Flexure based Machine Design

“How to make almost anything”
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Serial and Parallel

- **Serial**: actuators mounted on top of each other
  - Bulky for high DOF, slow response

- **Parallel**: each actuator mounted on ground base
  - Close chain parallel design, increased cross-sensitivity

Vs.
Flexures

• Overcome backlash with repeatable joints
• Ease of fabrication
• Very few joints
• Sub-micron accuracy achieved easily
• Limited range of motion
• Careful material selection
Flexures in biology

Fish fin and body dynamics - ziplock demo

Drag reduction in leaves - aquaplaning

Energy storage in Venus fly trap
CONSIDERATIONS

For a given hinge, the compliance and stress are derived by replacing the hinge by its approximate flexural spring. This was presented by Weisbord (1984). The maximum deflection, given to angular design, is always linearly proportional to the moment of stress.

Ignoring root strain, the maximum deflection for circular hinges can be derived and the bending moment is given by the maximum displacement of the hinges.

The maximum moment of stress is given by the maximum stress, and the maximum moment of stress is given by the maximum stress, which is always linear proportional to the moment of stress.

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**Flexure analysis**

*Simple beam flexure*

\[ \delta = \frac{FL^3}{3EI} ; \quad \theta = \frac{FL^2}{2EI} \quad \text{and} \quad \varepsilon \sim \frac{\delta^2}{L} \]

where,
- L is the length of the beams
- E is the Young’s modulus of the material
- I is second moment of the area of the beam cross-section

*Parallelogram flexure*

\[ \delta = \frac{FL^3}{2AEI} ; \quad \theta \approx 2 \left( \frac{t}{b} \right)^2 \frac{\delta}{L} \quad \text{and} \quad \varepsilon = \frac{3 \delta^2}{5L} \]

where
- t is the thickness of the beams
- b is the separation between the two beams of the parallelogram

All other quantities are same as defined earlier.
Analysis contd.

Double Parallelogram flexure

\[ \delta = \frac{FL^3}{12EI}; \quad \theta \approx t^2 \left( \frac{1}{b_1^2} + \frac{1}{b_2^2} \right) \frac{\delta}{L} \quad \text{and} \quad \epsilon = 0 \]
Analysis contd.

Finite element analysis
Planar flexures

Figure 13

This embodiment is almost ideal as far as performance is concerned, ... Flexure C

Intermediate Stage 2

Flexure A

Motion Stage

Flexure C'

Flexure B'

Intermediate Stage 1

Flexure D'

Flexure B

Flexure C

Flexure D

Fixed Stage

Fixed Stage
Micro-flexures/thermal actuators

Very Light weight = 0.07gm
Integrated actuator/flexure
High force

Bush et al. 03
Micro-flexures
Large displacement
Printed flexures

Compliant Revolute joint

Compliant Prismatic joint

Compliant Universal joint

6-DOF printed Compliant parallel kinematic mechanism
Printed flexures contd.
Questions