Microrobotics

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Week- 02

Lecture No- 06

MicroMechanics System Design (Design of Microrobots) - Module 01

This lecture will discuss micromechanics system design under module two in the micro robotics course. In this micromechanics system design, we will be discussing the micromechanics systems, micromechanical analysis with reference to static conditions, the energy methods for elastic beams with reference to dynamic conditions, the design and selection of materials for micro robotic systems, and control for surface walkers. These are some kinds of basic fundamentals that will be helpful in understanding the available micro robotic systems as well as in designing the micro robotic system based on the requirements. Let us understand through a simple case study; in this particular case study, the main motto is to establish a biomimicking micromanipulation robot in the form of a caterpillar. Essentially, it aims to biomimic caterpillar motion. If you closely observe the movement of this caterpillar, its motion is called two-anchor crawling motion.

It is called two-anchor crawling motion because there are two legs, so this is position one and this is position two. So for the locomotion, ideally, first the position two, that is the leg two, will try to anchor it, and then it will try to pull leg one towards leg two. By sequencing this particular operation throughout, locomotion is exhibited here. In this particular locomotion, we can also manipulate it on a micron level and, in certain cases, manipulate it on a macro level.

However, since the main motto is for a micron level, we may need to closely observe the different mechanisms that are involved in it. This mechanism has potential applications in micro-manipulation in the electronics industry, surveillance applications, handling some delicate components, moving delicate components, etc. For exhibiting or demonstrating this particular micromechanism, a PLA material was used. This PLA material was baked in such a way that it becomes flexible. We have bounded the shape memory alloy structure.

These shape memory alloy structures will be actuated using a kind of joule heating by applying an electrical pulse to them. In this particular case, while programming our shape memory alloy and while integrating the shape memory alloy into these PLA structures, we could establish two different types of locomotion. One locomotion is something like this: if there is a kind of structure over here, and when we try to wound a shape memory alloy structure in this, by actuating the shape memory alloy appropriately, there will be a kind of diametrical increase and decrease in the structure. This diametrically changing structure will be helpful for us for forward locomotion. Once this diameter is reduced and once this diameter is increased appropriately, it will take a positive direction.

Similarly, once this diameter is decreased and once this diameter is increased, we get a negative direction. So, this kind of locomotion is what we call peristaltic locomotion. In addition to this, one more locomotion, which we also call a single stair arrangement, is presented here. In the single stair arrangement, as shown here, what we have performed is almost equivalent to a two-anchor crawling system. In this two-anchor crawling system, one end of the shape memory alloy is fixed here and the other end of the shape memory alloy is fixed there.

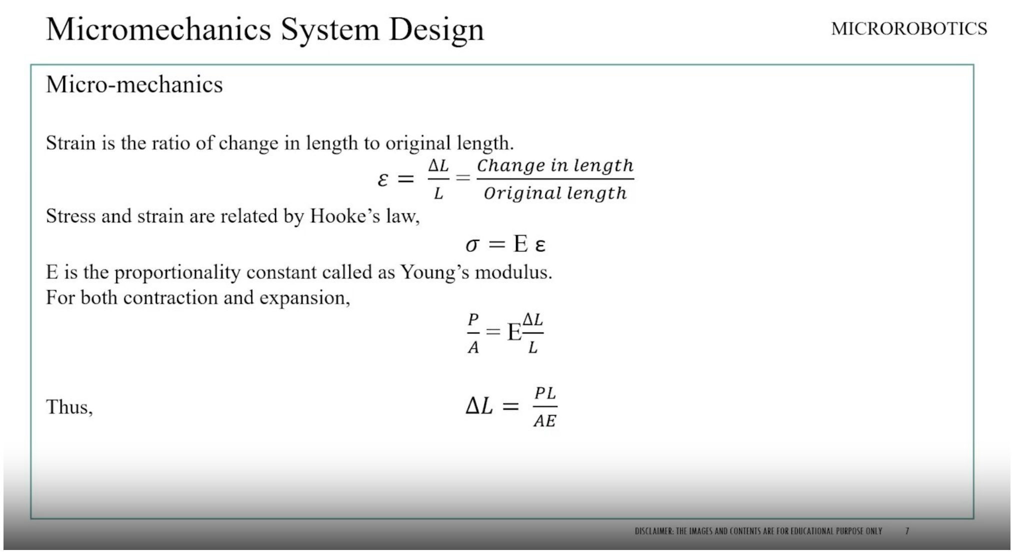
By actuating it, you get a positive and a negative displacement; that is, by actuating it, we get a kind of compression in the spring, which leads to a kind of compression in the entire PLA structure. When the PLA structure is arranged in such a way that inside we have a kind of single-end spring. This single-end spring will be capable enough in such a way that it is called a self-energized spring. This self-energized spring will try to pull back so that we can create a kind of peristaltic locomotion. Now, from this particular case from an experimental perspective, we performed the experiments and established the locomotion.

However, there is a need to understand the physics and the design behind this. The first micromechanics will discuss a microrobot that is considered in both rigid and flexible deformation. When microrobots use both rigid and flexible deformation of the element to achieve a desired motion, the element can be of different shapes such as rod, beam, membrane, plate, shells, etc. In this particular case, a rigid motion versus deformable motion in solids, microsystems have both types. In this particular case of a rigid body, no relative motion occurs between points, as in the movement of the block above and the rotation of the crank below.

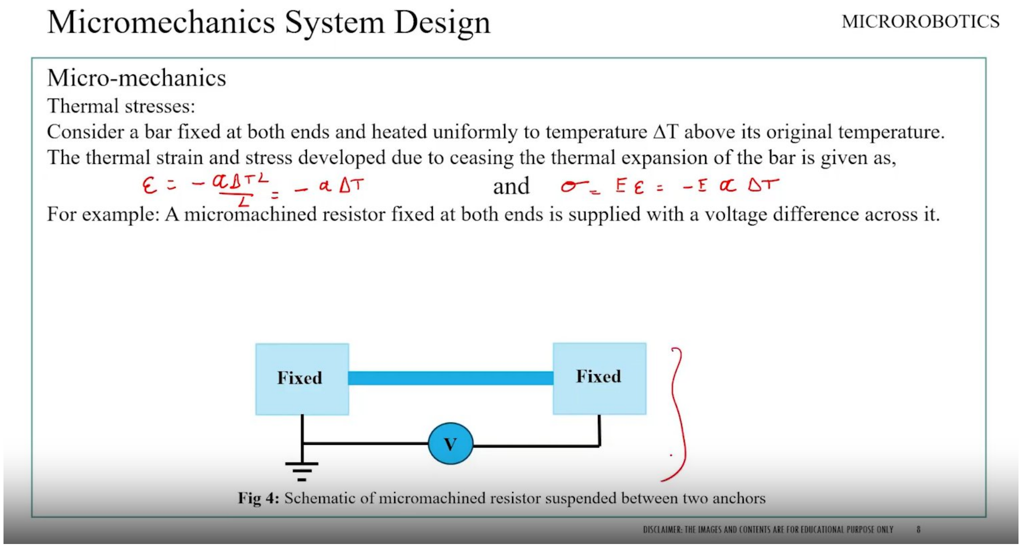
However, in the case of a beam, we have relative motion between the points when the bar stretches above or bends below. Let us consider a bar in a static state that can stretch or contract without bending. The bar is fixed at one end, and a load is applied at the other end. In this particular case, considering two different conditions: in the first condition, a bar is under a single load, and the internal force P is the same throughout the bar; in another condition, where the bar is under two loads, the internal force is different in sections of the bar. The stress acting through the length of the bar is represented as

$$\sigma = \frac{P}{A}$$

So, in this case, for uniform sections of the bar, the stress is the same throughout. For varying cross-sections of the bar, the stress varies while the applied load is the same throughout. For example, the conical or pyramidal tip of an atomic force microscope. In the case of a pyramidal tip, there is a kind of stress that is the same throughout, whereas in the case of a conical tip, there is a focused applied load that is exhibited here. Now, when I talk about the micromechanics perspective, let me just introduce you to some of the basic concepts.

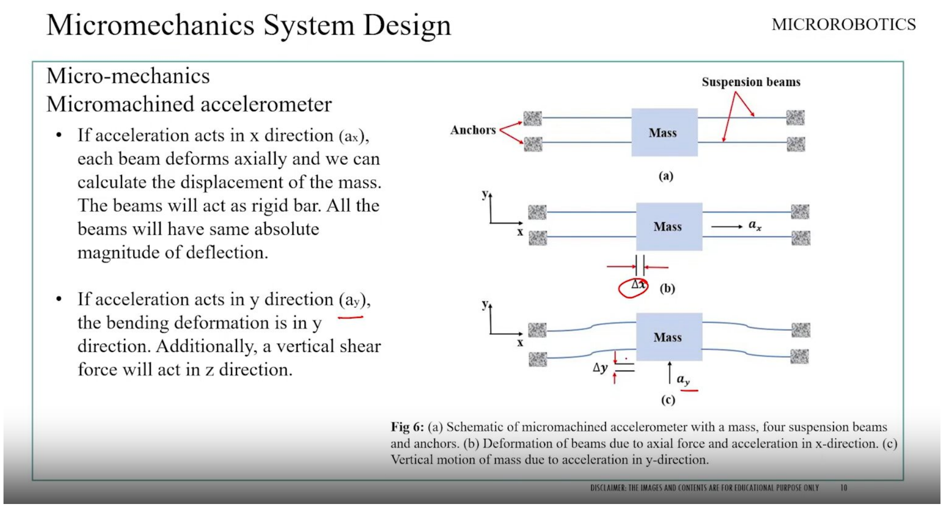


One type of strain is the ratio of change in length to the original length, which is represented as $\boldsymbol{\varepsilon}$ and is equal to ΔL by L, which basically corresponds to the change in length by the original length. Stress and strain are related to Hooke's law, which is represented as σ equals E$\boldsymbol{\varepsilon}$, where E is the proportionality constant, called Young's modulus, which applies to both contraction and expansion. Now, considering the equation of the earlier σ, when we try to equate it, P/A equals (E ΔL)/L. Thus, del L equals PL/AE. Now, let us consider that this is a kind of generalized equation that is used for a simple system.



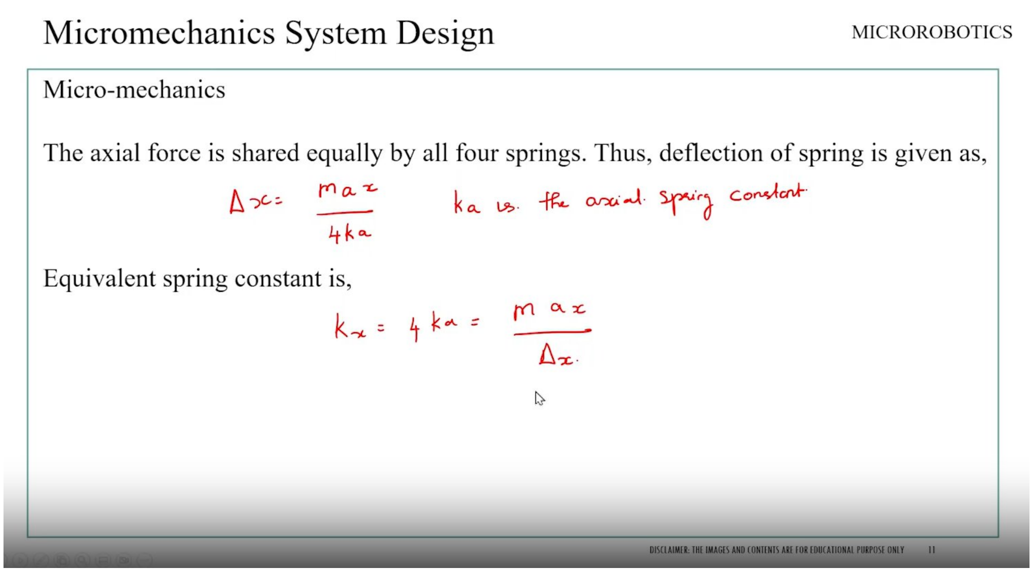
Now, let us consider the micro mechanics of thermal stresses. Consider a bar fixed at both ends and heated uniformly to a temperature ΔT above its original temperature. The thermal strain and stress developed due to the thermal expansion of the bar is given as $\boldsymbol{\varepsilon}$ equals $(-\alpha\Delta T\ L)/L$, which is $(-\alpha\Delta T)$, and σ equals E$\boldsymbol{\varepsilon}$, which is nothing but $(-E\alpha\Delta T)$. For example, a micromachine resistor fixed at both ends is supplied with the voltage difference across it. This is a kind of structure that is suspended between the two anchors.

Similarly, when we try to consider a kind of transformably deformable element or beam, this is a kind of load applied in a transverse direction to the length of the beam, which deforms the beam in the transverse direction. The deformation is calculated using beam theory. In order to calculate the deformation, let us consider a beam under a tip load F in the transfer direction. This is an example of a simple micromachined accelerometer. In this accelerometer, if I try to introduce it, we have a mass in place, then there are two anchors, and there are two suspension beams.

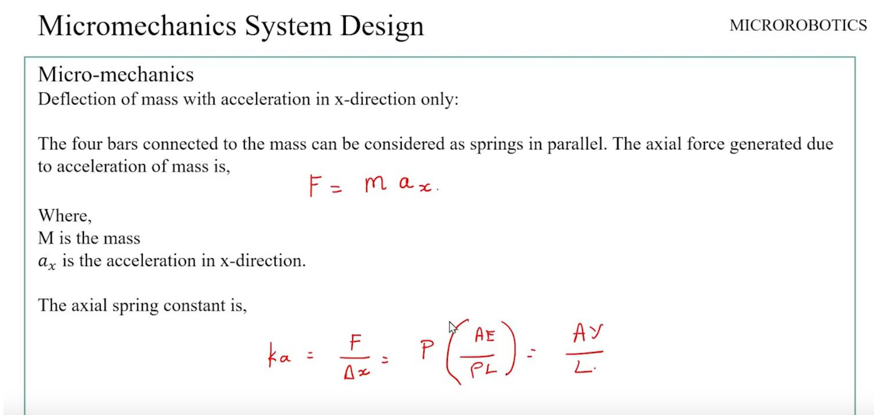


In this schematic, a micromachined accelerator with the mass of four suspension beams and anchors is present. Now, the deformation of the beam is due to axial force and acceleration in the x direction, while the vertical motion of the mass is due to acceleration in the y direction. With reference to the x direction, it is represented as Δx. If the acceleration acts in the x direction a_x, each beam deforms axially, and the displacement of the mass is calculated. The beam will act as a rigid bar.

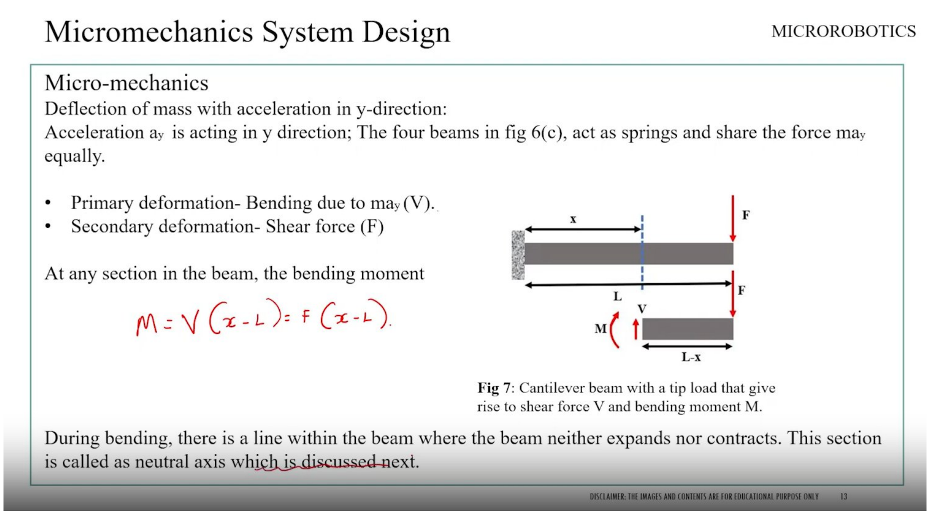
All the beams will have the same absolute magnitude of deflection. If acceleration acts in the y direction, we term it a_y, which is represented here. The bending deformation is called the y direction. Additionally, vertical shear force will act along the z direction. The micromechanics of this particular aspect are concerned.



The axial force is shared equally by all springs. Thus, the deflection of the spring is given as Δx equals (m×a)/4k_a. So k_a is the axial spring constant. Similarly, when we try to calculate the equivalent spring constant, it can be represented as k_x equals 4k_a, which is nothing but max divided by Δx. Now, when we try to consider this, the deflection of mass with acceleration in the x direction only involves the four bars, which can be represented as F equals, and the four bars connected to the mass can be considered as springs in parallel.



The axial force generated due to the acceleration of the mass can be represented as F equals (m×a_x), where m is the mass, a_x is the acceleration in the X direction, and the axial spring constant can be considered as K equals F by ΔX, which is nothing but P(A×E/P× L), which is (A×Y/L). Now let us take a deflection of mass with acceleration in the y direction. In this case, acceleration a_y is acting in the y direction. So the 4 beams that we mentioned here, which are nothing but the 6C configuration, act as springs and share the force equally. Primarily, the deforming bending due to the load is considered as V, and the secondary deformation shear force is considered as F.



At any section of the beam, the bending moment can be considered as M equals V(x-L), which is equal to F(x-L). So, in this particular case, if we try to nomenclate it, we have a kind of cantilever beam with tip T, the shear force V, and the bending moment M. During bending, there is a line within the beam where the beam neither expands nor contracts, and this section is called the neutral axis. Now, when we try to look into this, it is referred to as the neutral axis of the plane or the axis. In this case study, we were involved in establishing a jellyfish-like structure.

The main focus of the jellyfish-like structure is, in order to fabricate this jellyfish-like structure, what we did was keep a small piece of polyimide. In this, kapton polyimide integrates a shape memory alloy structure. In this shape memory alloy structure, we are trying to actuate the shape memory alloy in such a way that there will be a kind of bending, which is a form of actuation and deactivation that will result in bending in this particular system. Now in order to ensure the kind of a static or in order to ensure a kind of a dynamic analysis in this particular system. So what we have done is that this is a kind of Kapton polymer.

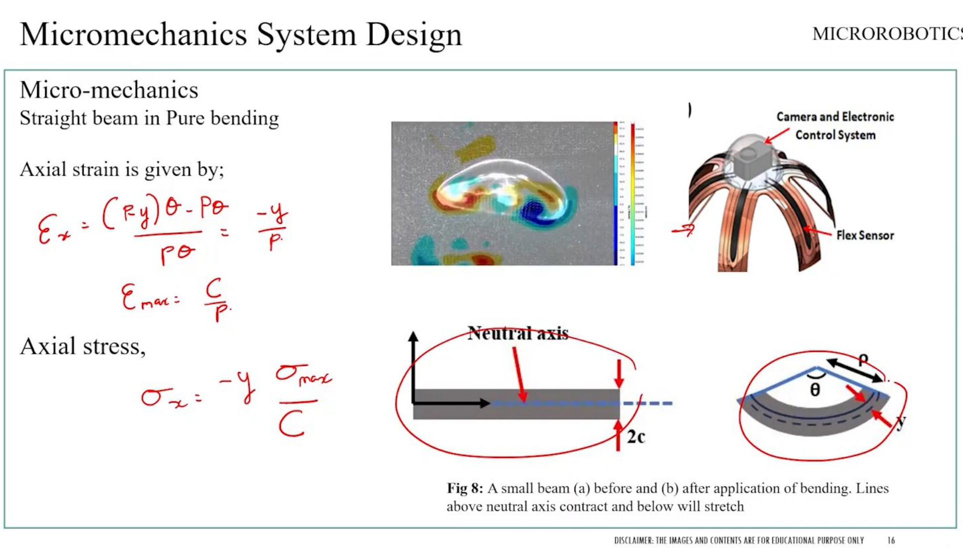
In this Kapton polymer, we take care of the retraction. A rubber string is established. However, in order to take care of the actuation, the SMA-integrated polyamide was established. In this SMA-integrated polyamide, small holes were drilled in the polyamide using a laser, and the SMA wires were strained up to 2%, and these strained SMA wires were integrated with these polyamide structures. This will result in actuation in the SMA, which will lead to deflection in the polyamide structures.

So what we are trying to do is integrate these strained SMA wires into these Kapton polyamide structures, which are well encapsulated using a kind of Kapton tape that will be integrated into the system. This becomes a kind of integrated structure with Kapton tape and Kapton polyamide, which are available, and these integrated structures are fixed into the rubber material. Since a two to three percent strain is already induced into it, one way of actuation is taken care of by the shape memory alloy, and the return stroke is taken care of by the Kapton polyamide, which is available here. So the main function of this Kapton polyamide is that the return stroke is taken care of, and the positive actuation stroke is taken care of by the shape memory alloy. However, in order to support the Kapton polyamide, an additional rubber string was also connected to this Kapton polyamide in such a way that there is a kind of actuation that exists.

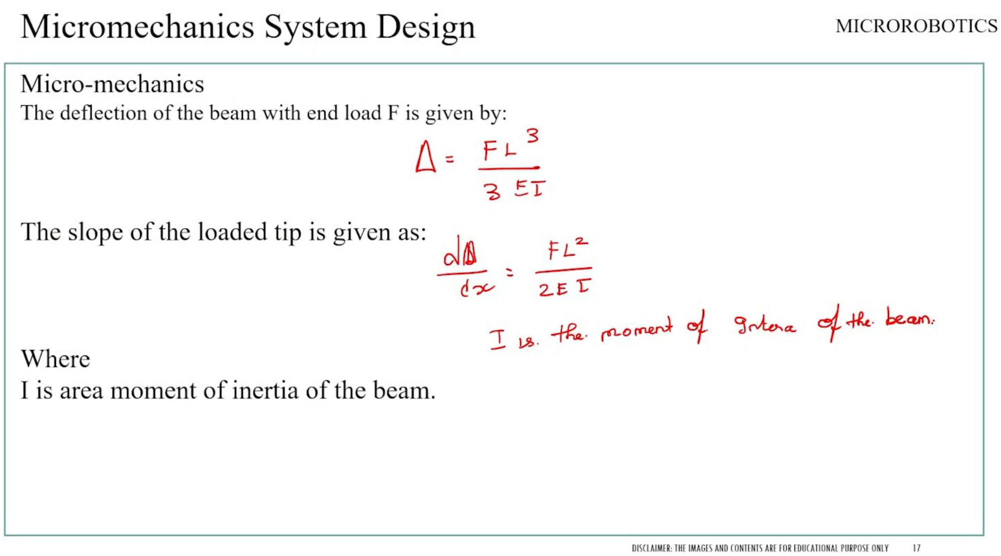
Through this actuation, we can have a continuous pulling of this particular SMA structure, which will result in a kind of bending in both directions. Let us consider whether there is a cantilever structure available here and if there is an SMA integrated with the wire. So what happens is that by actuating it, we can have a kind of continuous actuation. In fact, we can have control over the frequency. In this particular case, one of the important aspects is that we consider each tentacle of this particular SMA-based jellyfish structure, and these jellyfish structures, the deflection in these jellyfish structures was completely analyzed in such a way that each and every jellyfish structure, tentacles of the structure are considered as cantilevers, and with reference to the cantilever, the deflections were studied.

Now, one important aspect is that there is going to be a kind of change in the expansion and contraction. The expansion and contraction need to be appropriately studied, and they need to be modeled to study the overall waviness because frequency has a direct impact on swimming capability. Now we have done a kind of kinematic modeling of the system. In this kinematic modeling, we integrated the SMA-based structure and also performed an operation that exhibits in such a way that we can study the waviness and the kinematic analysis of the system. Now in this particular case, two important aspects come into the picture.

One is a kind of neutral axis which exhibits; the other one is a kind of curvature or waviness which may need to be studied in detail. Now, with reference to this neutral axis, if you try to see, this is a kind of actual jellyfish structure which is a model, and this is a prototype jellyfish structure that we are trying to mimic to create a motion similar to that of an actual jellyfish. In this particular case, there is a need to understand the neutral axis, and there is also a need to understand the overall curvature and the waviness that is exhibited here. So in this particular case, there is a need to understand the axial strain. Let us consider this beam to be a pure bending beam.



So the axial strain in the beam is considered as $\boldsymbol{\varepsilon_x}$ equals ((P-y)θ - Pθ)/ Pθ equals (-y)/P. So, $\boldsymbol{\varepsilon_{max}}$ equals C/P. Similarly, when we talk about the axial stress, the axial stress is $\boldsymbol{\sigma_x}$ equals (-y) $\boldsymbol{\sigma_{max}}$/C. Here, P corresponds to the overall length, and θ corresponds to the overall angle that is generated, and there is a y parameter that is exhibited here. So, the main function of the y parameter will take care of the overall bending characteristics in this particular system.



Now the deflection of the beam S, which is loaded with F, is given by

$$\Delta = FL^3 / (3EI),$$

and the slope of the loading tip is given as

$$d\Delta/dx = FL^2 / (2EI),$$

where I is the moment of inertia of the beam.