

**Compliant Mechanisms: Principles and Design**  
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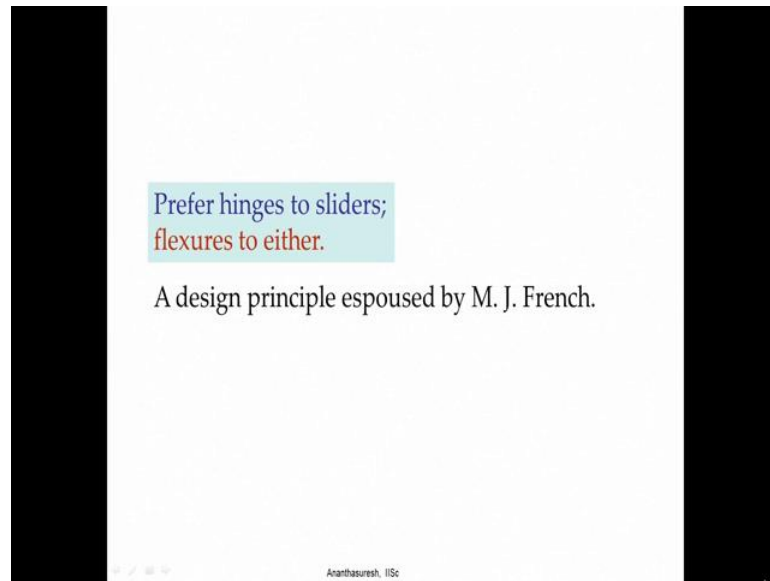
**Lecture – 02**  
**Spirit of compliant design**

Hello again, we looked at in the first lecture an over view of compliant mechanisms, were we considered how they are different from rigid body mechanisms. Rigid body mechanisms have rigid bodies connected with kinematic pairs, whereas compliant mechanisms have either elastic pairs or elastic segments or even both; you can have both elastic pair's elastic segments in one and achieve compliant mechanisms. Here we have elastic deformation use to transmit motion, force and energy or even transform energy as we saw in the case of in electro thermal elastic actuate.

Now in this lecture, let us look at what is mean by the spirit of compliant design. The spirit of compliant design is visually show here by saying that, we want to bend things, we want to twist things, we want to stretch and contract the elastic bodies. And I emphasize the word elastic; because a mechanism has to apply it is force and motion repeatedly.

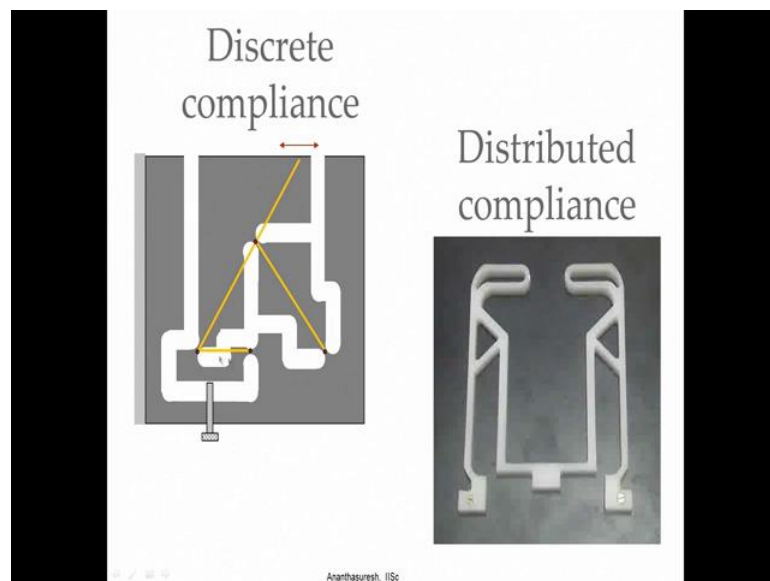
If it goes into plastic region then you can only do once, such mechanisms may also be there, but our emphasis is on things that are elastically deforming so that you can use them again and again and again. So, we want to bend things, twist things stretch things and contract things, and basically use elastic deformation. There is more than that for compliant design which is what we will discuss here.

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Once again in a design principle prefer hinges to sliders and flexures to either of them.

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So discrete compliance, we discussed already in the first lecture and distributed compliance. So here you have elastic pairs, here you have elastic segments that has to be born in mind as we go along in this course.

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**And then there is semantics!**

The term "compliant mechanism" was coined by Prof. Ashok Midha.

Two connotations and one concept

सुनम्य नम्य	Deformable Elastic Flexible Lithe Limber Lissome Pliable Pliant Supple ...	Compliant	Accommodating Acquiescent Agreeable Amenable Complaisant Non-resistant Obedient Obliging Yielding ...	अनुवर्ती अनुनैय
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సులభంగా బాగుచు; మృదువైనది; నమ్య      విధేయ, అనువర్తనశీల, నమ, అడ్డునడక తీ

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The word compliant needs to be understood properly. It is a word that was coined by Professor Ashok Midha when he was at pence state university and later at pared university where now he is at Missouri University of technology. He choose the word compliant as oppose to just calling them flexible mechanisms and there was a reason for it, he thought a lot to coin this word because the word compliant had 2 connotations, but one concept.

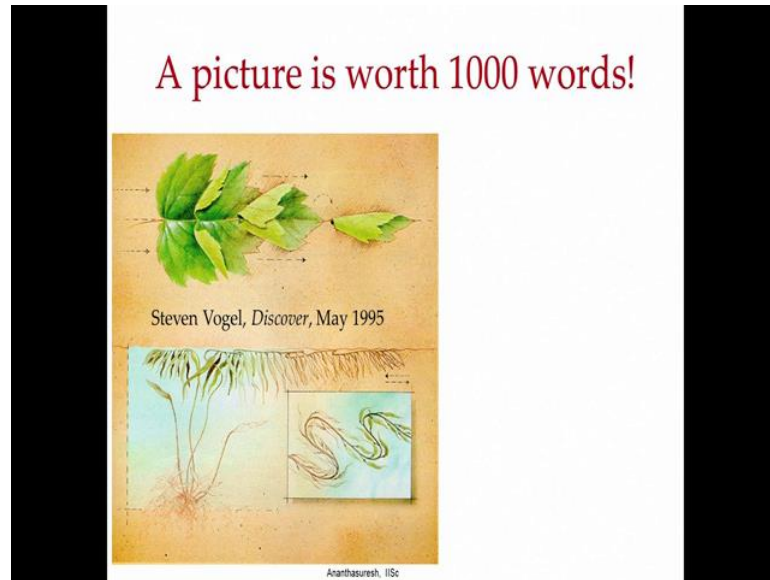
What are the 2 connotations? In the left side you have one connotation flexible connotation; that means, that it is deformable, it is elastic, it is lithe limber pliant whatever synonyms you can put where indicating something that changes it is shape; that is what elastic deformation does.

On the right side you have another set of words all are synonyms of the word compliant, where you have a different meaning, accommodating, obedient, yielding; yielding meaning not in plastic thing but bowing to pressure bowing to stress, non resistant complaisant. So amenable, agreeable, different concept and compliant designs actually most often (Refer Time: 03:43) back to these 2 connotations. You have elastic deformable segments there, but also the design there is very compliant, it obeys, it is environment whenever it is advantages to it.

In order to understand this In fact, I have gathered some words in different languages, Indian languages Hindi and Telugu and Kannada if you are watching and if you know

newer language words for these 2 connotations suffered compliant please do some many mail, because I what people to understand compliant mechanisms by first understanding the word compliant it has 2 meanings.

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As I say that picture is worth 1000 words, let us understand this compliant is a spirit of compliant design. Here you have a maple leaf which was studied by a biologist Steven Vogel, who was at Duke University in the biology department; he studied nature and found lot of interesting compliant designs. In fact, nature is full of compliant designs, here the maple leaf in high wind folds it itself and makes it arrow dynamic makes, it itself arrow dynamic, were the lobes and a slides will curve and make it very arrow dynamic.

So, that the dragon it will reduce in this high wind and so to the marine plants, which have roots in the soil and the bottom of the shallow waters and then the plant has to come up, where these stems are compliant. They are flexible in the first connotation of the word, but they are also compliant in the other connotation, that are obedient when water currents come here, they just take the shape of the water currents or if look from the top this thing if you will look from the top, it will be compliant if water waves are pushing that way pushing, they get pushed they do not resist, they are obedient.

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A picture is worth 1000 words!



Being compliant and strong is an equally, if not more, attractive alternative to being stiff and strong.

Tension leg platform  
Compliant offshore structures  
Bar-Avi and Benaroya, 1998

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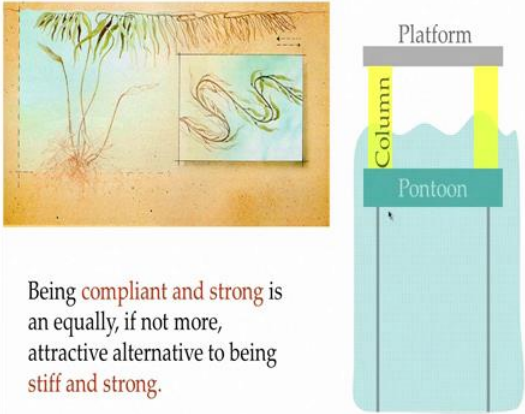
But they are literally flexible also. So, that is the word compliant in both connotations is very well captured in this marine plant.

And if you think engineers have not used it will be wrong because this idea of having a compliant design flexible and obedient design, has been used by many engineers, without realizing that they work in compliant mechanisms what they all would have realize is that being compliant can also be being strong, that is he do not have a stiff structure in order to be strong, you can have compliant and yet be strong and it will very large design here the tension leg platform for offshore structures.

When you have this big oil rig structure there, that in offshore meaning away from the shore you do not have pillar constructed to the bottom of the sea bed, instead you have cables running like this which are very flexible.

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### A picture is worth 1000 words!



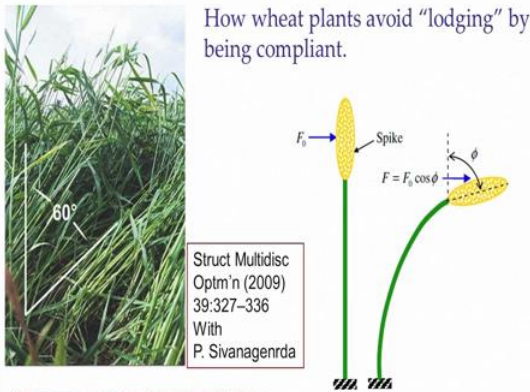
Being compliant and strong is an equally, if not more, attractive alternative to being stiff and strong.

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And also like marine plants they are very obedient to the water connects that come, which will keep this platform with the help of a pontoon like a float over this columns, and you have control systems to pull this cables to be retention. So, that you can stabilize the motion, but main thing to realize is that unlike the terrestrial buildings that we have stiff pillars and beams and columns and so forth, here you have cables that keep it afloat and stable.

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### The importance of being compliant



How wheat plants avoid "lodging" by being compliant.

$F_0$  Spike  
 $F = F_0 \cos \phi$

Struct Multidisc Optm'n (2009) 39:327-336 With P. Sivanagenra

<http://www.fao.org/docrep/006/x8234e/x8234e08.htm>

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And plants especially cereal crop plants are even know clever in using compliance, Here in agricultural literature you find this word called lodging or dislodging, that is when there is high wind this cereal crop plant especially when they are about to be reaped they undergo this deformation and follower they get uprooted, but there of course, very close to one another, but these are very clever in a sense that, if there is a green baring spike and there is a flexible plant stem, when there is force it will deform this cannot lever beam if you want to model that cannot lever beam, when it turns like this, when it rotates like this the drag force and it reduces because it between more arrow dynamic like the maple leaf.

So, a simple approximation for that be  $f \sin \psi$  normally  $\psi$  will be 0 degrees when it is upright, then we all of  $f \sin \psi$  will be acting, but when it bends over  $f \sin \psi$  times  $\cos \phi$  will be acting on it when  $\phi$  goes to 90 degrees almost equal to 0. So, these plants are very clever in the sense that by flexing they are reducing the drag force. One other aspect is that the movement arm that is the height from where the force is acting to the ground, that movement arm is also reducing; not only the force value is reducing, the movement arm will also reducing the bending movement that uproots this is actually quite low compare to when it is where to be stiff and very (Refer Time: 08:57) it will have a lot of things.

All the people feel that when it is bending over it is actually weak, in fact that is wrong. What they have found when this wheat plants were developed with (Refer Time: 09:1) height gene modification that is genetic modification, to grow the wheat plants to make them shorter, grow to a shorter height, smaller height they thought that this bending over will be prevented. But, wheat plants still bend to over by genetically modifying themselves to make the effective in (Refer Time: 09:32) of the plants to be lower.

So, they can bend and reduce the drag force, due to the wind as well as the movement arm. So, nature uses compliance very well. Here again you have flexible that is one meaning of compliance and the other is being obedient. When somebody is pushing you better bend over and reduce the load as they very cleverly do; maple leaves and the cereal crop plants.

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Don't they break?

Yes, they do...like all others that are not designed well.

But flexibility does not imply the lack of strength.

And, rigidity does not imply strength either!

- Ability to withstand overloads – “I bend but I break not.”

It is a question of choosing the right material and having a suitable design.

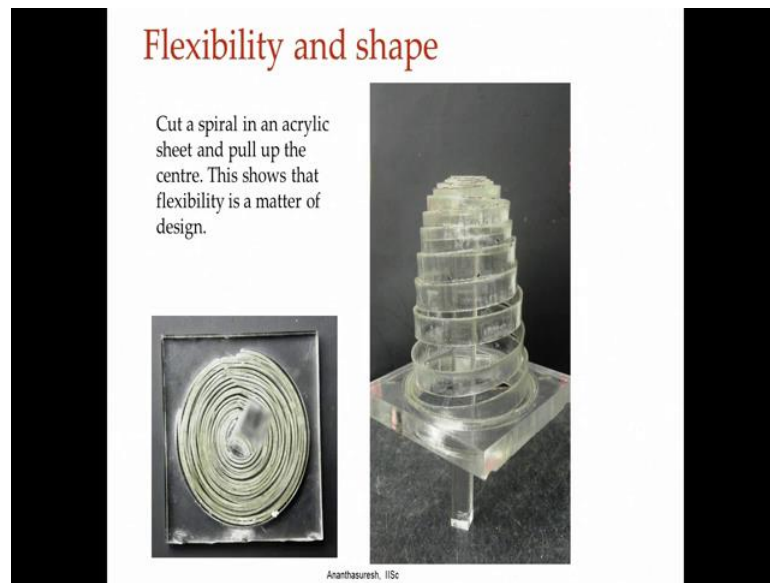
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As you are listening the first thing that you will wonder is; do not they break. We all think that whenever something is flexible and bends and elastically deforms, we think it is going to break. And that is not that is by, while it is a valid question, but it is not a concern when you design compliant mechanism properly; is a question of choosing the right kind of material that has right kind of geometry, if you have it you do not have to worry about it.

The ability to withstand overloads that is I bend therefore, I do not break; is the principle on which compliant mechanisms rest that is you can make something very flexible, but that does not mean it is not strong. It is not a sign of weakness at all when something bends, as we saw examples from nature.

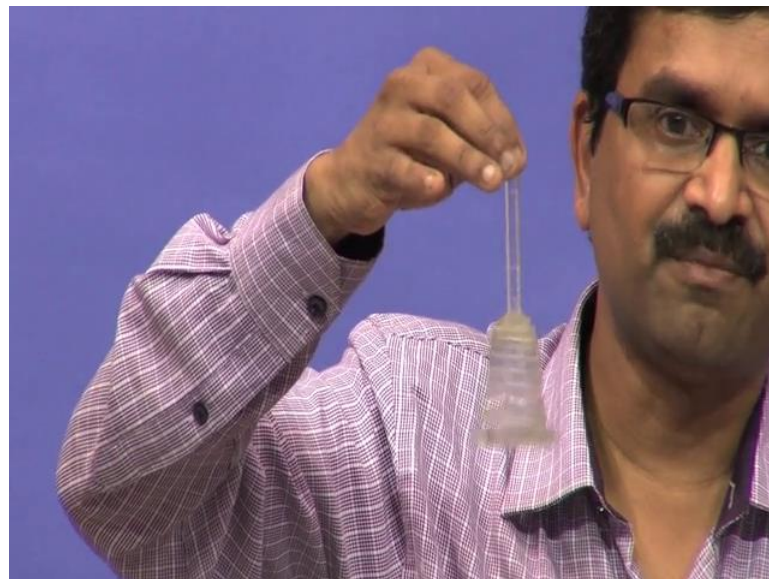


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And in order to show that I have a little device here.

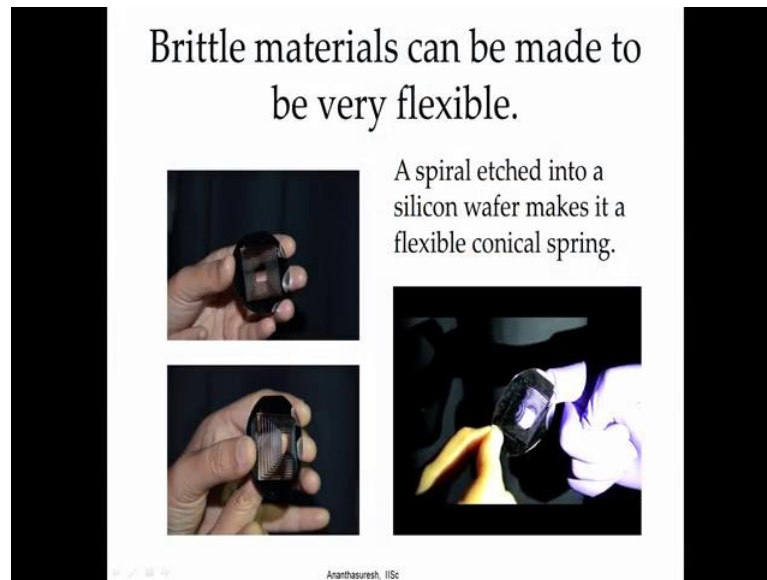
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That was basically an acrylic plate over here, in which a spiral is cut. So, it is cut with laser. So, you cannot see much over here and I have attached the rod here. When I do that it becomes very flexible. So, if you were to feel in your hand you would see how flexible it is, acrylic it is brittle material if I drop it is going to break, but we have made a very flexible spring out of it. If you think this acrylic is one thing, I would say any material even granite if you take and cut this we can make it to be flexible.

So, flexibility is not a property of the material alone it is also a property of geometry, in order to emphasize that what you see in this slide here is the silicon where you have etched a square spiral.

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That makes it very flexible, as you can see here that is like a conical spring you can have that spiral cut and make it very flexible. Silicon is very brittle material single crystal silicon, now we can see we can make springs out of it. In fact, the whole of Micro electro mechanical systems feel would not have developed if people did not exploit the flexible designs or compliant designs that can be made with brittle materials like silicon.


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**“One-piece clothes peg holds clothes in gales!”**

From the product description...  
**Up to 3 times stronger than metal sprung pegs.**

Imagine a clothes peg which:

- . Is a single moulded item
- . Has no metal parts to rust
- . No wood to stain clothes
- . Will not break, made of polypropylene
- . Grips your clothes even in gales



This BRITISH product which is UNIQUE in design has a POWERFUL integral spring action. Being made in 100% PLASTIC they are totally RUST FREE

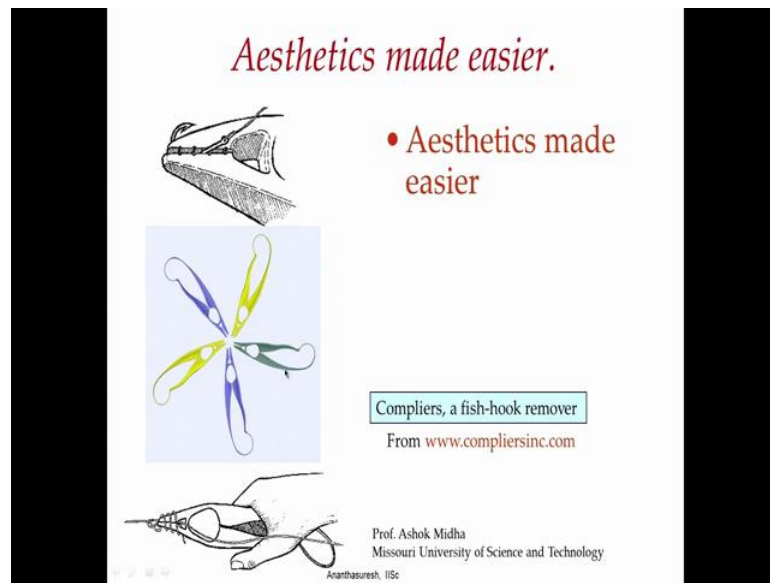
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And there are a lot of devices that we look around and find them, here is one that I have taken from the cover of this clothes pegs sold in United Kingdom, it is a British product they proudly say unique design has a powerful integral, spring action being made in 100 percent plastic they are rust free.

So, they are found a advantage that you do not have metal sprung things and the single molded item has no metal part to rust, no wood stain, is not wood is not being used, it is a plastic polymer, it will not break they tell you made of polypropylene and you can buy them. And in fact, we use them at home to see that they have single piece design you can have them in different colors and they actually they say up to three times stronger than metal sprung pegs.

So, people have confidence some people who confidence and they have this compliant mechanism used.

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And aesthetics also becomes a little easier here because you can make with polymers that have plotted lot a different colors, this one was Professor Ashok Midha students designed it to have a fish hook remover and they made it look like a fish. So, you can integrate aesthetics more easily than with rigid body linkages.

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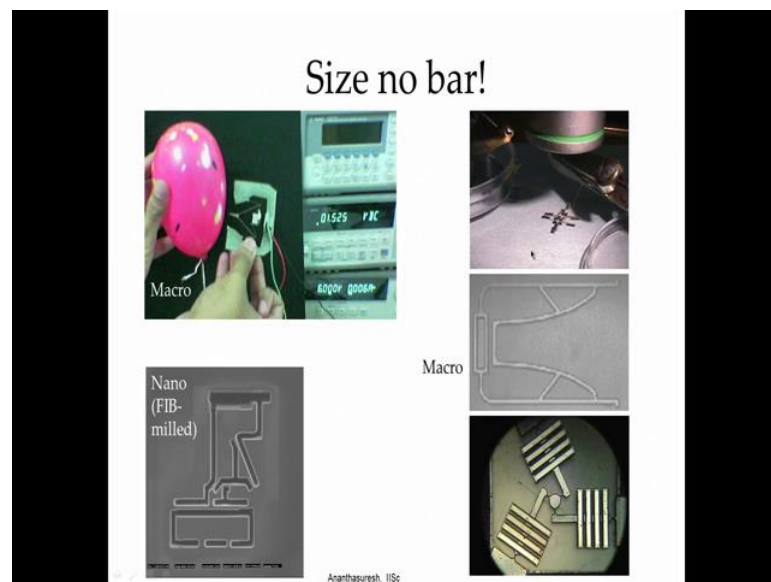


And there are number of products some of them are rigid body linkages here, this is the same function this is the eyelash curler, there is a rigid body, design there is a partly compliant design, there is a flexural joint here. This one has a little metal part that bends

it is also a partial one. If you look at this, this one is completely flexible all that you have is when apply some force they should be two points that should move vertically between each other. So, eyelashes can be curled, this a cosmetic industry product.

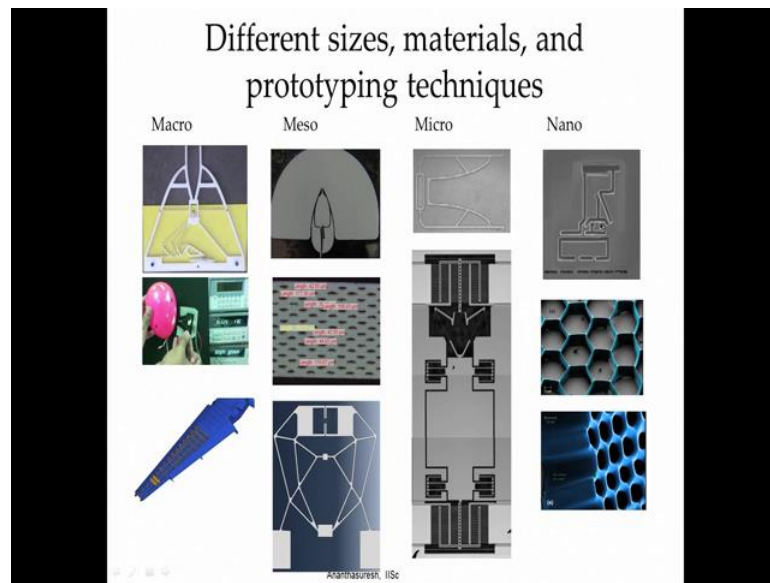
There are products like that which take advantage of compliance to make it a very simple design as you see in this slide. And beauty (Refer Time: 14:31) holder, I do not know which one you will buy, but the one that is here is really elegant because it has a nice curved shape made of steel or a stainless steel and it has enough deformation to make this things go vertically towards one another to solve this function.

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And size is definitely not a concerned here, we can make them Macro and this is actually Micro is not Macro this is Micro and they can also Nano we can make with focus. And be milling you can do that you can have any size that you like.

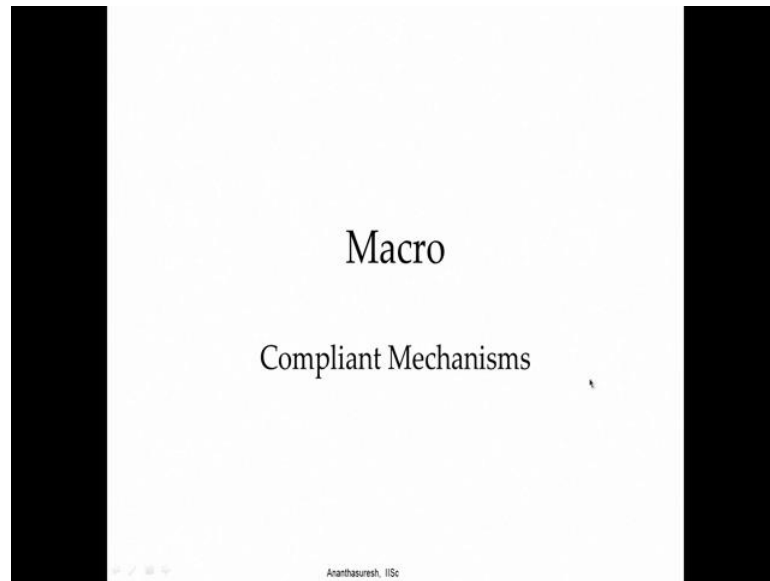
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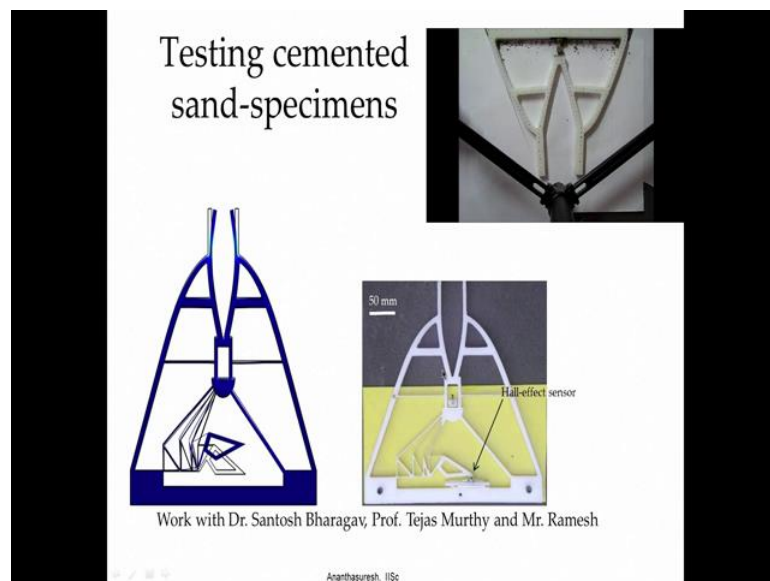
Let us look at some Macro devices, something with which you can crush a cemented sand specimen or even marf the wing of an aircraft, we can have such large compliant designs which people are contemplating today and you can have Meso which are smaller once, for example this one is a metal one, which is about a centimeter or 2 centimeter in size when I am pulling here this thing will open and close over there you can use sera with materials, this was used in armor. For example ceramic material also can be to deform as long as you design properly, these are 3D printed one you can have a lots of polymers.

At Micro scale you can use silicon like you see in these things, we will discuss more about applications of compliant mechanisms in Micro electro mechanical systems, we can have Nano scale as well these are scaffolds use for growing biological cells, these a focused and been melt four bar linkage, more for fun than any application, but Nano scale you can have this compliant designs.

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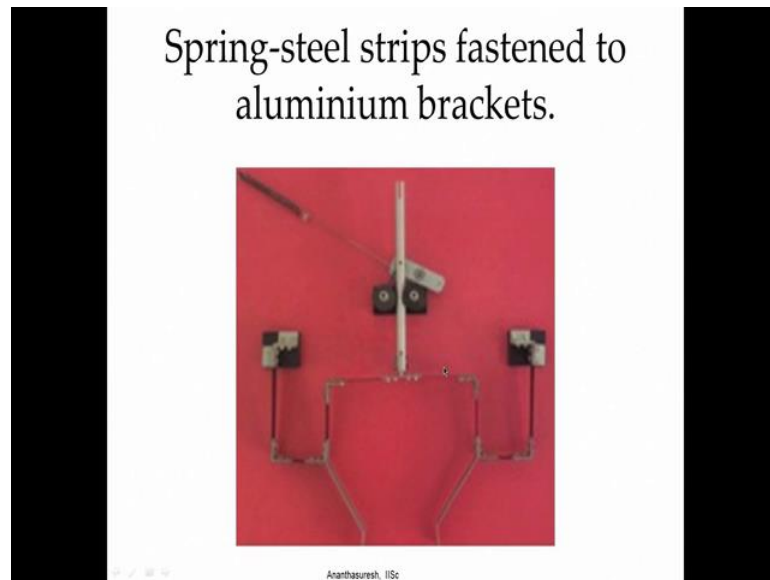


Look at some more these things this is a Macro one, where you can test the cemented sand specimen which can be kept over here as it will be showed in this movie, this is where the cemented sand specimen that why with your fingers you cannot crush, it is quite different very strong.

But you can use this force amplification force compliant mechanism, that when you apply force you can actually crush this cemented sand specimen and there is a display amplification mechanism here that indicate how much the force have been applied, you

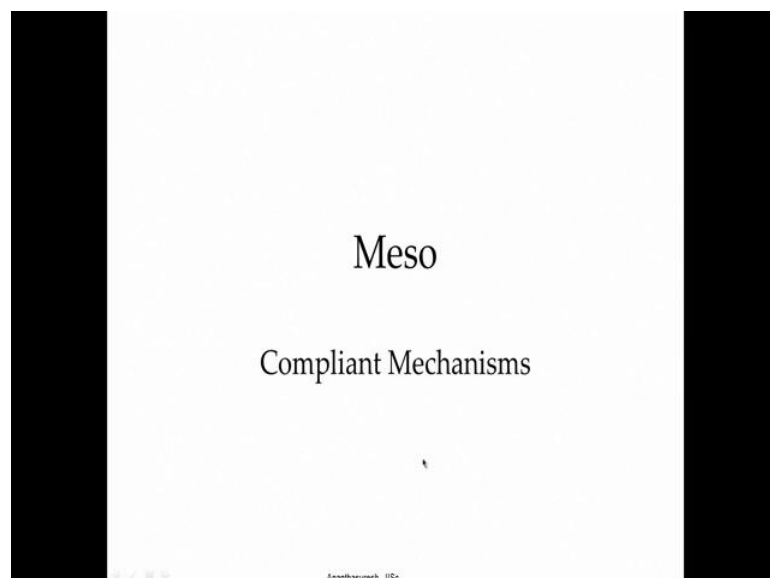
start first crushed there and you put a hall effect sensor here there a real proto type, you can actually measured what force was applied at the time the cemented sand specimen failed at this point and your force supplied over there.

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So, we can make very stiffens and we can make compliant mechanisms with spring steel strips, not just polymers you can use any material here aluminum brackets are there over here and here otherwise spring steel strips here, here and here are the ones that endow this mechanism the elastic flexibility.

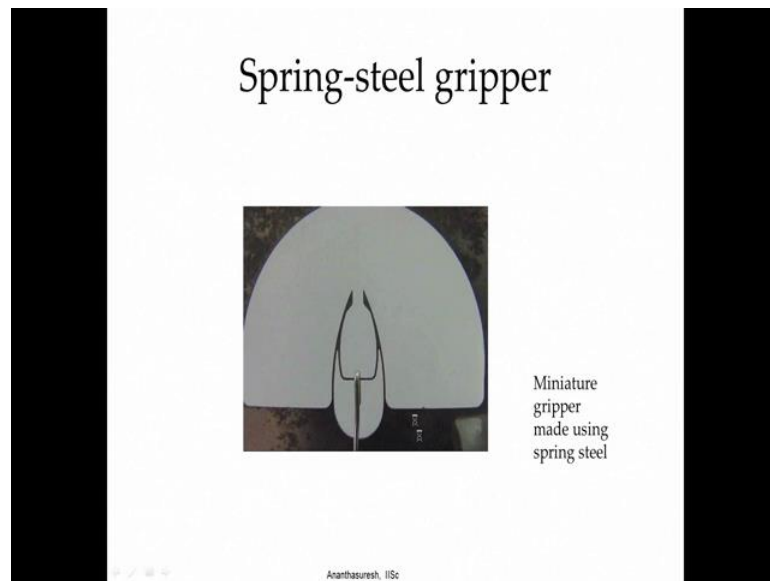
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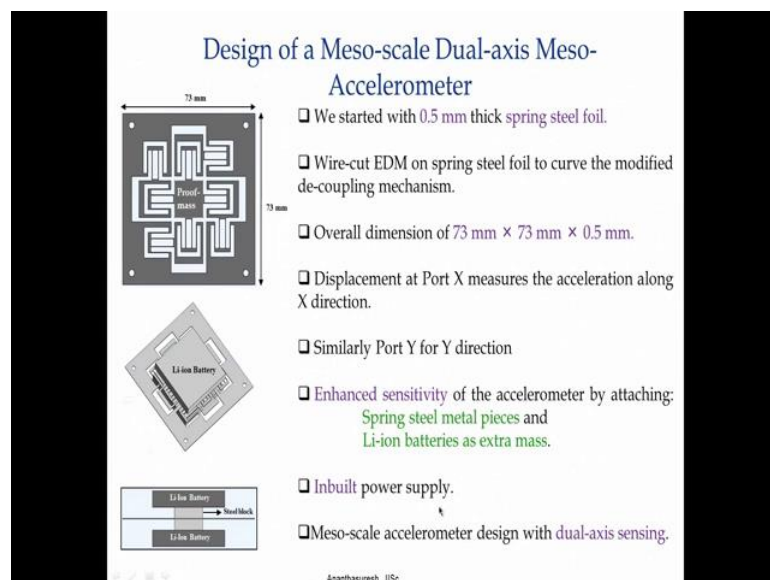
We will go down to Meso scale.

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As already showed this mechanism, which is made of a spring steels strip, very thin strip, which was cut with these beams which are 150 or 170 Microns in width, here we can make with metal also grippers.

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And we can also make sensors; here is a Meso scale dual axis accelerometer with x y z decoupling compliant mechanism, which I showed in the first lecture as the one that has two translation degrees of freedom. If this the mass what is call proof mass, rest of it all

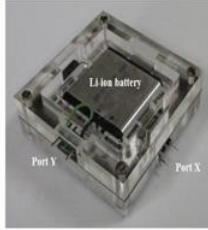
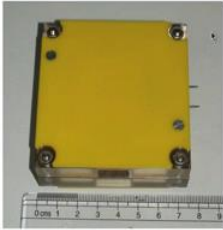
one piece you can just make of a metal sheet by etching and you can use the battery to act to the mass.

So basically you can put 2 batteries and either side for cemetery and here is where the steel thin film is there, I am showing the side view here and that is going to look like this in the top view and you can have built in powers supply and whenever there is acceleration. This will move a little bit you can measure it in various ways, it will be hall effects sensor is one and you can make accelerometer.

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**Packaging**

□ The device is placed inside the acrylic housing and the final manual assembly, shown in the figures below, is performed using screws.

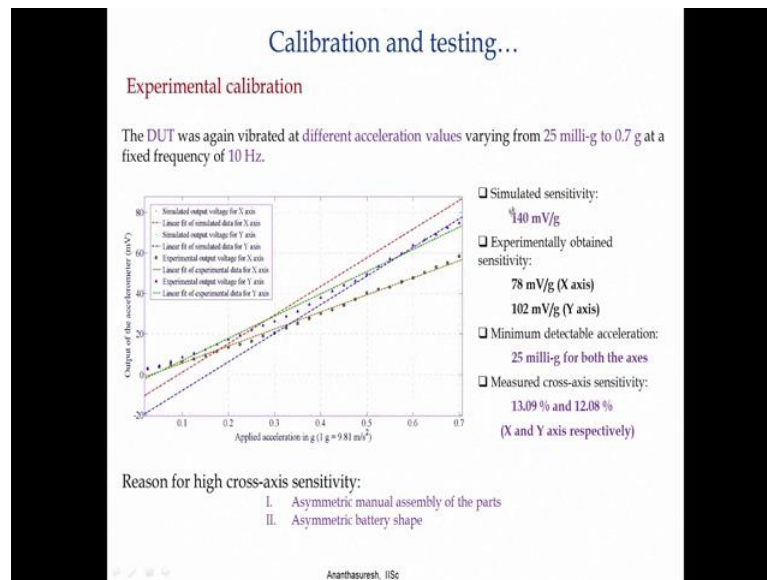


□ The overall dimension of the packaged meso-scale spring steel dual-axis accelerometer is 73 mm × 73 mm × 28.5 mm.

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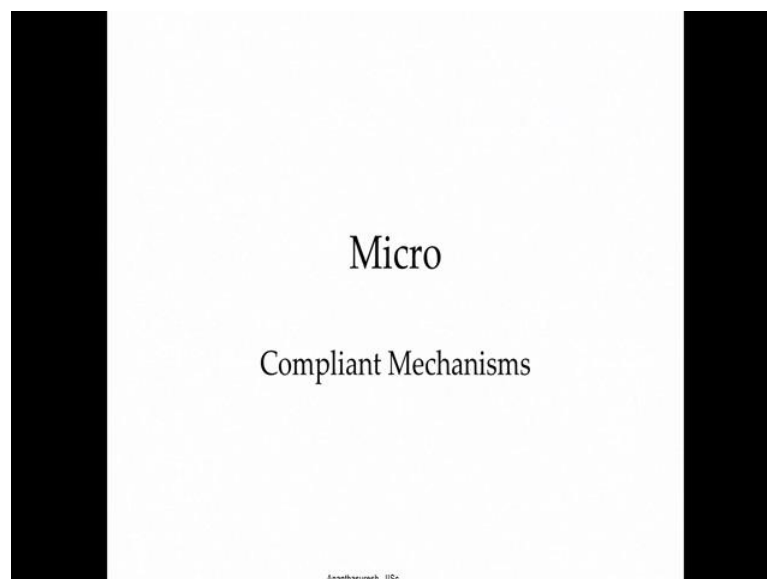
And this was made and tested by the students, where the size is big is a Meso scale as suppose to (Refer Time: 18:47) where be actually have a detail case study for you to consider, but the Meso scale one which is quite large.

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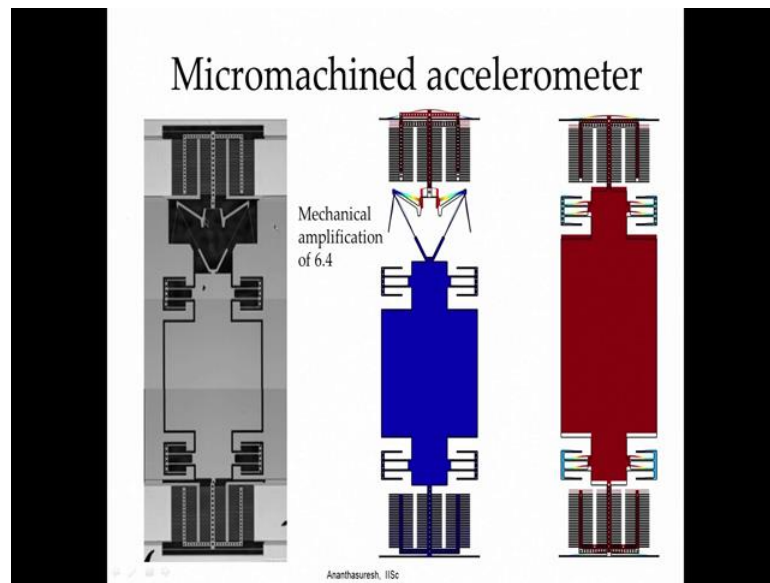
But it can give the reasonable resolution very simple in batteries part of that used as a mass 25 milli-g, sometimes even milli-g can be result using these compliant mechanisms if we also include amplification.

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Go down to Micro.

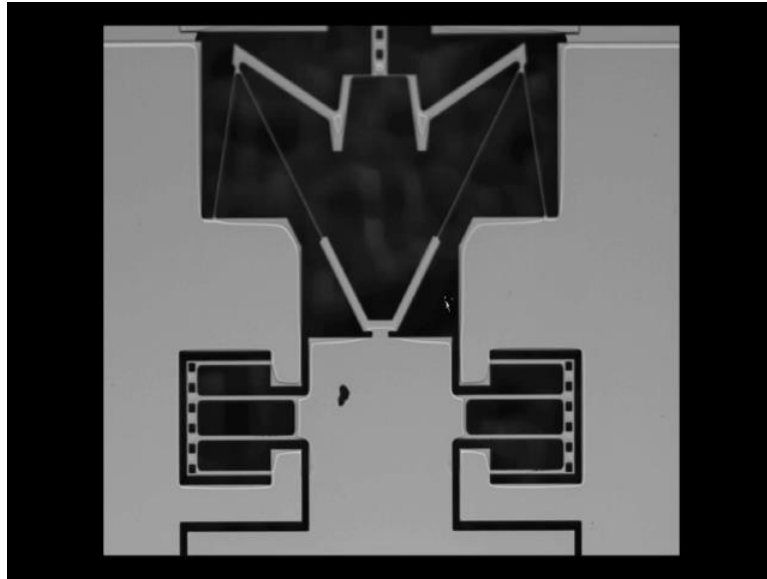
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So, here is a Micro scale compliant mechanism again these a proof mass if there is acceleration this mass will moves because it is suspended with this compliant beam suspensions, but instead of measuring the displacement here, you measure it a little away by having this displacement amplification devise here, which in finite element it is movement here is not at all visible, whereas this one has gone from here to there.

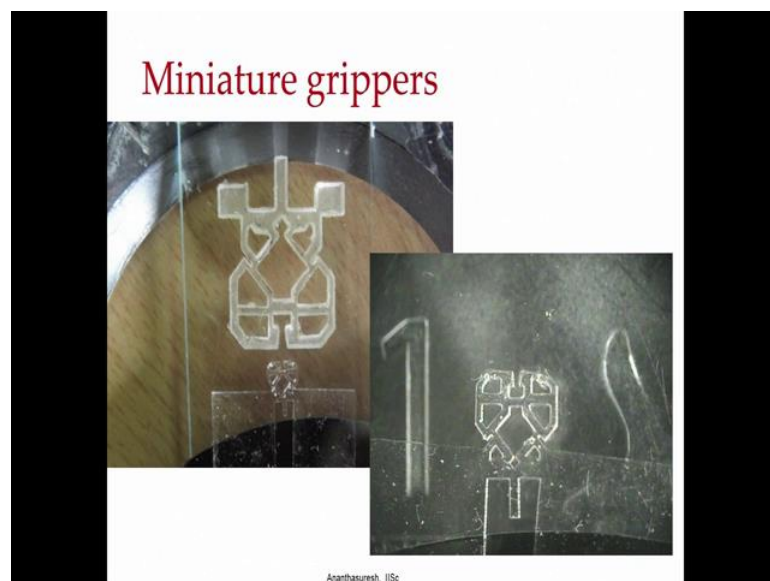
There is this amplification, you have sensing (Refer Time: 19:44) here electro static capacitance based sensing of the displacement, there you can have amplification of 6.4 with the compliant mechanism, if you were to take a mechanism that is this big both of this and this occupy the same area; here we have cut down on the proof mass and added this DACM; Displacement Amplification Compliant Mechanism, we get much more displacement for the same acceleration there subject to these 2.

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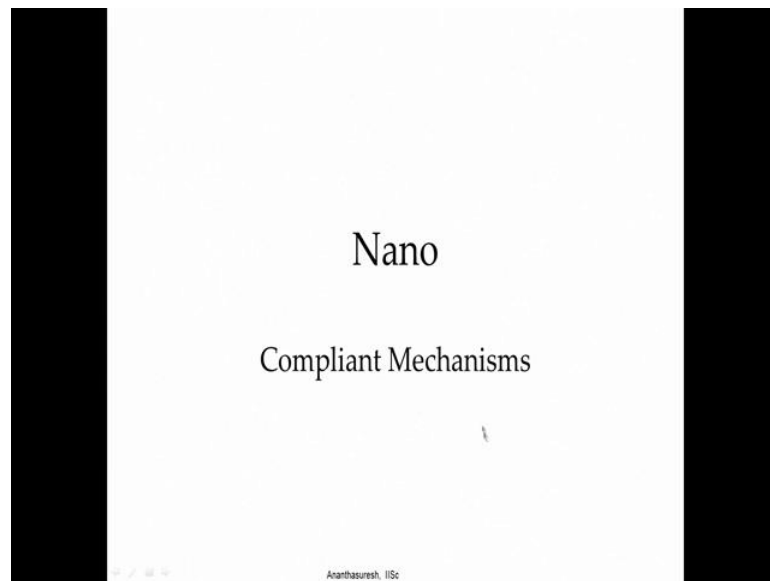
And you can look at the thing here, it is moving if we observe closely we can see this is moving over there and as we move up with the proof masses that proof mass will not be moving. Now you see the beams there is movement here, when you down to the proof mass that would not be visible because there is amplification of over 6.4 or 7 here. So, the beams here that you see are only 5 Microns in diameter and many of them are used in MemS designs and you do not have to worry about their breaking because their design such that, there is large displacement in the strain and stresses are kept small.

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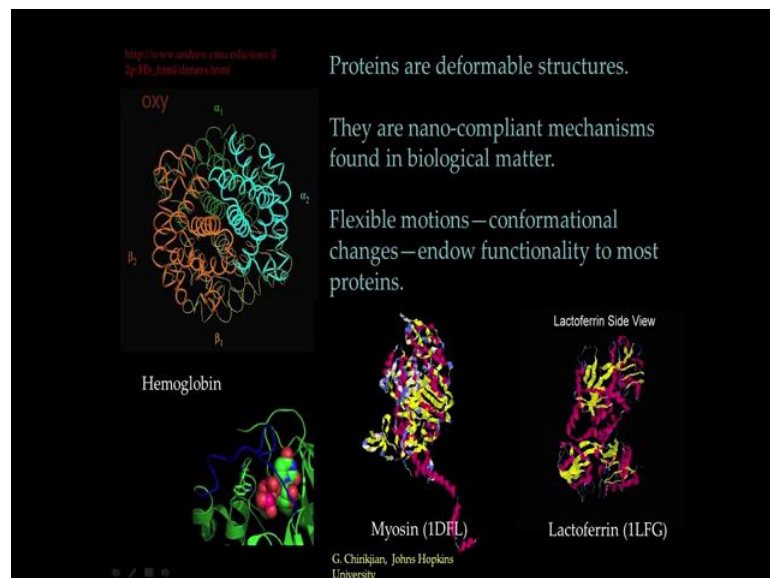


And it polymers of course, you can make many more and here are Miniature grippers you can make a gripper and make another gripper, that can be grafts with the previous one and make it smaller and smaller and you can make the width of this to the limit of what lithography, portal lithography will allow you and which in our lab we go down to 5 Microns very easily, these one of the larger grippers as large as the one in the and the 1 rupee Indian 1 rupee coin.

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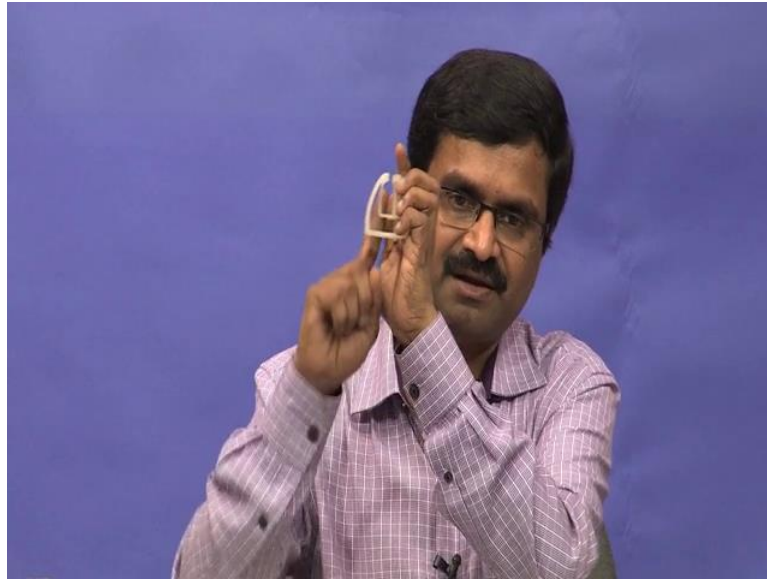
Go down to Nano scale you have proteins is just an artistic rendering of how proteins work, but they are also compliant mechanisms. In fact, if you look at this one there is a (Refer Time: 21:42) something happens over there. It looks like a gripper a kinds of gripper that are already showed and a (Refer Time: 21:48) of bacteria also involves elastic deformation of the single chain protein chains, they are made of amino acid residues or hemoglobin which let us oxygen molecule in and out they all work like mechanical devises in particular compliant mechanisms.

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And you can have them in 3D too, what you see here on this side here, is a basically at 2D compliant mechanism turned into a 3D, such as the one that I will demonstrate with my finger here, you have basically one part of one layer under 3 of them, you put there like this become the 3D compliant mechanism.

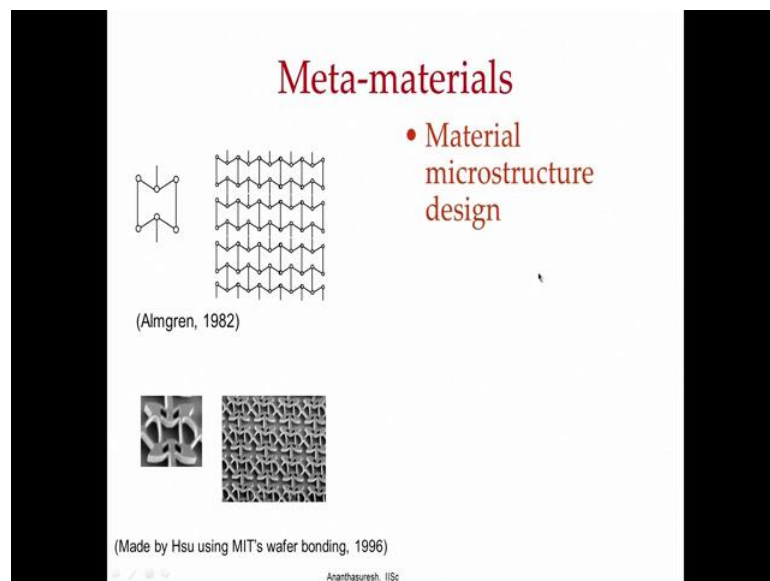
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This is like cheating, this is very simple 2D have meant to 3D, but real 3Dimensional compliant mechanisms also possible as you can see in the on the slide, which has basically a shell crowd shell, which is a spike, I am showing very simple example to show you that there are compliant mechanism around us, we can fold it and make it like this.

So, you have several devises such as this thing around you if you want to see.

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**Meta-materials**

- Material microstructure design

(Almgren, 1982)

(Made by Hsu using MIT's wafer bonding, 1996)

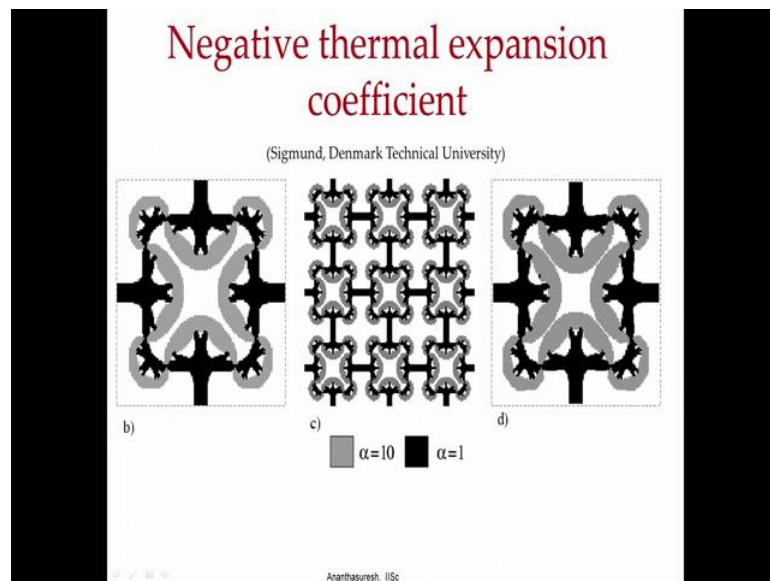
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And if you go down and look at materials it itself, these days people talk about meta materials, meaning that they are not really materials, but you can make them behave like materials; what you see here is a building block, if I want to pull this to the right and pull this to the left, we can see that this rod will move up this rod will move down, meaning that this reentrant structure will straighten so that when I move something like this stretch other direction also which structures.

That is the negative poisons ratio behavior which you can have a compliant mechanism building block like this, when apply force here this and it will move out this way and if we repeated, you get an unusual material that has negative poisons ratio. We designed at and one of the students in MIT had actually made it long ago. So, we can have material Microstructure design with compliant mechanisms, so that you can achieve unusual properties.

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Here is another example unusual property, where there are 2 materials that are used one of them has 10 times thermal expansion coefficient as oppose to another one, as compare to another one this has let us say unit, this has 10 times thermal expansion coefficient alpha.

Now if there arranged in particular fashion which professor Sigmund did one of his works were when you heat it, it will actually contract rather than expand this one building block you can see over here, you look at the gap here, that gap has reduced. So,

over all things it actually becomes a little smaller that is when you hear it, it can actually contract that is unusual behavior, but you can get it with compliant mechanisms.

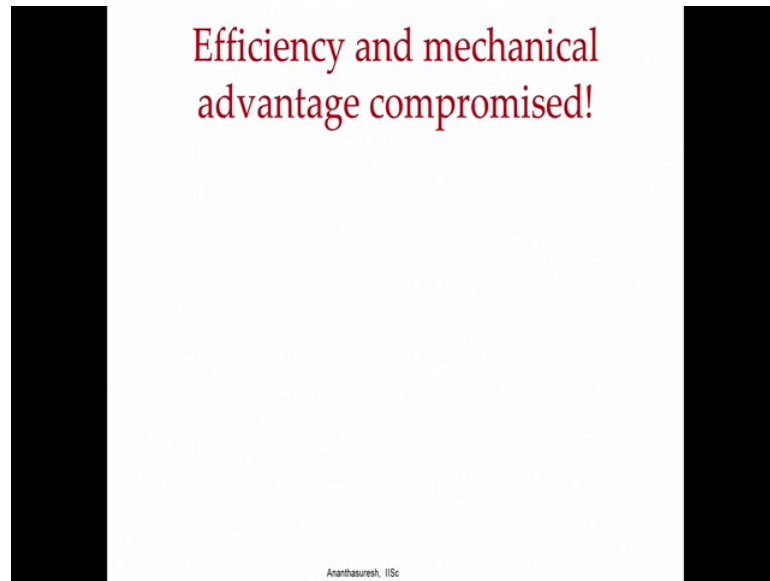
So, at the Micro structural scale you look at them has compliant mechanisms and in fact, any material the way atoms and molecules are arranged, you can actually look at them under scale as complained mechanisms, that are why I call proteins as Nano scale compliant mechanisms.

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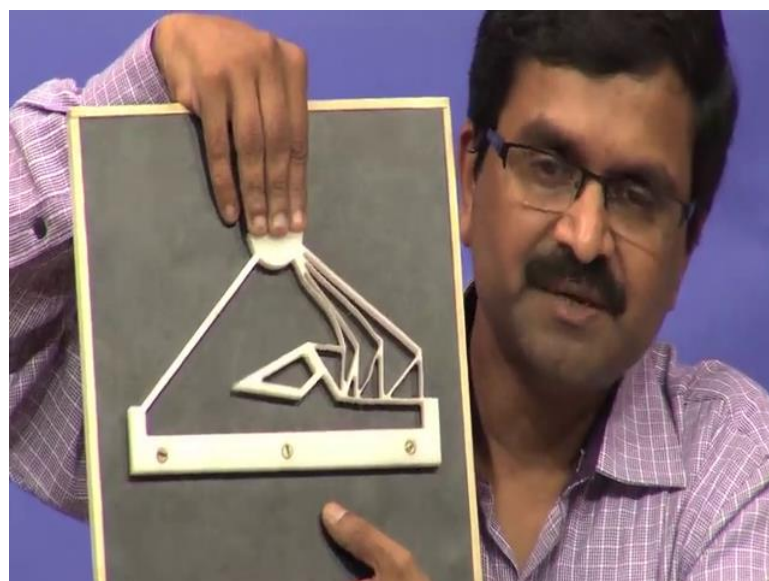
Having said all this spirit of compliant design I hope you understood now, will let us also balance over view by taking about a few disadvantages of compliant mechanisms there will be.

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So, it is nothing like free lunches they say and it has to do with 2 things, one is mechanical efficiency, other is mechanical advantage both of these are compromised in compliant mechanisms. And it is something that can be overcome, but one has to design for it. Let us think about mechanical efficiency, in a rigid body linkage if there is no friction whatever input energy you put in that is available at the output because there is no loss anywhere in the mechanism, but that is not true with compliant mechanisms, here when you supply some input energy, part of it gets stored as strained energy inside the structure.

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So let us look at this device for example, when I applying some energy here by doing work, it is deflecting all over, when it deflexed it stores elastic energy up strain energy in it and only the rest of it that is my input energy minus whatever the energy stored in the mechanism is what is the available at the output and that is not good, your mechanical efficiency is low, that is a disadvantage of compliant mechanisms and one has to overcome that if that is important to you.

The other one which is more settle is to do with mechanical advantage, let us look at the slide and understand what we mean.

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### Efficiency and mechanical advantage compromised!

$$\Delta W = \left( F_{in} + \frac{\Delta F_{in}}{2} \right) \Delta_{in} - \left( F_{out} + \frac{\Delta F_{out}}{2} \right) \Delta_{out}$$

$$\approx F_{in} \Delta_{in} - F_{out} \Delta_{out}$$

$$= \Delta SE$$

$$\Rightarrow F_{out} \Delta_{out} = F_{in} \Delta_{in} - \Delta SE$$

$$\Rightarrow \frac{F_{out}}{F_{in}} = \frac{\Delta_{in}}{\Delta_{out}} - \frac{\Delta SE}{F_{in} \Delta_{out}}$$

$$\Rightarrow MA = MA_r + MA_c$$

(Salamon and Midha, 1998)

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More about in a later lecture.

So, here what we are showing is the additional work your mechanism moving and I moving by delta in little bit and I am getting some (Refer Time: 27:09) and what is the work done delta w that you have is the input energy minus output energy, that is what will be you are change in strain energy that you have and we of course, neglecting the delta F in times delta in which is the higher order term, delta F out time delta out higher order term. So, the work that you are doing gets stored as strain energy and there is some input energy and output energy that you have you gets this. Basically delta w is Delta SE and we are neglecting the higher order terms for the sake of argument.

Now, using this that is delta SE is equal to F in times delta in, minus F out times delta out, you can rearrange this in this fashion F out delta out is equal to F in delta in minus delta SE, basically I have taken the this side and got in this other side. Now I divide

throughout by let say  $F_{in}$  and  $\Delta_{out}$ , so I will get  $F_{out}$  and I bring this over here and here, so what I get here?  $F_{out}$  by  $F_{in}$  is your mechanical advantage, that is output force divide by input force is your mechanical advantage likewise  $\Delta_{in}$  divided by  $\Delta_{out}$  input displays by output displacement, is a mechanical advantage because the reverse of it is your a geometric advantage,  $\Delta_{out}$  by  $\Delta_{in}$  now we have  $\Delta_{in}$  by  $\Delta_{out}$  is mechanical advantage is the rigid body counter part of it. In rigid body there would not be any strain energy. So, what you have will be  $F_{out}$  times  $\Delta_{out}$  is equal to  $F_{in}$  times  $\Delta_{in}$  energy balance is there or work balance is there

Here we have  $\Delta$  strain energy coming in between and that is coming with the negative sign. When you have some rigid body mechanical advantage, the compliant mechanical advantage happens to be negative\ because  $F_{in}$  and  $\Delta_{out}$  where both positive we have a particular direction for input force, is a particular direction for output, if output moves other way, that mechanism is useless to you because both of them have to be in the direction that you intent, so that is positive.

Strain energy most often is positive because when you are doing this, then you are deflecting something strain energy will be positive unless you design a mechanism that has  $\Delta SE$  negative, negative times negative will have positive component. But most often mechanical advantage compliant mechanism, as compare to rigid body counterpart will be negative. Will discuss this more in a complete lecture later on, but most often both mechanical efficiency and mechanical advantage are compromised in compliant mechanisms enhance we have to be doubly careful in designing them.

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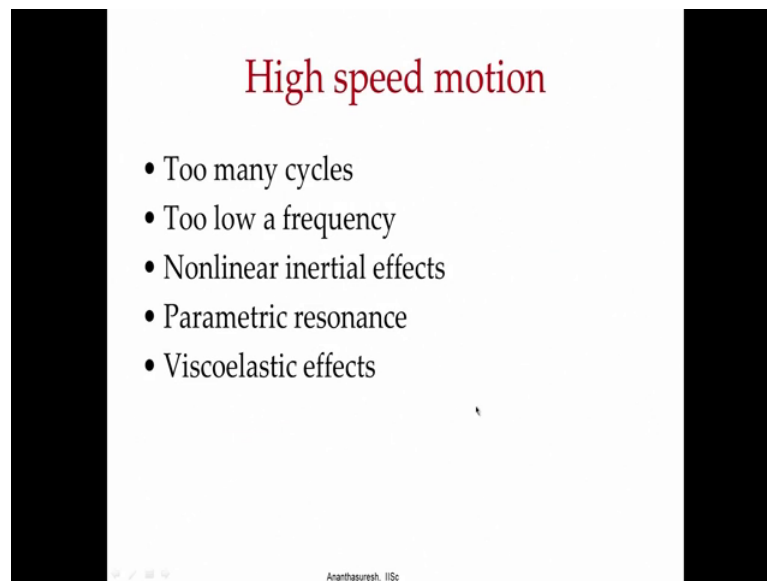
And. In fact, ideas for that already exist one of them is called the Static balancing. Here you preload the mechanisms like this professor just herder (Refer Time: 30:24) lot of work on static balancing has done, we can preload a mechanism. So, that energy stored already and when you where to apply some input force somewhere, the loaded energy pre loaded energy will be use to deform the compliant mechanism, without taking anything from your input energy all of that can be made available at the output.

(Refer Slide Time: 30:51)



So, static balancing is one way to overcome this mechanical efficiency problem, that is what is done by one of my PhD students who is now what IIT Guwahati and another student Amrit Hansogi, Sanagemsh Deepak is the one whose PhD thesis cause an static balancing where is has created mechanism these 2 friends Amrit and Sanagemsh have done this where a large compliant mechanism as a little spring somewhere with pre loaded energy, when you try to pull this rod up, this spring will relaxes gives it is energy to deform the things.

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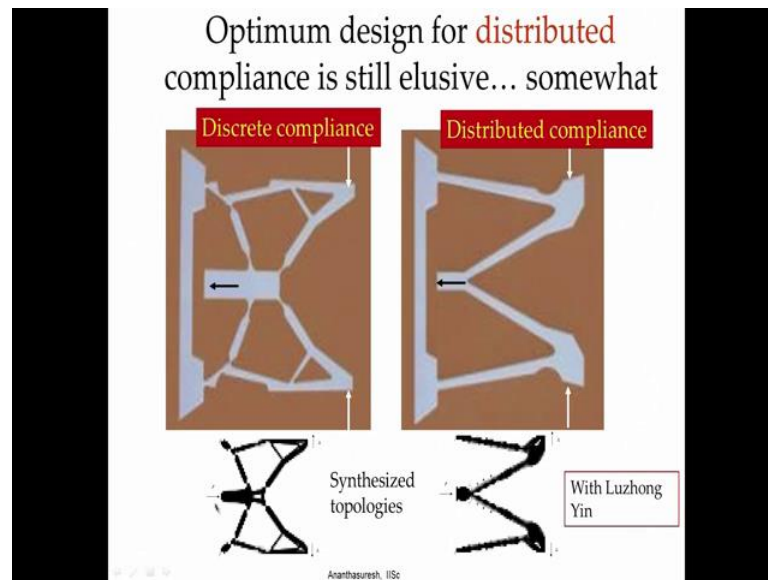


So, that compliant mechanism deforms and gives you the functionality, but all your input energy is with you, your bank deposit is with you and that gives the output work to be done, whereas only the preloaded energy will be use to deform the compliant mechanism. Taking about disadvantages, while mechanical efficiency and mechanical advantage can be countered by having preloading which was also seeing in detail in a much later part of the course, let us also note that at high speed.

When there are too many cycles, compliant mechanism are not so good. Because you are actually deflecting the mechanism deform with the mechanism and look into parametric resonance and also this Viscoelastic effects, non-linear inertial effects, all of this will complicate were analyses I am not saying it is a disadvantage from the view point of design, but in terms of analysis that you have to do it can be quite complicated, in

practice if you really want to high speed compliant mechanism you can actually have it, there is no problem but one has to do extra work for that.

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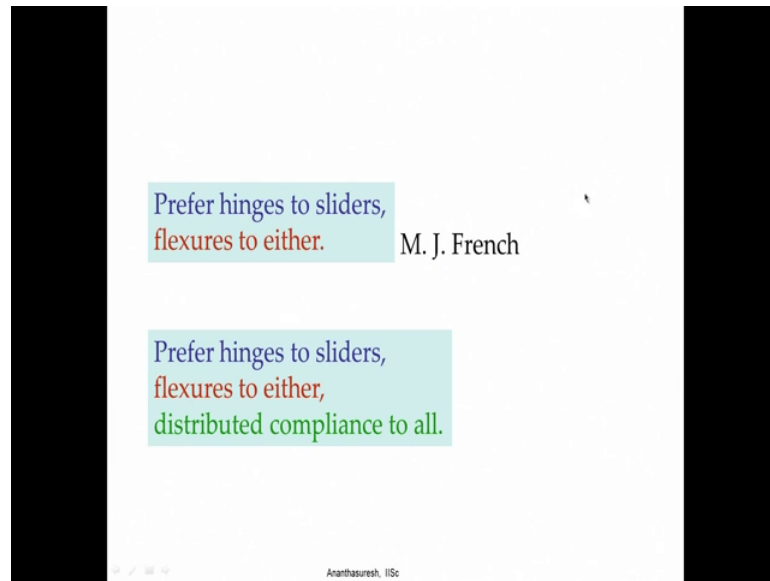


Now, let us come back to our discrete versus distributed compliance, were instead of having a flushes if you want to have a true compliant mechanism in the spirit of compliant design, the distributed compliance is much better.

There are design methods for synthesizing both, as you can see here the topology will understand the word little a bit later is very different for discrete compliant mechanism and distributed compliant mechanism because even though they both do the same thing, their shape topology is very different and their perform is also very very different wait and pressure distributed compliance.

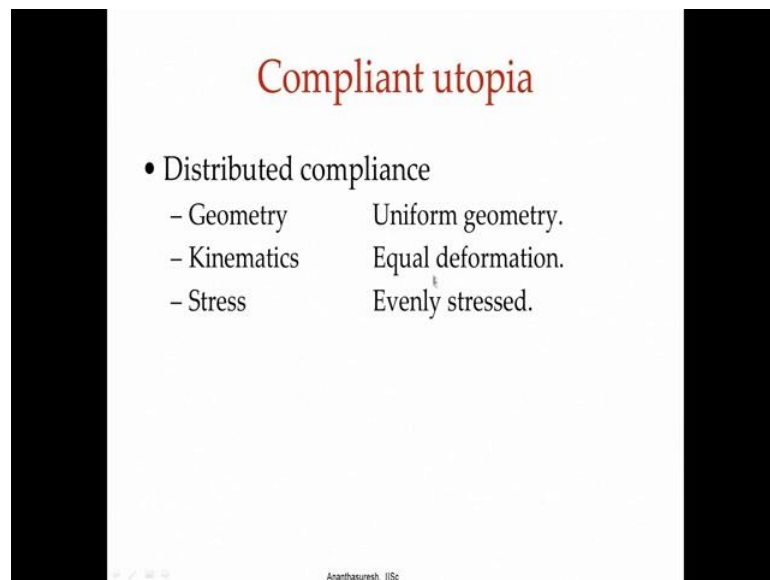


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So, if you want to add another line to what Michel French said; prefer hinges to sliders, flexures to either he said but I would like to add distributed compliance to all, if you do that then you are capture these sprit of compliant mechanisms really really well.

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And how do you define this distributed compliance? I would say that something that has uniform geometry and has equal deformations in this entire structure and the stress and strain are evenly distributed, then that will be the best compliant mechanism what is there and helical spring that is some that we see everywhere is a very good candidate.

If you look at the geometry it is same (Refer Time: 33:58) diameter everywhere in the helices and it is deformation everything twist just equally all along the spring and the strain and stress are also uniform throughout and you can see how much deformation that can have, you can take a spring and stretch it and compress it and that gives you a very good distributed compliant design here.

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Just to end this even the logo of our lab, as students have design with compliant mechanisms and we have used them in many disciplines at many scales which you will see in this course later on.

(Refer Slide Time: 34:34)

**Multi-disciplinary and Multi-scale Device and Design Lab**

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industries.

And these are all the students who had work on PhD students, master's students, project staff and collaborators and lot of sponsors you have done.

(Refer Slide Time: 34:46)

**Look, Sci-Walker with compliant legs!**

Pulkit Kapur, summer intern in IISc.

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So, I will end this by showing that one application in robotics, if you have compliant legs you can make something very easy to control, in this case there is single degree of freedom mechanism. It has 6 legs, all of them are compliant, is able to going in rough terrain. There is no control what so ever, just there gayer with one motor.

There are 2 motors to get more (Refer Time: 35:12) otherwise it is basically one motor, it is just doing by it itself. And having compliance again going back to the notion flexible, that is already there and then being compliant meaning obedient we just when some obstruction comes you just bend your leg and move on. And that is a way to go for it.

Thank you.