Micro Robotics

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Week-2

Lecture-8

Micro-Mechanics System Design (Design of Microrobots) - Module 03

Let's discuss unimorph and bimorph concepts. These unimorph and bimorphs are used in different smart material-based actuator devices. In the previous section, shape memory alloy bimorphs and piezoelectric-based bimorphs were discussed. So, in the case of piezoelectric or shape memory alloy bimorph actuators, the degradation of these actuators basically depends upon continuous actuation, as well as continuous overloading, which results in the raising of residual stress in the SMA bimorph. This effect of residual stress impacts the overall life cycle of the SMA actuator, where the actuator can be made of an SMA bimorph or an SMA spring. We have used two shaped memory alloy springs, which relate to two hooks in a fixture. With the help of a programmable power supply, the joule heating was applied to them in a programmed fashion, and a load was attached to the springs. The springs will expand due to the load and return to their original position when an electrical supply is applied to heat them. A continuous loading and unloading of the SMA springs will happen in due course of time. The joule heating from the electrical supply exhibits thermal heat over the springs.

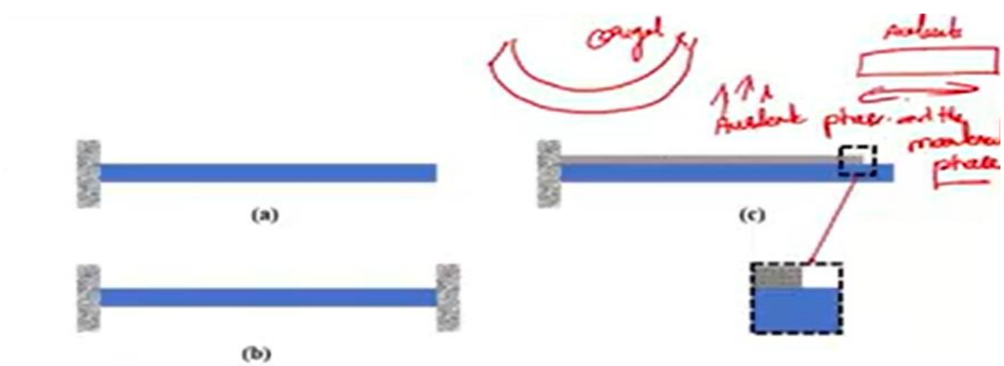


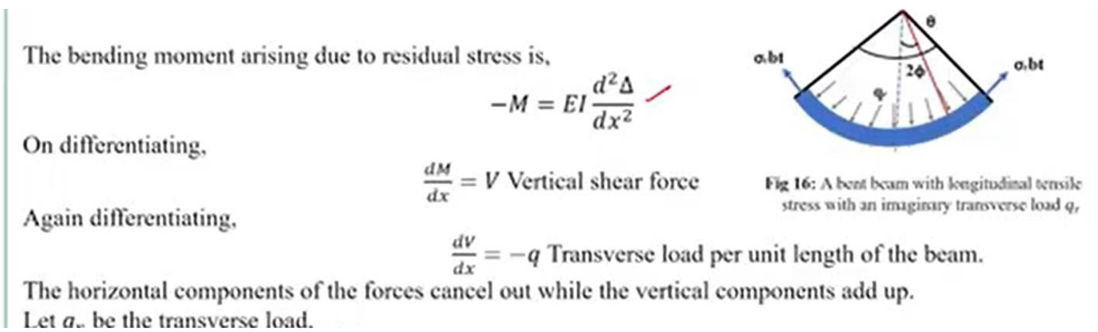
Fig 15: Effect of residual stress along the length (a) a fixed-free beam simply expands or contracts (b) Both side fixed beam with no bottom constraint holds the stress within and (c) A fixed-free beam adhering to the substrate at bottom

Hence, it shows a strong impact on the SMA springs in the form of actuation in such a particular system. Such thermal heating in the springs attracts more oxide formations on the surface. So, when these springs are actuated, they will try to break the oxide film. Later, in due course of time, the oxide formation starts getting percolated into the lattice of these shape memory alloy structures, leading to the formation of defects. Hence, it results in the breakage of these springs. Therefore, the actuation behavior of the SMA spring slowly degrades. The impact of the residual stress is very small in spring. But in the case of a bimorph, a shape memory alloy was deposited on a polyamide sheet, where the sheet was stretched during the deposition. So, it is in a strained condition during deposition. Initially, the polyimide has a curled structure in normal conditions.

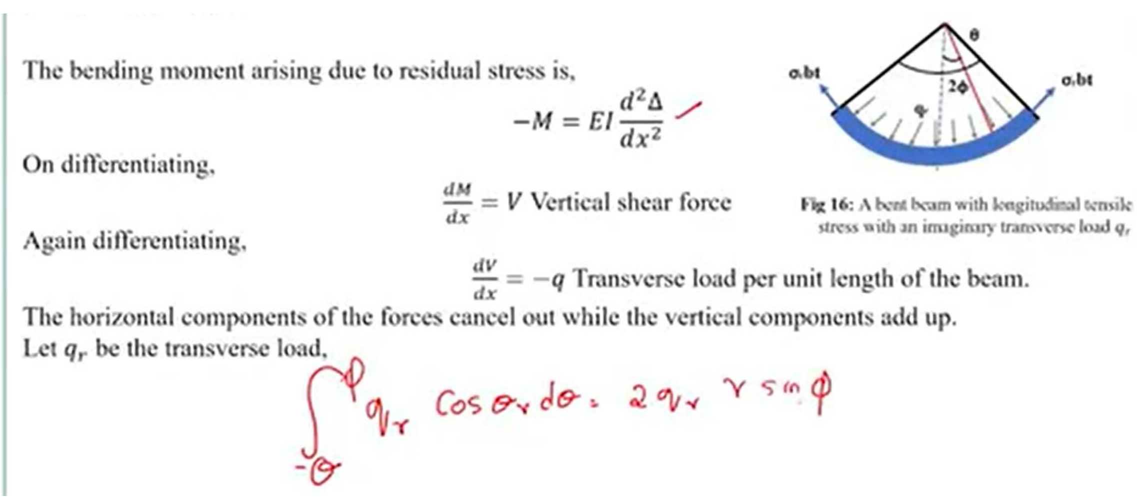
It is in a flat structure due to the applied strain during deposition. Therefore, when we supply heat to the bimorph, it becomes straight. Hence, in the ambient condition, it is in a curled structure, and in the actuated condition, it becomes straight. So this behaves like switching between the austenite and martensite phases. of SMA. Hence, we can use these shape memory alloys for the fabrication of high-frequency actuations mostly used in micro robotic systems. It deploys a kind of stick-slip motion or one kind of peristaltic motion. A similar peristaltic motion can be evolved with such a micro-robotic-based system where continuous actuation and deactivation are employed within a short displacement. Therefore, it has a restriction toward a particular frequency. As we strain the Kapton polymer before deposition, there is a chance of residual stress being imparted to it.

Now, when we heat or cool it for multiple cycles, it will be in actuated and non-actuated conditions for a larger life cycle; hence, residual stress will start building up and lead to failure. Now, as far as residual stress is concerned, we try to investigate the effect of residual stress along the beam. So, let us consider a fixed-free beam that simply expands and contracts, and the fixed beam with no bottom constraint holds the stress within this. Similarly, when you try to see over here, a fixed-free beam is adhering to the substrate at the bottom. So, these residual stresses in the micro-mechanical system may arise due to the following reasons. One is due to a thin film depression. Another reason might be due to the thermal expansion of the material. In this case, it is a kind of heterogeneous material. So, there will be varying thermal expansion that is exhibited here. Then oxidation, substitutional doping, or ion implantation during the microfabrication will also contribute to raising a certain amount of residual stress or imparting residual stress into the material.

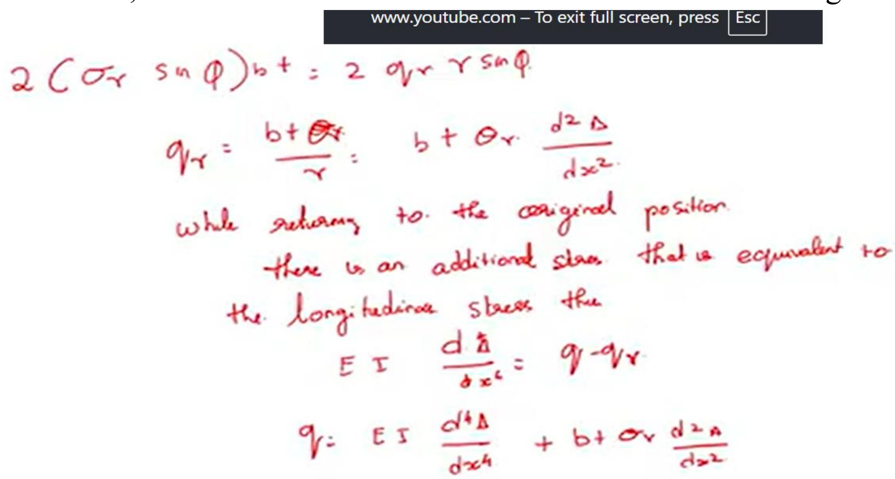
The most important aspect is the lattice mismatch in epitaxial growth. Therefore, in the fabrication of a shape memory alloy bimorph, we ensure that the Kapton polyamide has a good match with respect to the shape memory alloy, so that the lattice mismatch is eliminated and proper epitaxial growth is achieved. In case there is no proper epitaxial growth, it may result in poor adhesion. In due course of time, the shape memory alloy thin film may peel off from the substrate. Next, in this case, there is a shear force that acts at the right face of the beam in the case of this particular C. This is also one of the key points that we may need to consider. Now, when we try to investigate the overall micromechanical behavior, the bending moment arises in the SMA bimorph, which is a kind of curled structure occurring under cooling conditions. This is a kind of bending moment that arises due to the residual stress or the stress that has been incorporated here. So, to quantify this residual stress, it is represented as minus m, which is equal to E times I d squared del by dx squared. On differentiating this with reference to dm by dx, we find that v is the vertical shear force.



And again differentiating, we get dv/dx equals minus q, which is the transverse load per unit length of the beam. The horizontal component of the forces cancels out while the vertical component adds up. Let QR be the transverse load. Now, the transverse load can be represented as θ by φ QR cos θ R dθ, which equals 2qr r sin φ. So, 2θr sin φ BT equals 2qr r sin φ and qr equals b t σr b t θr by r, which is nothing but b t θr d² del by dx².

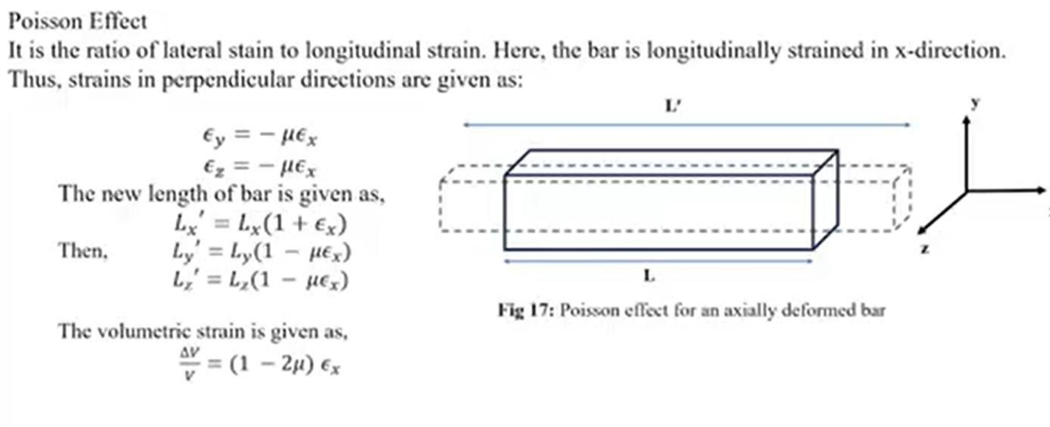


So, while returning to the original position, an additional stress is generated that is equivalent to the longitudinal stress. Thus, E_i d^4 del by T_x^4 equals q minus q_r, where q equals E_i d^4 del by dx^4 plus B_t sigma_r d^2 A by dx^2. So, this is the kind of force, like a transferred load, that gets generated because of the bending moment arising from the residual stress incorporated into the system. Now, we are discussing the Poisson effect of such a structure. So, the Poisson's effect is the ratio of lateral strain to longitudinal strain.

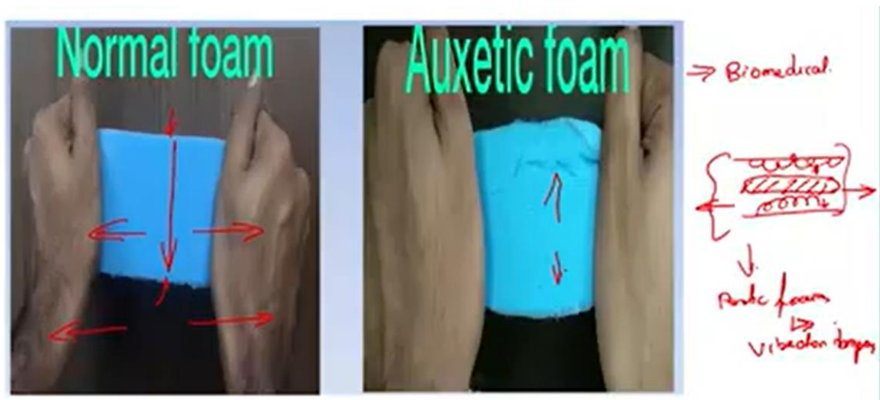


Here the bar is let us consider a bar of length l. So, the bar is longitudinally strained in the x direction. The strain in the perpendicular direction is given as epsilon y equals minus mu epsilon x, and epsilon z equals minus mu epsilon x. So, the new length of the bar is given as $L' = L_1 + \varepsilon_1$ and then $L'_\gamma = L_\gamma - \mu\varepsilon_1$ and $L'z = Lz - (1 - \mu\varepsilon_1)$. So, the volumetric strain is given as $\Delta V/V = 1 - 2\mu\varepsilon_1$.

So, this Poisson ratio has played a vital role. We are discussing different types of foams that are being efficiently used for gripping applications in micro robots. In certain cases, these kinds of foam are used to manipulate inside tubes, and in some cases, they are used as vibration arresters or vibration holders for a system. Now, relating to such poisonous effects, the auxetic structure is introduced. The auxetic structures are smart materials that have potential applications in micro-robotic-related domains. So, if we closely observe these auxetic structures or auxetic foam, they have the capability to have a negative Poisson ratio. The negative Poisson ratio is described as the case of a normal foam, as shown here in this figure. So, when I try to pull it in this direction, it is expected that the dimension will be reduced along the breadth, and it will be appropriately compensated along the length. This is a kind of simple Poisson ratio. In the case of the auxetic form, when we try



to pull it, the structure will also expand.



That is, the expansion is observed along the breadth. This concept is known as a negative Poisson's ratio. So when we try to look into the overall aspect, this kind of structure was largely investigated in 2012. In 2012, the first paper on auxetic structures was reported. Later, there were many researchers who worked on this auxetic structure.

They also worked on 3D printing these auxetic structures and the use of these auxetic structures for different applications. Since this kind of auxetic foam has a negative Poisson ratio, it has potential applications in the biomedical field. For example, if there is a wall blockage, this kind of auxetic foam-based structure can be integrated. Then, when we apply a kind of elongation in this orientation, there will automatically be an expansion in this direction. This expansion will support the removal of the blockage.

So this is one advantage of this system. In addition to this, such kinds of auxetic foam can be efficiently used for vibration damping. So, it can be used as a kind of vibration arrester. Since there is elongation happening along the width or along the dimension, it has potential applications for arresting vibrations. This is one advantage of this auxetic form with a negative Poisson's ratio.

Hence, consider some generic aspects related to the micromechanics of the torsion of a beam. Consider a simple circular beam to discuss the fundamentals of the micro-mechanical effects in different beams. Let us take a simple circular beam. In this circular beam, consider the length of the circular beam as L, the twisting occurring at an angle theta, and r as the radius. So, the length L and r, which is the radius of the beam, are subjected to a torque T, and the modulus of rigidity of the bar is represented as G equals E by 2 by 1 plus mu, and the beam rotates by an angle theta.

The shear stress generated is given by τ equals G θ r by L, which is nothing but T r j. J is the polar moment of inertia of the beam, which is useful in torsional springs and the spiral-shaped actuators discussed earlier. Now, while discussing the dynamics of the system, we need to understand the usage of this spring-mass under a damper system. In order to understand any kind of dynamics, it is better to consider a spring-mass system under a damper. So, in this particular case of the spring concept, m is the mass and b is the dashpot, which is a damper that is used.

A beam of length L and radius r is subjected to torque T.
The modulus of rigidity of bar is

$$G = \frac{E}{2(1+\mu)}$$

The beam rotates by angle θ.
Shear stress generated is given by,

$$\tau = \frac{G\theta r}{L} = \frac{Tr}{J}$$

Where, J is polar moment of inertia of the beam.

Useful in torsional springs and spiral shaped actuators.

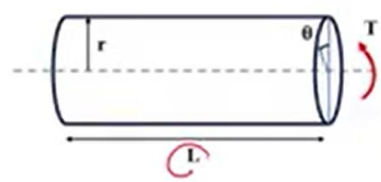


Fig 18: Twisting of circular beam under torque

Thereafter, when we study the force acting on it, the force f of t is represented as m d^2x/dt^2 + b dx/dt + kx. k is the spring constant, and b is the damping coefficient. Hence, k is introduced, b is introduced, x is along the plane, and f of t is the type of force that is exerted. So, when we try to represent this in the form of a free-body diagram, the force is exerted in this direction of the free body. there is a kx and then there is a mass m d squared x by dt square and b dx by dt.

The forces acting at every instant are given as,

$$F(t) = m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx$$

where.,
k is the spring constant
b is the damping coefficient

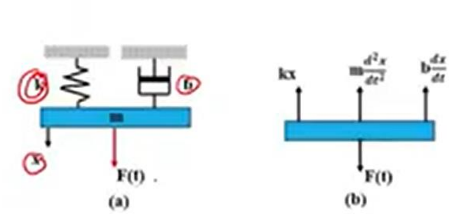


Fig 19: A spring mass damper model and its FBD

So, this is a kind of a spring mass damper model, which is being established. Next, one more important aspect with respect to this overall component or the overall characteristics, which we call the Coriolis component. Main example of this Coriolis component is a Foucault pendulum. This is an overall schematic of a Foucault pendulum, where the pendulum rotates on the z-axis. The ball is oscillating along the y-axis and experiences a Coriolis acceleration along the x-axis. Now, let us consider v is the velocity of the ball with the moving frame. Omega is the angular velocity of the moving frame relative to the fixed freedom and the Coriolis acceleration is given by AC equals 2 V omega. So, the Coriolis component is applicable in mechanisms such as micro machine tuning force, as well as dual mass vibration gyroscopes. These are some of the applications of this Coriolis component. So, overall Coriolis acceleration is given as AC equals 2 V omega, which is represented over here appropriately.

V is velocity of the ball with moving frame.
Ω is the angular velocity of the moving frame relative to fixed frame.
The Coriolis acceleration is given as,

$$a_c = 2V\omega$$

The Coriolis component is applicable in mechanisms such as micromachined tuning fork and dual mass vibrating gyroscopes.