ME 6102: Design of Mechatronic Systems

Integrated Mech Elect Philosophy

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Integrated philosophy: Idea

- Many decisions in mechanical domain can be changed to suit ease in electronics domain and vice-versa
- Q: Any examples you observed from the laboratory work of Assignment 1?
- Hard disc drive arm design: optimized for wt and applied force and space (thinking of constraints at design stage itself)

Discussion on Hard disc arm actuator design

- Q: what is shape of the arm and why?
- Q: Why not to use motor in HDD?

3

Discussion on Hard disc arm actuator design

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4

Discussion on Hard disc arm actuator design

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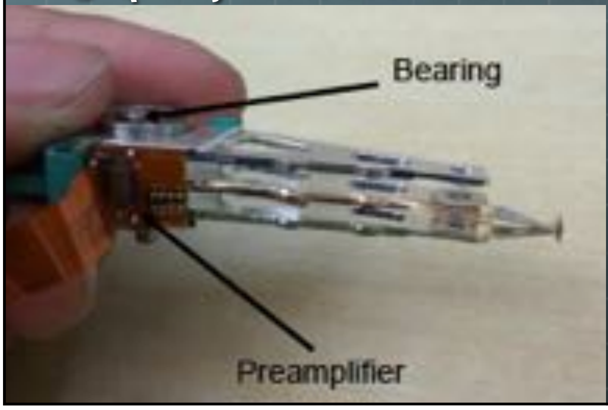
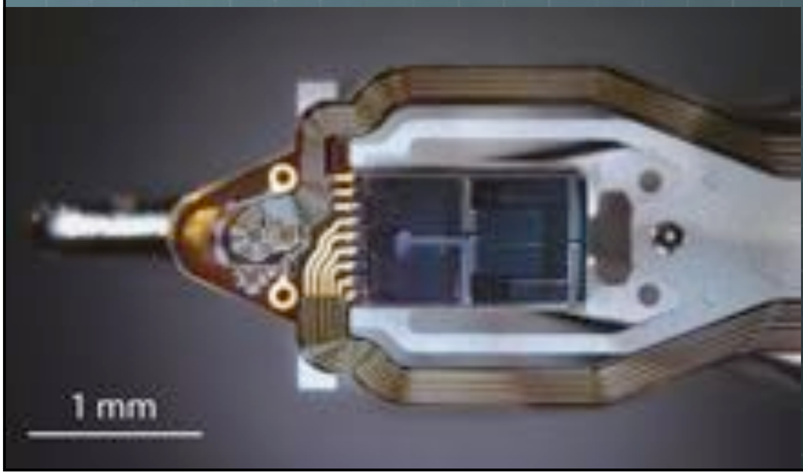
- Q: Why not to use motor in HDD?



Discussion on Hard disc arm actuator design

- Q: Read head of HD



Example, Motion control

- Suppose you are asked to design a single linear axis motion control system that works at higher speed, and have 100 nm resolution
  - Short range of say 200 micron
  - Large range of 10 mm
  - Extremely large range of 200 mm
- Q: What do you think you will use as plant, sensor, actuator in each of these cases? Why?

Normal low speed motion control stages

- Use of screw as against the rack and pinion arrangement: non back drivable
  - How do we take care of play or backlash?
    - Spring loading but how?? Recall CD drive!!
  - Why we need non back drivable?
    - Think in case the stage is vertical
  - How do we take care alignment or rather misalignment of screw axis with respect to guide axis
- Use of ball screw: expensive
- Q: How to get extremely low resolution over large range??

Normal low speed motion control stages

- Spring loading: Type 1
  - Spring connecting the stage and fixed supports
  - See how exactly it is by opening this manually operated unit ➔

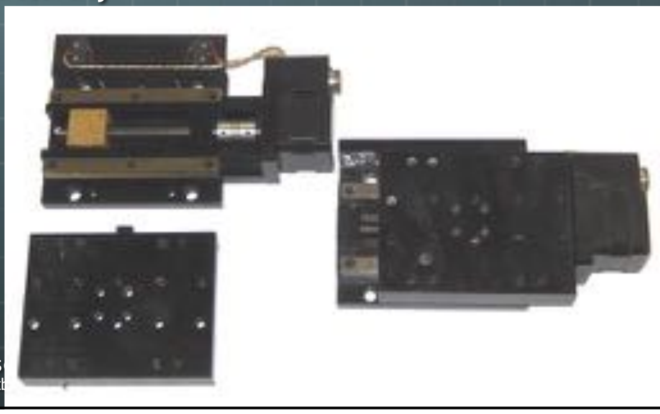
Normal low speed motion control stages

- Spring loading: Type 1
  - Spring connecting the stage and fixed supports
  - What could be problem with such arrangement?
  - Think!

How can we achieve Larger range?

Normal low speed motion control stages

- Discussion on Holmarc actual mechanisms: How to take care of backlash and get higher positioning accuracy



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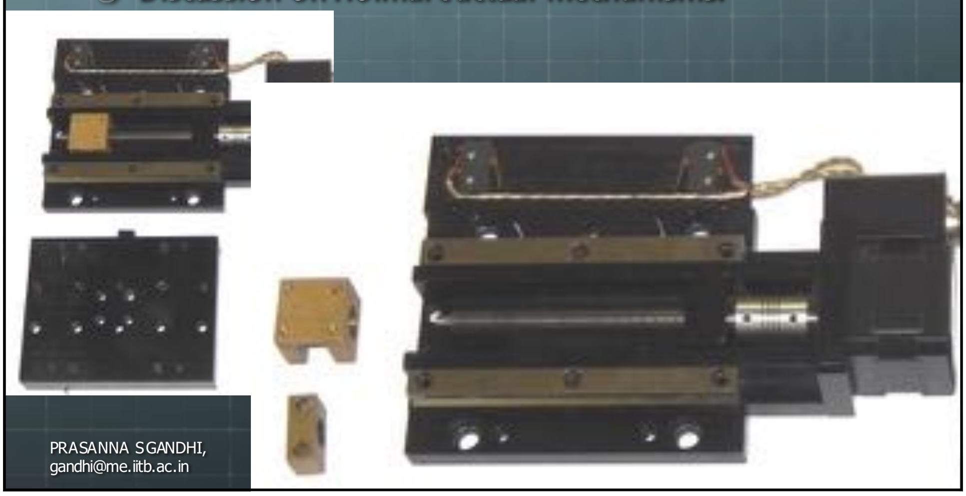
Normal low speed motion control stages

- Discussion on Holmarc actual mechanisms:



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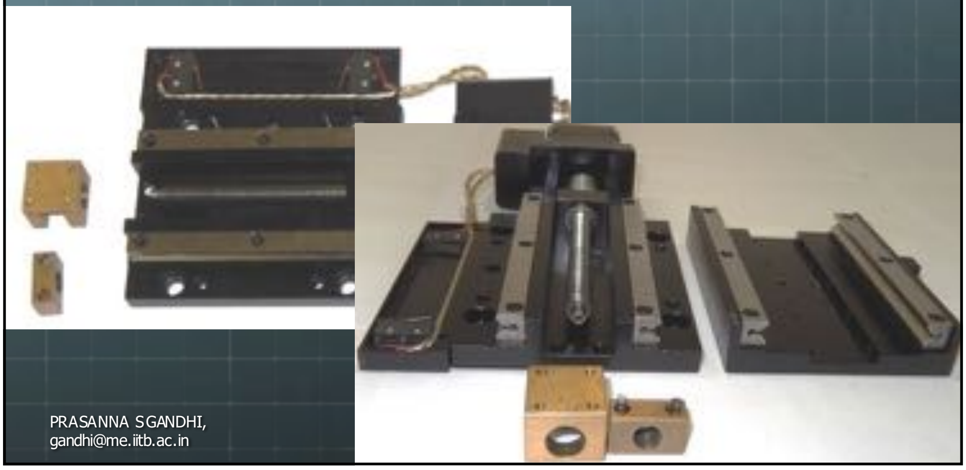
Normal low speed motion control stages

- Discussion on Holmarc actual mechanisms:



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Salient features: Motion stages with moderate resolution

- Manually operated OR
- Motor operated
- Fundamental issues:
  - Removing backlash: Achieved by spring loading
  - Maintaining parallel the axis of motion with the axis of lead screw which drives the stage: Achieved by a novel construction using slider nut
  - Arrangement to combine both these

The resolution/repeatability that can be obtained with this arrangement is 5 micron.

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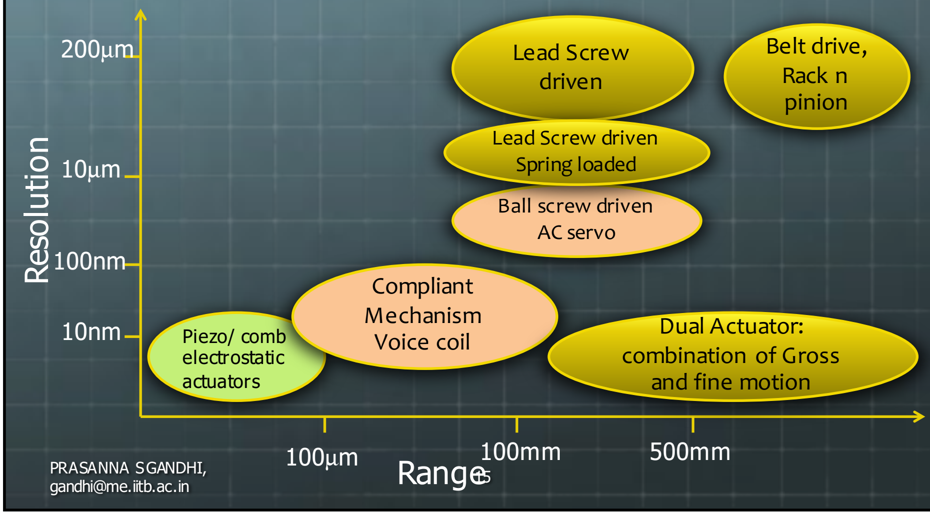
Linear motion control stages

Resolution Range Speed

- Typically high resolution systems would be small range and may or may not be high speed



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Use of compliance in motion control systems

- Advantages
  - High precision positioning with moderate range
  - High speed possible with good control implementation
  - No backlash
  - No wear and friction (good from control perspective)
  - Lower energy requirement
  - Higher durability
  - Less noise
  - No lubrication needed
  - Ultra low maintainance (no wear and tear)

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Use of compliance in motion control systems

- Basic motion elements

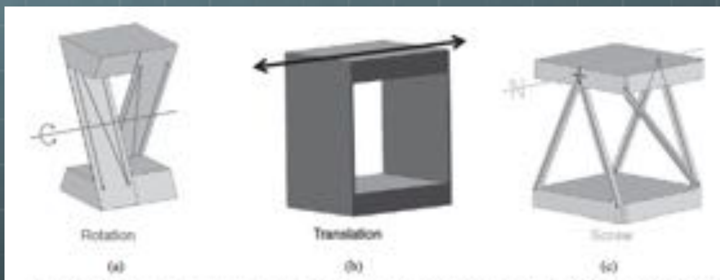
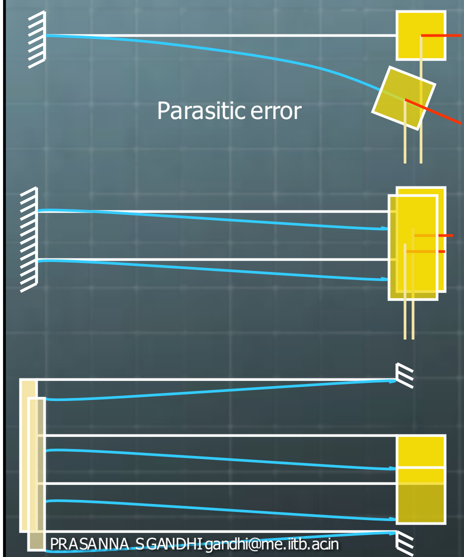


Figure 6.4 Parallel flexure systems that possess a single rotational DOF (A), translational DOF (B), and screw DOF (C)

Compliant Mechanism

Concept



- To implement idea with nanometric scanning resolution innovative use of double parallelogram flexure mechanism and mechatronic system around it

More links
https://compliantmechanisms.byu.edu/
http://www.flxsys.com/gallery

Various other possible compliant elements

- Two stage double parallelogram mechanism
- Rotary joint with compliant mechanism
- Bistable compliant mechanism

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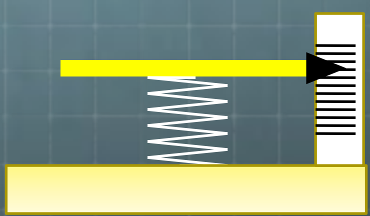
Enhancing Range: sensors with actuator



- Q: what happens to sensitivity when the range is increased and vice versa?

- Example: Measurement of weight
- What the sensitivity and range of measurement depend on??
- Stiffness of spring (assuming it to be only linearly moving spring) + spacings of markings on scale (for human eye to distinguish there will be limit on spacing)
- Aside point: If additional guides are there then friction will also play a role

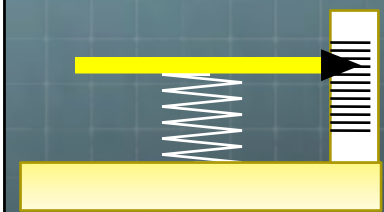
Enhancing Range: sensors with actuator

- Sensitivity decreases if we demand higher range: because in for higher range to be covered on a given length of scale we would require stiff spring.
- Hence minimum weight required to cause deflection corresponding to a unit measured spacing will be higher implying sensitivity decrease.

- Q: how to enhance range and at the same time have increased sensitivity?

Hint: Use an additional actuator inside the sensor system? HOW?

Enhancing Range: sensors with actuator



- Actuator needs to apply force to balance the external load and keep pointer to zero always.
- With pointer always pointing zero actuator force becomes equal to weight ☺ and further the measurement becomes independent of stiffness ☺
- To know how much force to apply using actuator, we need to keep track of where the pointer is → to achieve this, sensor signal should be available in electrical form (some conversion element like linear potentiometer or so would be required)

- Q: Can you suggest any mathematical way to achieve the zero positioning?

Hint: What should be the mathematical expression for the actuator force in terms Of feedback of displacement in this case?

Enhancing Range: sensors with actuator

- Thus we need a closed loop control system to read pointer position as feedback and give input to actuator continuously to make finally the pointer position zero
- One can suggest a simple expression with position measured as x and force of actuator as F

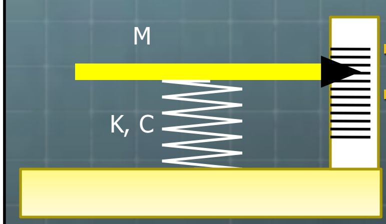
$$F = K_p(x_d - x) = -K_p x$$

- Where Kp is a constant (proportional) and xd is desired end point which is 0 in this case. The force in the steady state would correspond to the weight.

- Q: How can we know if the expression proposed will give proper result?
  We will need a model of the system to answer this question.

Enhancing Range: sensors with actuator

- What model do you think will represent the essential dynamics of this system?
- What are inputs and outputs?
- Input: actuator force and output is pointer displacement x. There will be dead weight of the platform say M and damping in the spring say C, so can you think of model? Say without friction.



$$F = M\ddot{x} + C\dot{x}$$

- Q: How can F has two expressions? Do you see the difference?
- The expression above governs how the system will evolve given F and the earlier expression dictates F based on feedback x. Substitute and you will see how the system is behaving.. And so on

Process of selection of project

- Innovative idea: something not done before
- Need to have some smartness built in (feedback/ closed loop control)
- Doable with available resources of machining
- You will have to do things yourself from scratch
- You may salvage some things from defunct instruments

Some ideas for project

- Single flexible beam motion control system
- Mini Atomic force microscope
- Smart plant watering system with least power consumption

Analysis of Compliant Mechanism

- Simple analysis for getting approximate solutions
- More detailed analysis: CBCM method, nonlinear FE analysis considering geometric nonlinearities
- Problem for links in compression: Account for buckling

Static Analysis

- Typical structures used in Compliant mechanisms
  - Cantilevers: single and multilayered structures with various loading conditions
  - Flexure beam mechanisms
  - Flexure hinges and rigid links
  - Torsion bars (rectangle or square)
  - One may need to consider buckling for structures in compression

Types of structural analysis and applications

	Typical structures and application	Analysis/theory required to be used for static and dynamic analysis
1	Cantilever, beams, single or multilayered: comb actuators, biosensors, compliant mechanisms, micromirrors, AFM, bilayer actuators,	Static: One dimensional -Beam bending theory-> mostly Euler-Bernoulli beam, multilayer analysis, thermal analysis Buckling theory for compression Dynamic: Euler Bernoulli beam with assumed modes method, FE
2	Torsional bars: rotating micro mirrors,	Static: Torsion theory Dynamic: vibration
3	Plates circular, rectangular: Pressure diaphragms, diaphragm micromirrors,	Static: Two dimensional stress analysis (FEM) Dynamic: FE

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Static Analysis Tools

- Euler-Bernoulli beam theory (shear in most cases can be neglected)

$$\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y} \qquad M = EI\frac{d^2y}{dx^2}$$

$$I = \int y^2\, dA \quad \text{Example } I = \frac{1}{12}bd^3 \text{ for rectangle}$$

- Multilayer structure analysis
- 2D plate theory analysis: diaphragms
- Thermomechanical analysis
- FEM analysis tools

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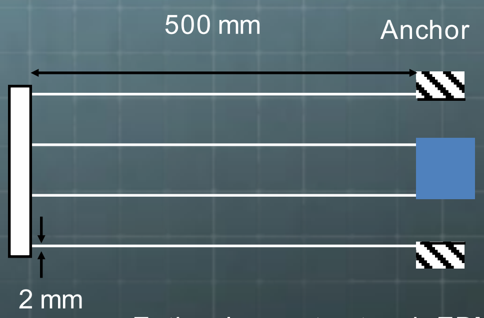
Static Analysis: Examples

Example 1:



Entire planar structure is EDM machined out of 35 mm thick slab

- Aim: to determine actuation force needed to move mass by say 5 mm?

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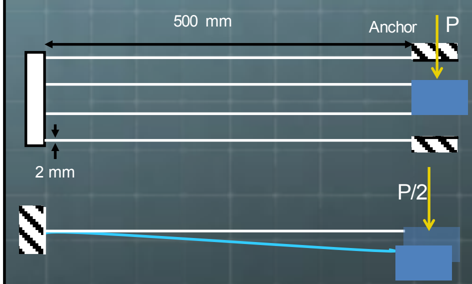
Static Analysis: Examples

Example 1:



- Q: Do we know moment at any section?

- Breaking of structure into sub components
- Consider one member further to carry out its analysis
- Can you see boundary conditions to be used and equation to be used?
- Lets start with small deflection assumption and Euler Bernoulli beam theory

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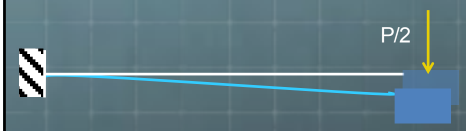
Static Analysis: Examples

Example 1:



- Since the moment is unknown we consider the equation in terms of shear force:

$$M = EI\frac{d^2y}{dx^2} \; and \; \text{Shear force } S = EI\frac{d^3y}{dx^3}$$

- Q: What are the boundary conditions?

$$\frac{dy}{dx} = 0 \text{ at both } x = 0 \text{ and } x = l$$

$$EI\frac{dy}{dx} = \frac{P}{2}\frac{x^2}{2} - \frac{Pl}{4}x$$

$$EIy(x) = \frac{P}{4}\frac{x^3}{3} - \frac{Pl}{4}\frac{x^2}{2} + C$$

$$EI\frac{d^3y}{dx^3} = \frac{P}{2}$$

$$EI\frac{d^2y}{dx^2} = \frac{P}{2}x + C_1$$

$$EI\frac{dy}{dx} = \frac{P}{2}\frac{x^2}{2} + C_1x + C_2$$

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Static Analysis: Examples

Example 1:

- Another boundary condition y = 0 at x = 0, hence C = 0.

$$EIy(x) = \frac{P}{4}\frac{x^3}{3} - \frac{Pl}{4}\frac{x^2}{2}$$

- Q: What are the boundary conditions?

- To get deflection at the end point x = l

$$EIy(l) = \frac{P}{4}\frac{l^3}{3} - \frac{Pl}{4}\frac{l^2}{2} = \frac{Pl^3}{24}$$

$$y(l) = \frac{Pl^3}{24EI}$$

- This is only half part. Considering other half deflection will be

$$y(l) = \frac{Pl^3}{12EI}$$

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Static Analysis: Examples

Example 1:

- Another way of looking at the same problem is by considering stiffness of each of the members seen at the end point.

$$y(l) = \frac{Pl^3}{12EI}$$

$$K = \frac{12EI}{l^3}$$

- And then springs in parallel or series.. Can you think for this problem?

Smart Sensors

- Concept: how can sensor be made smarter to cater for various needs