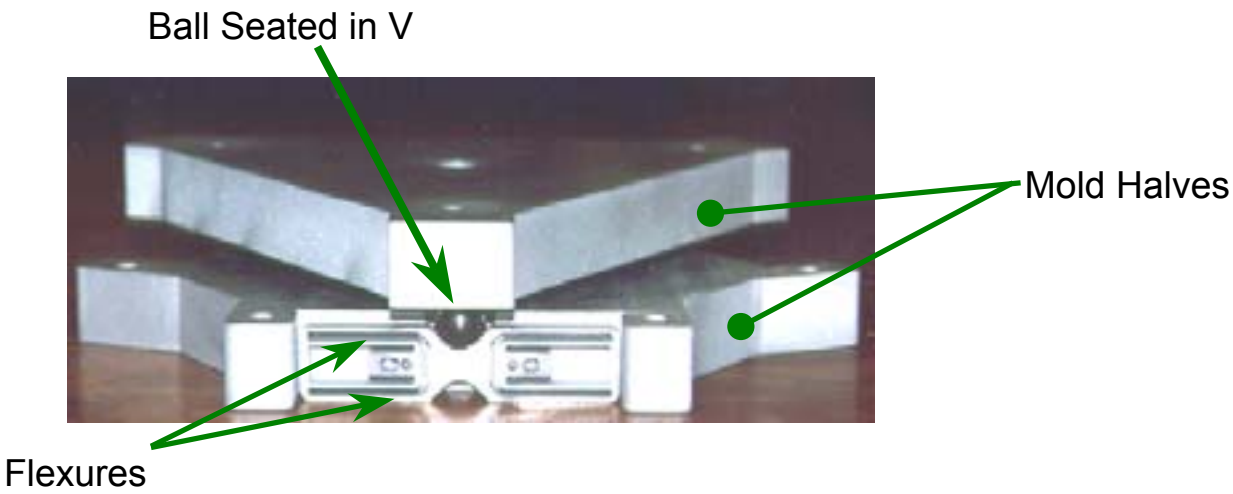
PARTIAL CONSTRAINT

Adding and taking away constraints

It may be helpful to add/remove DOF in coupling applications

For instance, KCs can not form seals

- We can add compliance to KCs to allow this to happen
- This is equivalent to adding a Degree of Freedom



Care must be taken to make sure

- compliant direction is not in a sensitive direction
- Parasitic errors in sensitive directions are acceptable

Stiffness ratio

Actuation loads should be:

- Applied through center of stiffness
- In compliant direction

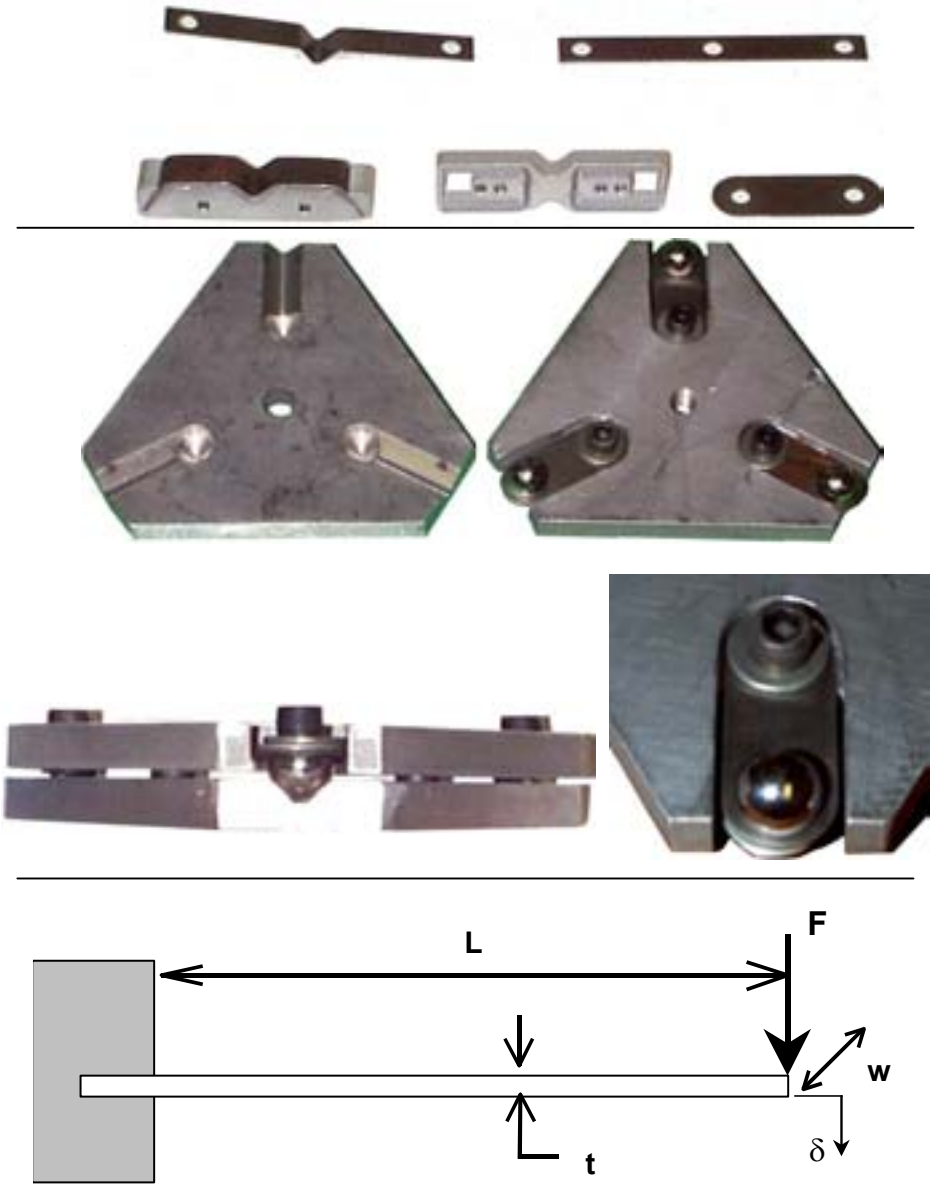
Error loads are often proportional to applied loads

- Example: Bolt head friction
- $T_B \sim F_B R_B \mu$
- Design for $k_{sensitive} >> k_{non\text{-}sensitive}$

Practical metric is stiffness ratio:

$$\frac{k_{sensitive}}{k_{non\text{-}sensitive}} >> 1$$

Stamped compliant kinematic couplings



Characteristics

Stroke	≤ 0.25 inches
Repeatability	5 -10 microns

Ball movement in non-sens. direction

Applications/Processes

1. Assembly
2. Casting

Design Issues (flexure)

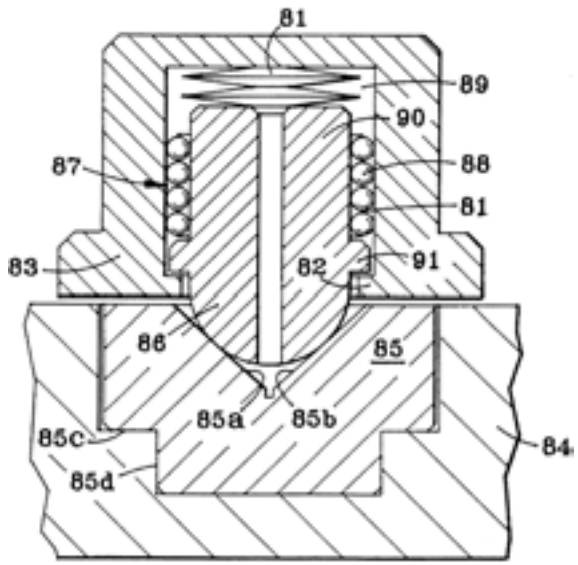
1. $K_r \sim \frac{w^2}{t^2}$
2. Tolerances affect K_r

Cost

$ 10 - 200

U.S. Patent 5, 678, 944,
Slocum, Muller, Braunstein

Integral spring compliant kinematic couplings



Characteristics

1. Repeatability (2.5 micron)
2. Stroke ~ 0.5 inches

Applications/Processes

1. Assembly
2. Casting
3. Fixtures

Design Issues (flexures)

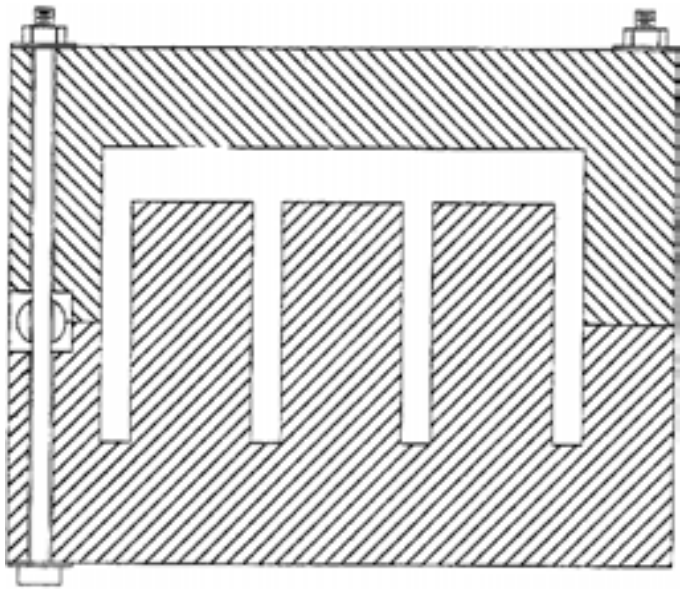
1. $K_r = \frac{K_{guide}}{K_{spring}}$
2. Press fit tolerances

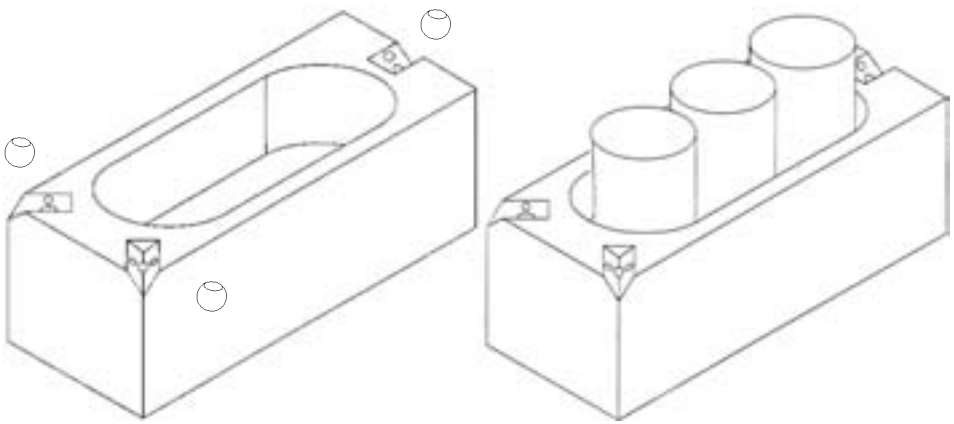
Cost

$ 2000

U.S. Patent 5, 678, 944,
Slocum, Muller, Braunstein

Plastic compliant kinematic couplings





Characteristics

1. 180 microns
2. ~ 0.125 inches
3. 1 Time Use

Applications/Processes

1. Sand Casting

Design Issues

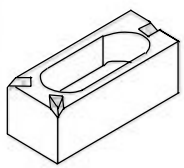
1. Loose Sand
2. K_r application specific

Cost

1. Modify Pattern
2. Purchase Balls
3. Tie Rods

U.S. Patent 5, 769, 554, Slocum

Experimental results

	Coupling Type	Prototype	Average Repeatability: Radial μinch (microns)	Average Repeatability: Standard Deviation μinch (microns)	Average Repeatability: Angular μ radians	Average Repeatability: Standard Deviation μ radians	Manufacturing Cost $
Stamped	1. 	Water Jet (mate-ball)	300 (7.6)	100 (2.5)	35	21	23
Stamped	2. 	Stamped (mate-ball)	400 (10.2)	200 (5.1)	120	70	10
Stamped	3. 	Stamped (mates-V)	200 (5.1)	100 (2.5)	52	30	10
Stamped	4. 	Stamped (mates-V)	300 (7.6)	100 (2.5)	57	23	10
Springs	5. 	Ultra Die Set Coupling	100 (2.5)	N/A	N/A	N/A	2000
Plastic	6. 	Grooves made in mold sand	19,000 (480)	7000 (180)	3900	1300	(cost to modify pattern)