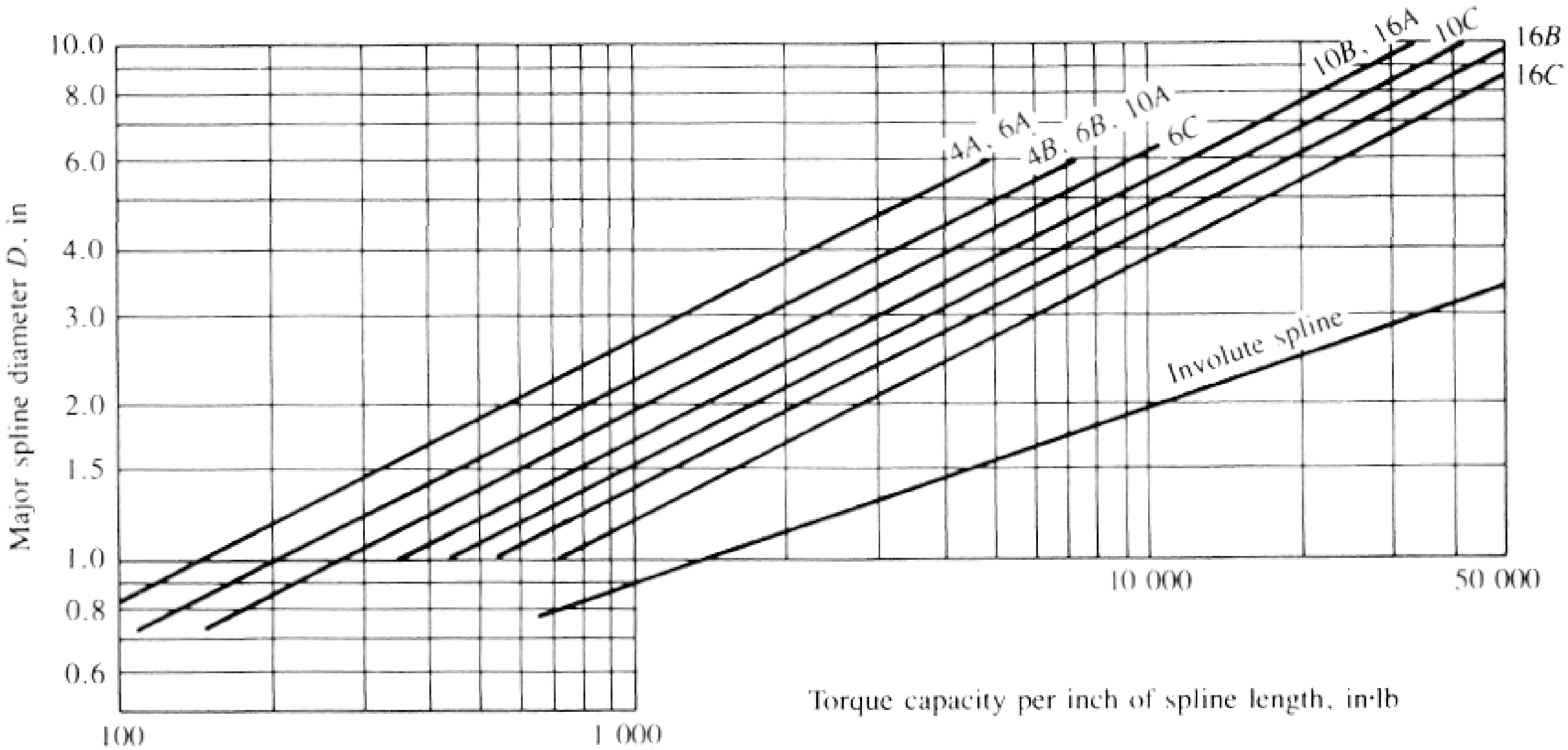
$$h = \frac{1}{2}(D-d)$$

$$T = 1{,}000 \cdot N \cdot \frac{D+d}{4} \cdot \frac{1}{2}(D-d)$$

$$T = 1{,}000 \cdot N \cdot \left(\frac{D^2 - d^2}{8}\right)$$

T = Torque per unit length
N = Number of teeth
D = Major spline diameter
d = Minor spine diameter
d = f (D)

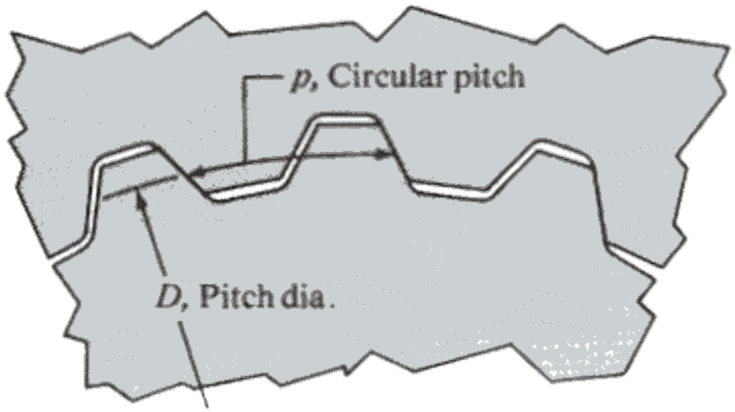
Torque Capacity Curves
(SAE Straight-Tooth Splines)



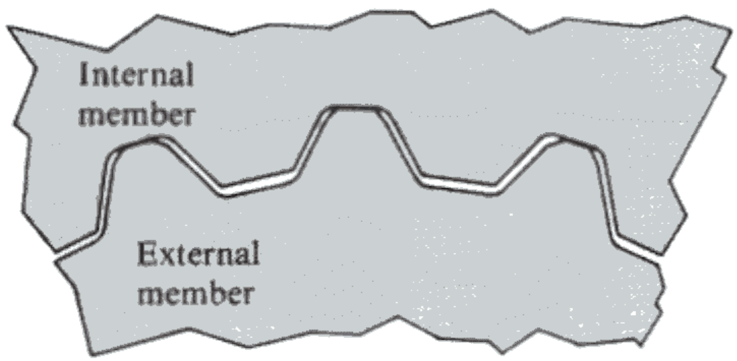
Note that an involute spline has a higher torque capacity than does a straight-tooth spline of the same major diameter.

Mott, Fig. 11-7

Involute Splines



(a) Side-fit spline



Note chamfer on tips of external spline teeth

(b) Major dia. fit spline

N = Number of spline teeth
P = Diametral pitch
$D = N/P$ = Pitch dia.
$p = \pi/P$ = Circular pitch

Minor dia.:

Internal: $\frac{N-1}{P}$

External: $\frac{N-1.35}{P}$

Major dia.:

Internal: $\frac{N+1.35}{P}$ side fit

$\frac{N+1}{P}$ major dia. fit

External: $\frac{N+1}{P}$

Involute splines generally have a 30° pressure angle.

Mott, Fig. 11-8

Standard Diametral Pitches and Lengths

Diametral Pitches

There are seventeen diametral pitches in common use:

2.5	3	4	5	6	8	10
12	16	20	24	32	40	48
64	80	128				

Standard Lengths

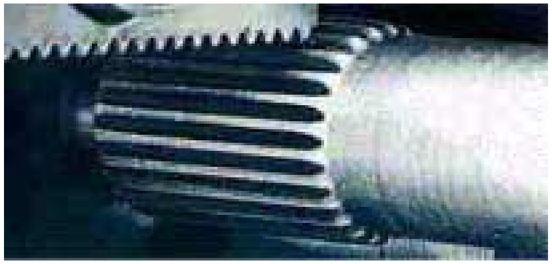
Common designs use spline lengths of 0.75 D to 1.25 D, where D is the pitch diameter of the spline. When these standard lengths are used, the shear strength of the splines will exceed that of the shaft from which they are made.

Spline Manufacturing Methods

Splines are either "cut" (machined) or rolled. Rolled splines are stronger than cut splines due to the cold working of the metal. Nitriding is common to achieve very hard surfaces which reduce wear.

Rolled Spline Process

Forged blank is rolled under tons of pressure prior to heat treating.

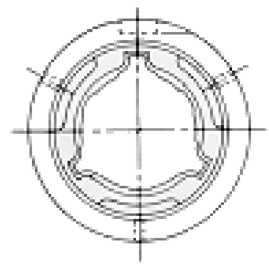


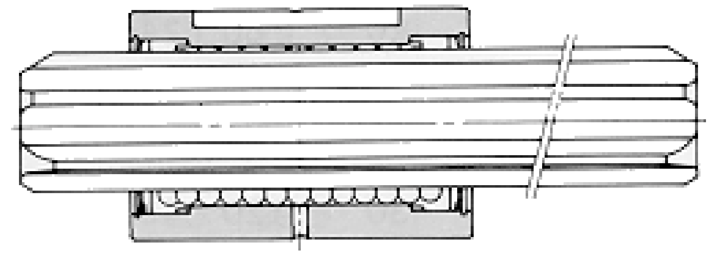
The finished spline is more accurate and stronger (35%) than cut spines.

Spline Failure Example

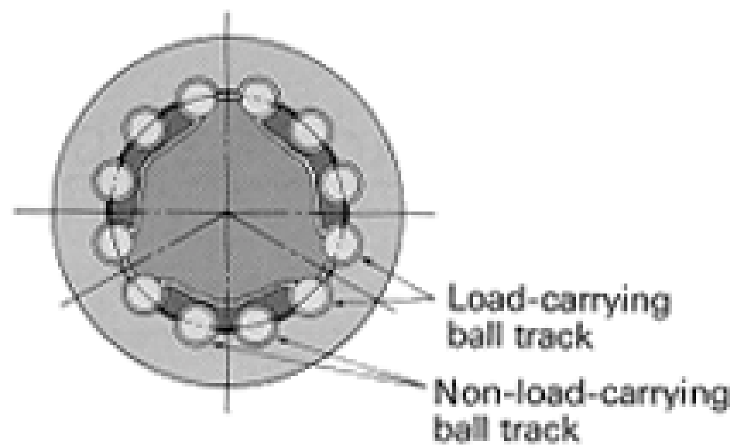
Note the yielding of the shaft outside of the engagement area due to a torsional load. The mating internal spline forced the external slines to remain parallel. In this case the spline is stronger than the shaft.

Splined Linear Bearing





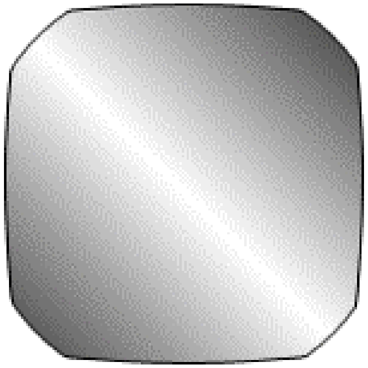
Circular shaped splines have been combined with ball bearings to create linear bearings that can resist a torsional load.

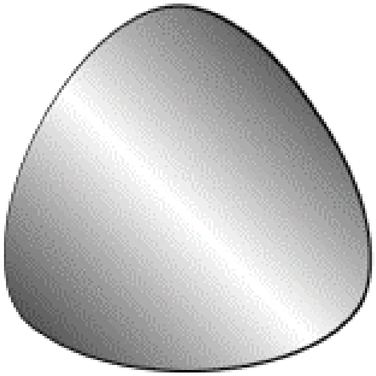


Polygons

An alternative to splines that has significantly lower stress concentration is the polygon. Four and three lobed polygons are shown.

Design information on polygons is available from General Polygon.



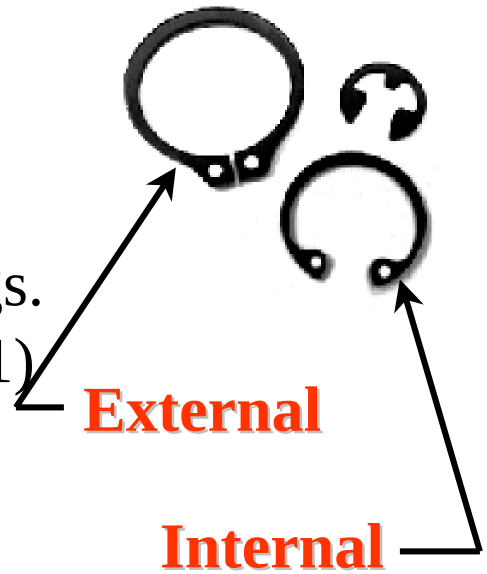


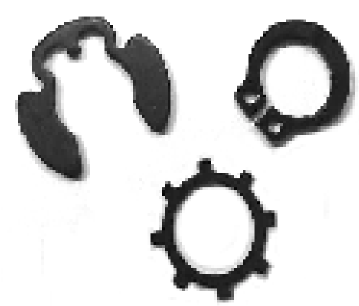
www.generalpolygon.com

Retaining Rings

- Retaining rings are used on shafts to maintain the axial position of components.

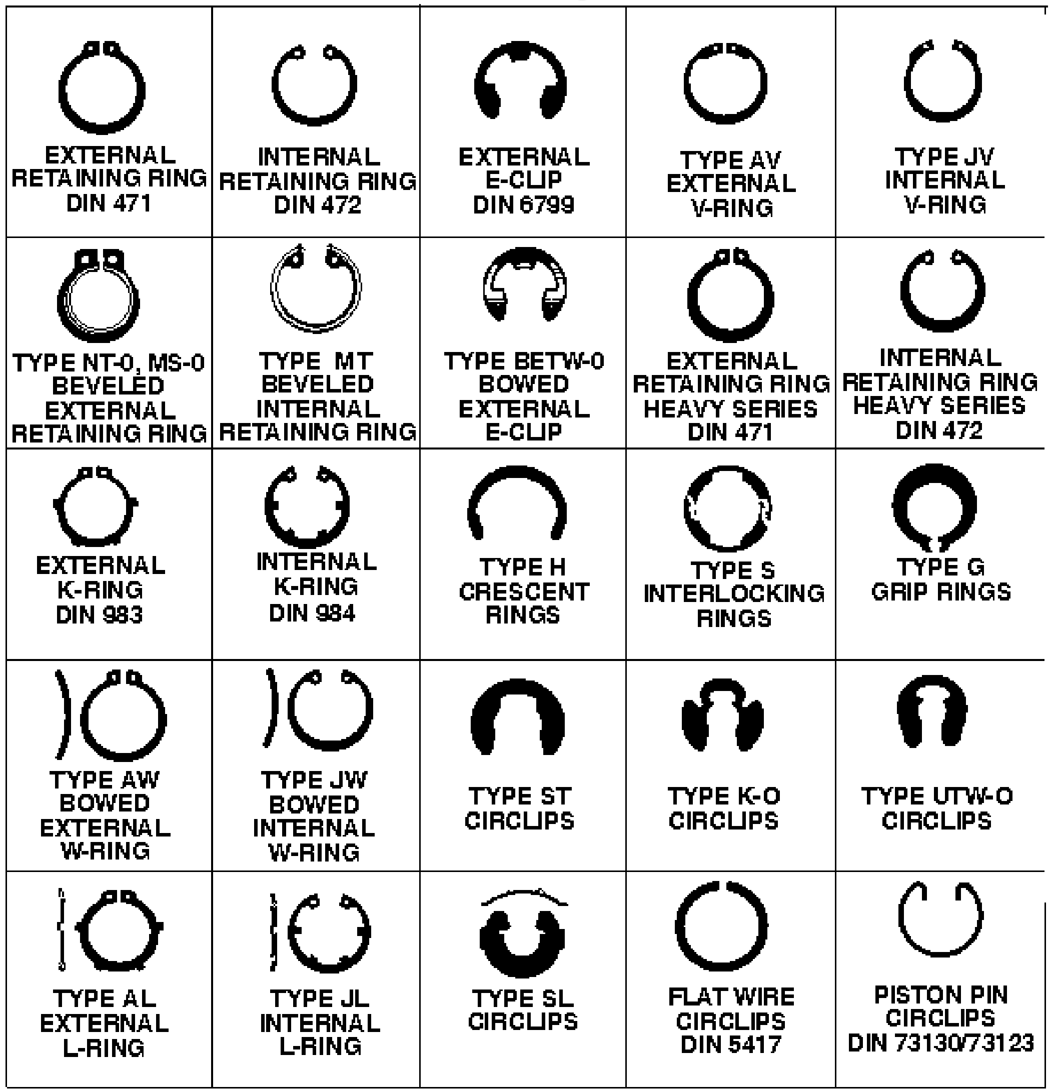
- There are many types of retaining rings. In general, they may be classified as: 1) internal and 2) external.





www.rotorclip.com

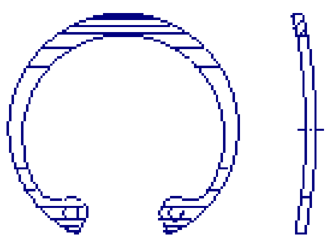
Different Types of Retaining Rings



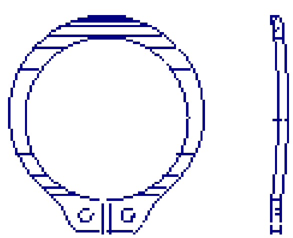
Spring Loaded Retaining Rings

- “Bowed” retaining rings provide restoring forces to the components being held.

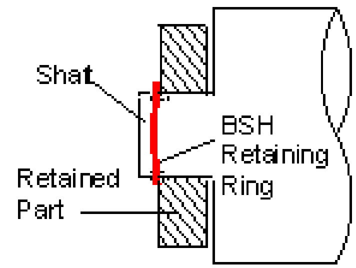
- Flat retaining rings allow small amounts of axial motion of the held component.

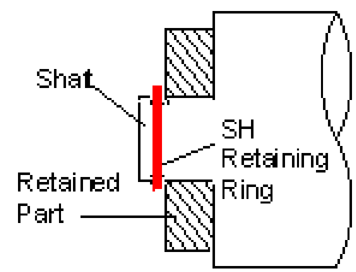


Bowed Internal Retaining Ring

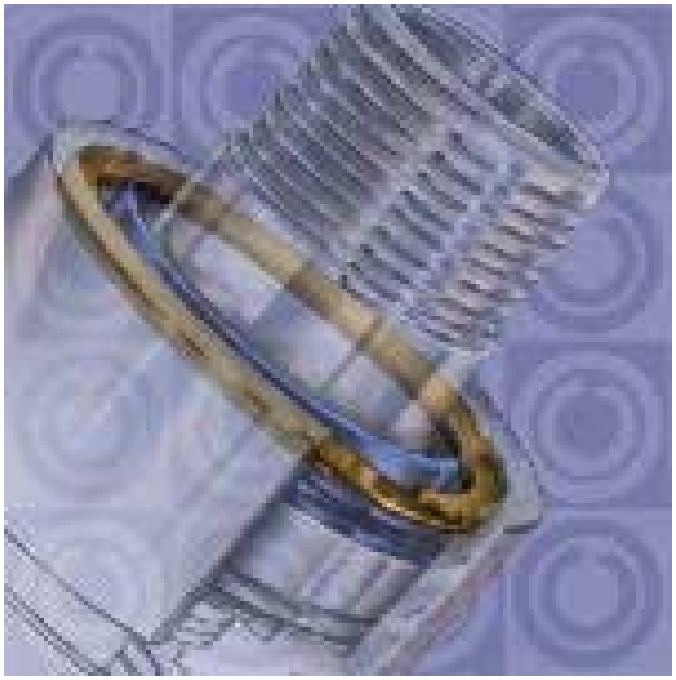


Bowed External Retaining Ring

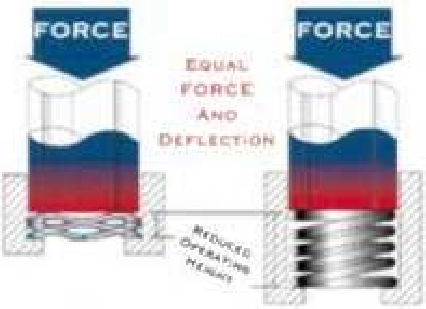




Smalley Compression Spring Retaining System

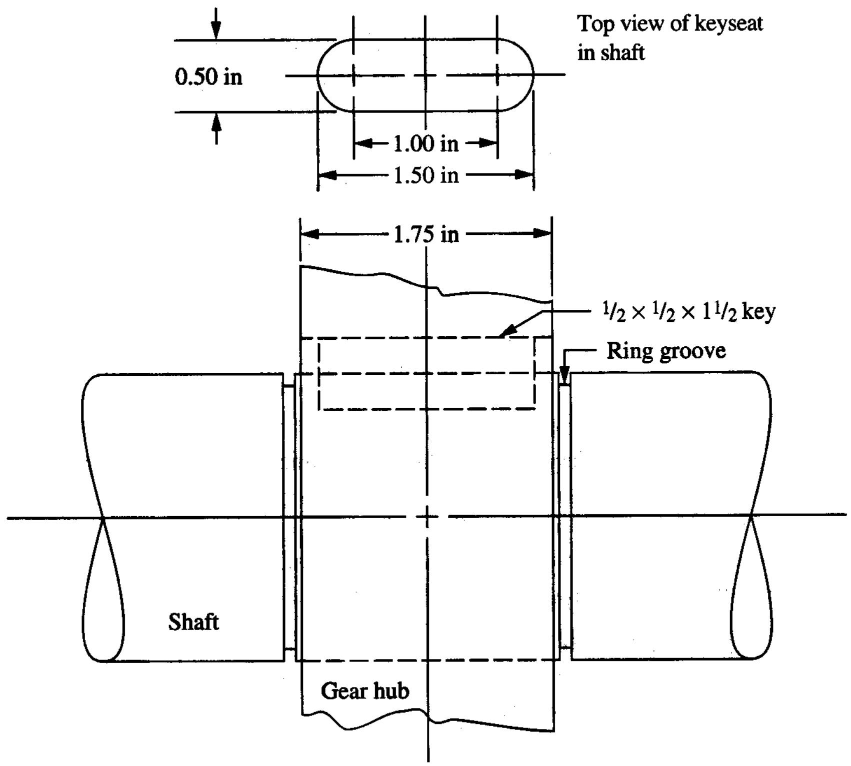


Higher restoring forces can be obtained using compression rings manufactured by Smalley.



www.smalley.com

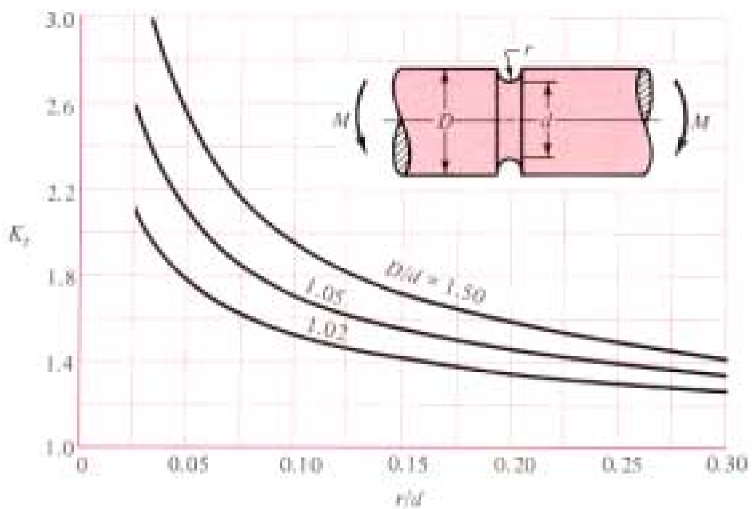
Retaining Ring Stress Concentrations

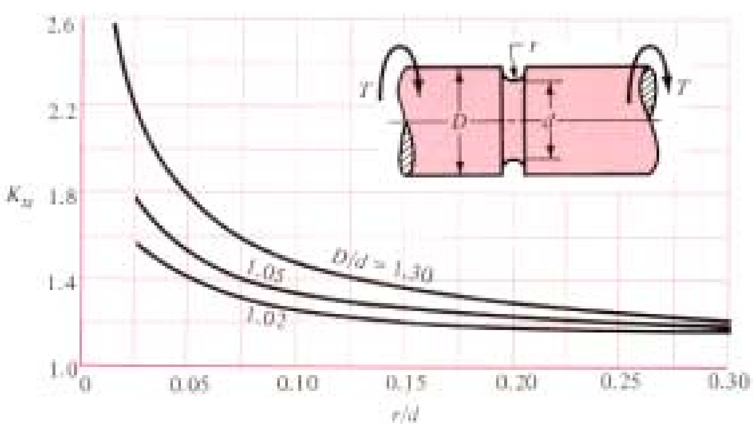


- External retaining rings used on shafts require that grooves be cut into the shaft.
- The grooves generally have sharp corners or very small fillet radii which result in significant stress concentration factors.

Mott, Fig. 11-5

Retaining Ring Stress Concentration Factors





- The high stresses at the root of the retaining ring groove will be highly localized and will not significantly effect the static strength of a shaft made from a ductile material.

- The stress concentration factors will be important in determining the life of the shaft and must be included in life calculations.

Shigley, Fig. A15-14 & 15

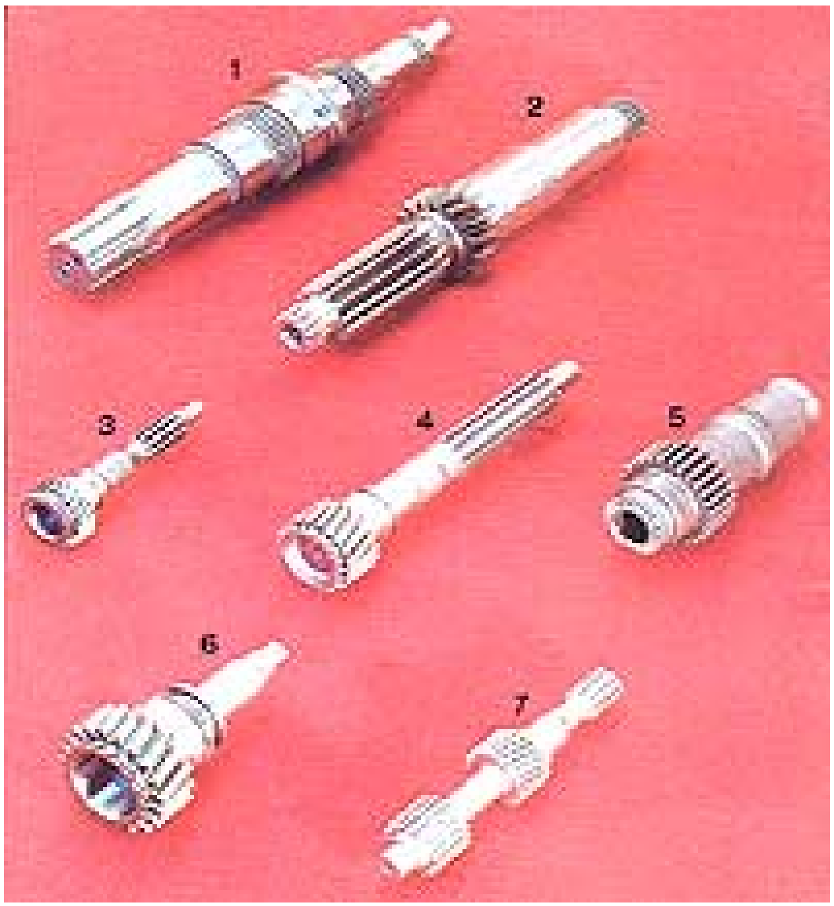
Retaining Ring Design

Dimensions and design guidelines for retaining rings are contained in catalogs and literature published by retaining ring manufacturers.

Rotoclip, Inc. **Smalley** **Waldes Truarc, Inc.**

Designs that use retaining rings must take into account how the rings will be installed and make sure that sufficient assembly clearance is provided.

Integral Shafts



- An alternative to attaching components to shafts is to machine the components directly onto the shaft.
- This higher priced approach is often the only approach available when tight space constraints exist.
- Complex combinations of components can be obtained using modern CNC turning centers.

www.astas.co.za/shafts.html

Assignment

1) Make a drawing of an SAE straight-tooth- 4-spline connection having a major diameter of 1.5000 in and a class A fit. Show all critical dimensions. What is the torque capacity of the spline?

2) Identify two applications of retaining rings used in mechanical equipment. Describe the applications and discuss why you think retaining rings of the type used were chosen by the designer.