Complaint Mechanisms: Principles and Design
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Lecture – 55
Bistability in elastic systems

Hello, we are into the tenth week of this course on complaint mechanisms principles and design, we already talked about 6 different design techniques including the comparative analysis and then we are now looking at some final points in complaint mechanisms one of them we discussed was the mechanical advantage, which actually not a final point it is an essential point, but a final detail pertain in to complaint mechanisms.

Now, we look at another detail which pertains to the Bistability that we can get use in complaint mechanisms, will explain what Bistability is and what the features of Bistable phenomena are and then what applications that exist that used or exploit the Bistable behaviour of complaint mechanisms.

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So, in this particular lecture, we are looking at Bistability in elastic systems complaint mechanisms being in elastic system.

So, it leads to Bistable complaint mechanisms, but you just look at how to look at Bistable phenomenon that is there in the elastic systems.

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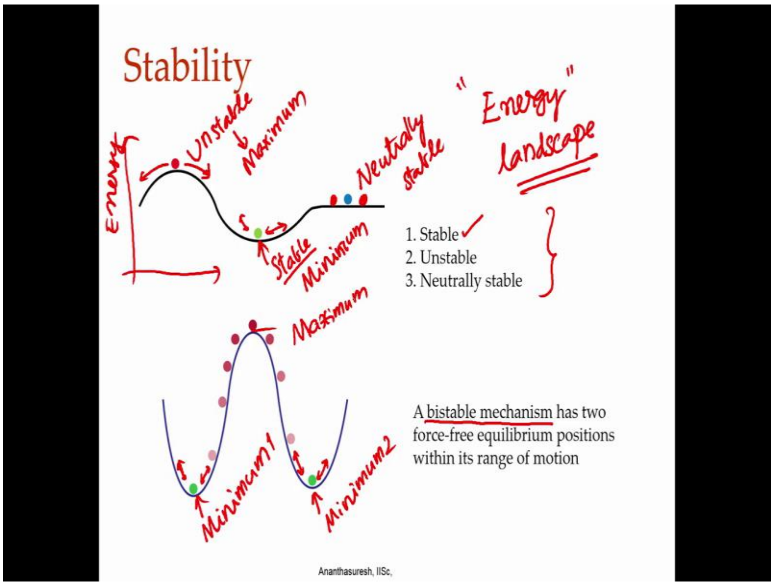

So, we have talk about stability that is a term that is familiar to everybody, has to what is stability? That is when you perturb system from where it is, it will come back to it if it is stable. So, that is the thing. So, everything that is not moving is at equilibrium under the forces. So, you have a equilibrium, that will be called stable equilibrium if any perturbation from that equilibrium position brings it back when the perturb influence vanishes.

So, that we have a system introduce a an influence a perturbation, a little force or some moving of the environmental variable as long as that effect is there, it will be away from that equilibrium, the moment you remove that effect that is disturbing effect it should go back, if that happens such a system is in stable equilibrium, if it does not do that it will be unstable. But you also have a something in between there is a neither stable nor unstable, that will be the neutrally stable, that is the familiar concept which is shown graphically here.

That we have stable equilibrium when something is in the valley. So, that is stable and when something is sitting precariously at the top of a hill that is unstable, it is very clear. If you perturbate it is going to follow of the clip, if something is that valley if you perturbate it is going to come back, you move it that way it will come back whereas, here if you move it which going to be only that.

With another one which is neutrally stable, it is just on a flat plants cape that if you perturbate, you just go in to go there and stay, it is not going to comeback not going to follow of the clip. So, that kind of a thing is neutrally stable. So, this energy landscape this is what we call it energy landscape for an elastic system, complaint mechanism being one of them make an elastic system.

So, if you have this behaviour, then what is Bistability? Bistability is that in the energy landscape there are two minima. So, stable corresponds to a minimum point as you can clearly see here and unstable corresponds to a maximum point. What is this maximum in order to talk in to about? This is the energy we are talking about what is shown here if I put plots also like this, there is energy what energy? It is the potential energy that we should talk about. So, similarly energy potential energy is shown here.

If it has two minima there is a minimum 1 and there is a minimum 2 that is called a bistable mechanism, the elastic system has two minima, then it is Bistable if it is 3, it will be thrice stable it have many multi stable. So, all of those are stable if you perturbate here it is going to come back and the same thing here of course, in between 2 minima there is also a maxima that has be there. That means, that unstable point is also that we have two stable points between them there is an unstable equilibrium also.

So, Bistable mechanism has 3 equilibrium positions two of them stable that is two minima and one of them in between is unstable. So, they are inherently complicated systems very non-linear the strain energy or potential energy varies in this fashion.

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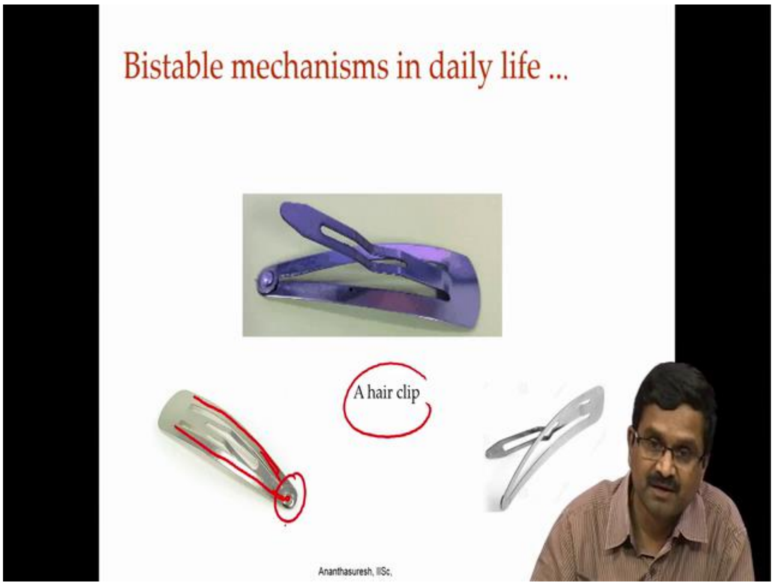

So, that is the first motion. Now these are all around us, in our daily life there are lots and lots of Bistable mechanisms which will see some of them today in the presentation.

So, these a hair clip that is common place, which is simple metal thing very cleverly designed it has two states and this is we use them all the time and now we can actually study. There are no kinematic joints here, is completely 1 piece employing structure. So, all of us have seen these hair clip and bistablity as we saw in that hair clip there are two stable states under no external force that is the thing.

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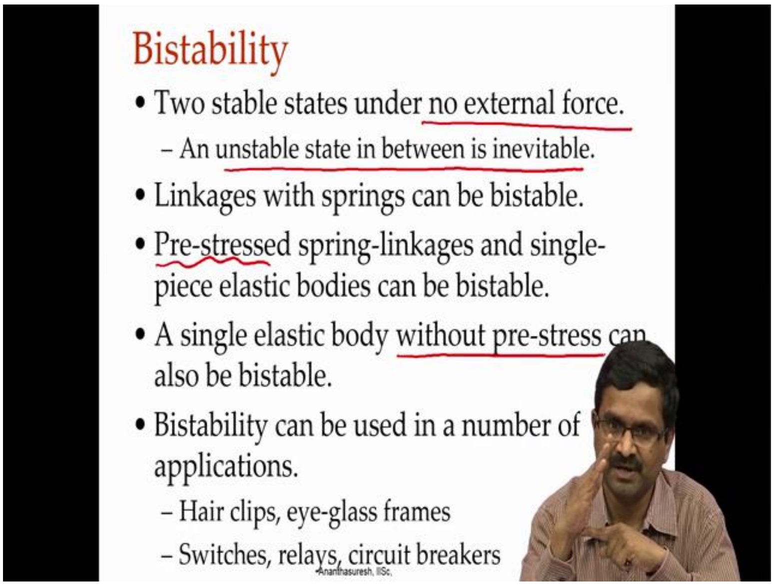

So, once you take a hair clip, then buy it is in one state nobody is applying any force, when you do this other way you leave it free it will stay there. So, under the in the situation that there are no external forces, there are two stable states and of course, in between the two unstable stable state there is an inevitable unstable state also as we illustrated with this valley here and then another valley. Linkages with springs can be bistable such things exist. In fact, there are many devices before complaint mechanisms came into the picture, there were lot of linkages that have springs in them that is elastic component.

So, we can make them Bistable and pre stressed spring linkages were also very common and they can be single piece elastic bodies, the hair clip being one of them. In fact, hair clip has pre stressed, how does that pre stressed come about? What it should do is you should take one of these clips and break open this joint, then this piece here and this piece here there actually forced to come together and riveted there you remove that rivet then it will lose the bistablity.

So, there is a pre load here and that is why it is Bistable. see if you wonder as a mechanical engineer you should actually look at all these things, that are around that are lot of interesting things, which are not easy to analyse unless you apply yourself these one of those you have to see there is a pre stressed, when you take this 2 pieces and rivet them here only then it has the Bistable behaviour otherwise it is not.

So, having pre load is a very important aspect of getting the bistability, but of course, without pre stress also you can have complied which will see examples of, but if you have pre stress it is easy to do and that is what we said without pre stress also it is possible there can be Bistable and Bistabilty can be used in lot of applications, hair clips to eye glass frames, eye glass frames you can fold them like this or open it and In fact, if you take if it is opened like this, if you start moving it, it will come back I can even illustrate may be with my own glasses. So, if I do this it is going to come back.

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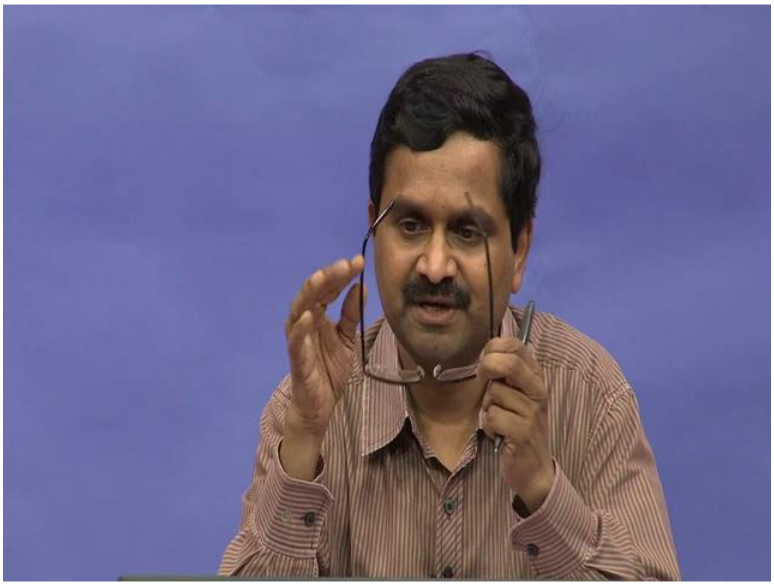

So, there is a little complaint mechanism here; if I do this it is going to come back, but if I go past certain stage it does not do what it did here, I am pushing it is coming back it is stable this is one stable thing. There is another stable which is this now I do this again it is coming back in between there is a neutral stable position, now it stays there little portion, any perturbation there it stays there I am pushing slowly and behind suddenly it goes there similarly if I do this, it is still stable that is on the flat energy landscape here and then it just goes there.

So, from this simple eye glass frames and hair clips two, lots of switches and relays and circuit breakers and even bigger things used bistability which is what will see examples of.

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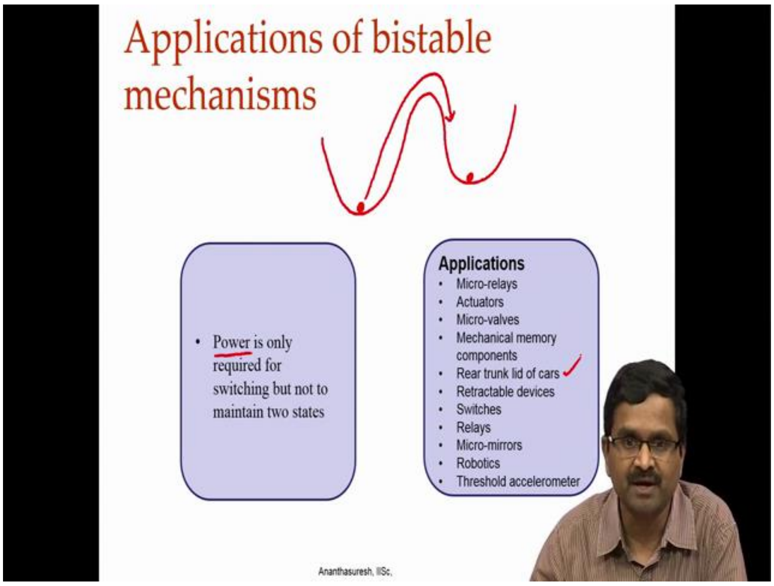

So, some of applications Bistable mechanisms, why people use Bistability in actuate systems is that, the power is needed only for switching the states from here to here if we have this valley.

So, if we get the pen, if I have a valley and a hill and another valley if we have let us say we are here and we want to go here like a switched my eye glass frames, to go here I have to go over the hill I just have to take it up to this part and leave it will go by it itself. So, if you want to do that, for that power or energy is needed only for that. To stay here there is no problem by definition Bistability, does not depend on external forces they can a preload which is given, but after that you do not have to give that is why a lot of situations where a thing a switch for example, has to be in that on state or off state only to switch you have actuation required, but not to maintain it.

Based on that there are lot of things listed here micro relays, actuators, valves, mechanical memory components and the cars have calculate their nobody holds it there, it just goes there move it comes back.

So, and there are retractable devices and there are switches, at relays, at the mirrors and lot of robotic components and lot of other senses and actuators they use this Bistability.

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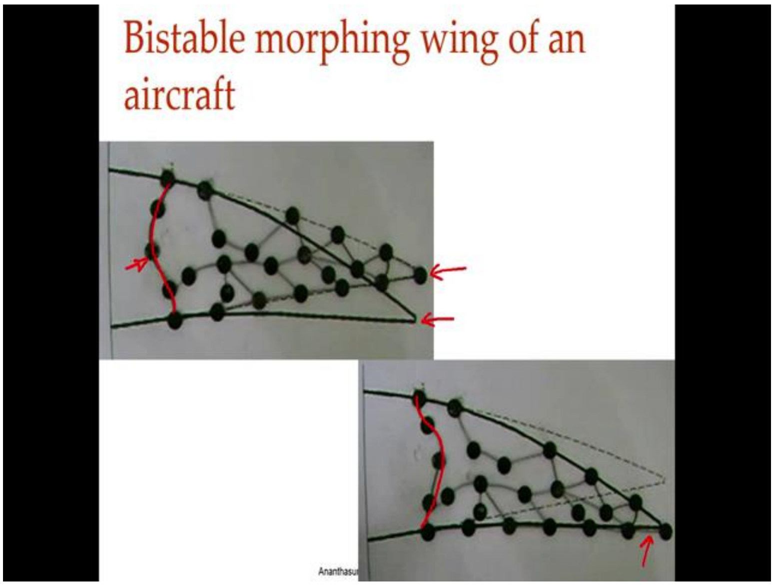

So, here is a model that shows how we can have two states for the trailing edge of in an air craft wing, it is just a model to say that here is no force it is over here and then other thing it has gone over there, that is state one and state two so we have.

Here is an example of a Bistable mechanism that is very large, it can be used to morph the aircraft wing. So, what you see in the figures is the trailing edge of the aircraft wing, which is in one stable state that moves to another stable state as you can see in the diagram below.

So, neither state it will be stable it will be stiff and stable, but if you want to switch between one to the other, you have to actuate some were. If you see this one is like that and that goes to this one when you apply this force over here, if you an actuator if you push that is going to come, lets watch you video that we had already seen once to see this closely now that we have discussed Bistable mechanisms. So this video so that is gets that.

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So, this is also complaint mechanism kit you get to watch it may be third time in this course. So, it is all assembling now this little parts to make like Lego to make complaint mechanisms that have seen earlier and it finishes that, so makes the mechanism. So, you can make a mechanism that looks like this or this way and after this you also see the bistable thing that is of interest to us now. After this we see that you can make a mechanism out of that. That was the point at that time behaviour is exactly to us what you see in the kit, this is the leading edge of the aero foil.

So if you just pull that, it is going to come to another state and the trailing edge which I showed in the previous thing, we gone push where I showed it goes to other stable state and it stays there without external force that is what you should see, here these points are fixed lift extremes. So, you can have complaint mechanisms 1 piece you can have them to behave like Bistable elastic systems. So, that the two states you can have; it can be for the wall, it can be for many other things we need to maintain two states

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There also this binder clips, so let us go back and get the pen back, So, we have bind a clip that also the Bistable you met wonder when you as in this clip how does it know that it has to go there or here because it has very clever little design there, which in this video difficult for you to see it like eye glass frame. What does I glass frame have to have the Bistability such as narrow space here, within that they have put in mechanism and if you look at that you will understand there is a nice little in inclined cut here, where these beams that is these things deform ever so slightly these two beams as you turned.

So, some energy stored basically we have to have this energy increasing going to a maximum and coming down and preaching a minimum, that is the thing that one needs for Bistability. So, strain energy should increase to a maximum and then start coming down decrease to a minimum and then going up.

So, that is the Bistability where you are that is one minimum, goes to the maximum and then comes back to another minimum and for that we can design them.

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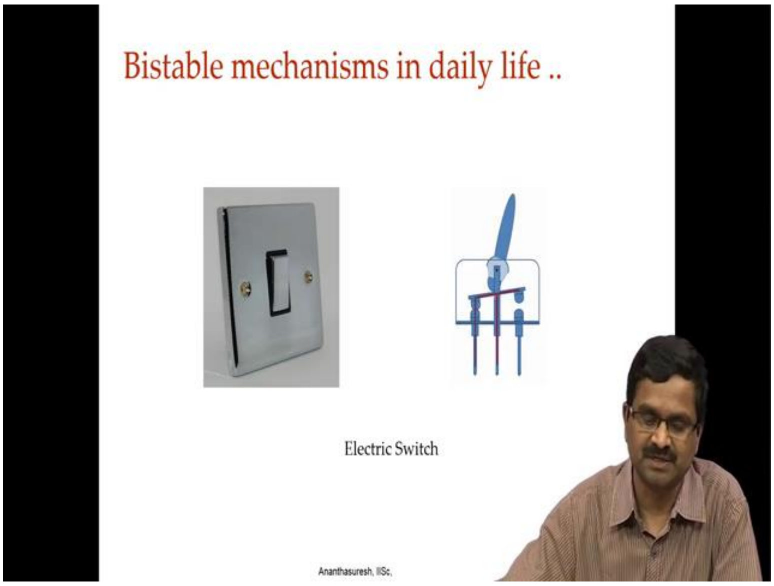

Normal switches that you see all the time we turn them on and off and that also has a Bistability. In fact, we hear that click sound whenever you switch on or off, on that has something like this and there are springs which are not seen here where is a mechanical engineering you should actually take a part one of the switches to see, how it is getting that? Sometimes they do not work, then what happens you just through it way, but you can actually repair it put it back, if you know how it to works.

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So, that has something like this and there are lot of designs this is one of them what it shows here. That got to be a spring, here could be a torsion spring over there are some translational springs that are there. And there are daily life lots of little thing, here it is a Sippy cup that can be tucked in so that you know the milk that baby suck is very carefully sealed off and it requires a lot of force you switch here on purpose it is also 1 piece plastic device, where there is a membrane over here that actually deforms and has two states.

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And there are shampoo bottle lids all of them many many lids here have some special hinges, some of them used to have this old design that little thing is magnified here, there is a flexure, there is a flexure and there is a beam another flexure, they have Bistable, now they have what are called butterfly hinges, you should take look at one of them. It is not clear from the images, but there all over the place lot of plastic boxes that we buy, with commercial consumer products creams and oil and all that or shampoos and they have all have these Bistable lids.

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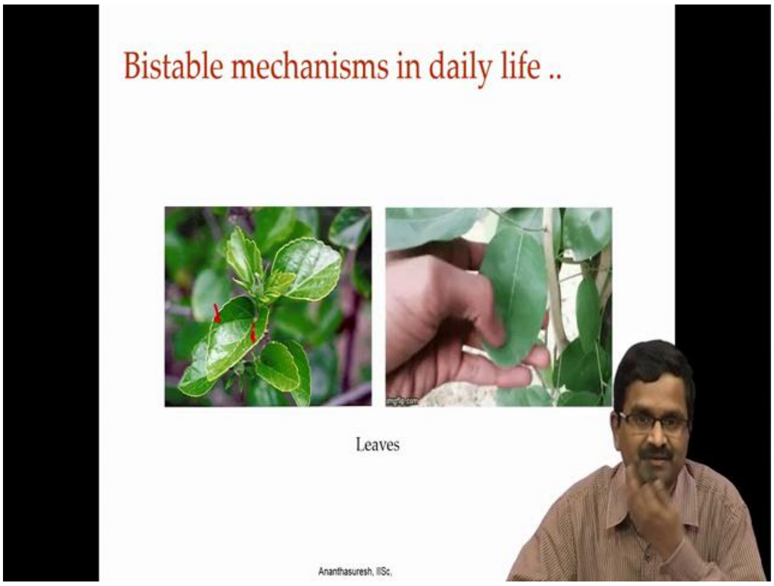

And bistability exist in nature also, as this video will demonstrate we have this leaves, which are hibiscus leaves, some other varieties of cashew nut leaves, tree leaves also Bistable. So, as you can see in this one, they are like cup shape like this they go in the other way. So, I mean you not flip in them like this, but you just press from the bottom and it goes other way I cannot bend my hand, but you can see the leaf going Bistable this way or that way and the same thing here apply force downwards here and here it will become upside down and stay there.

So, Bistabilty is there why should leaves Bistability? There is no answer, but they exist in nature as well.

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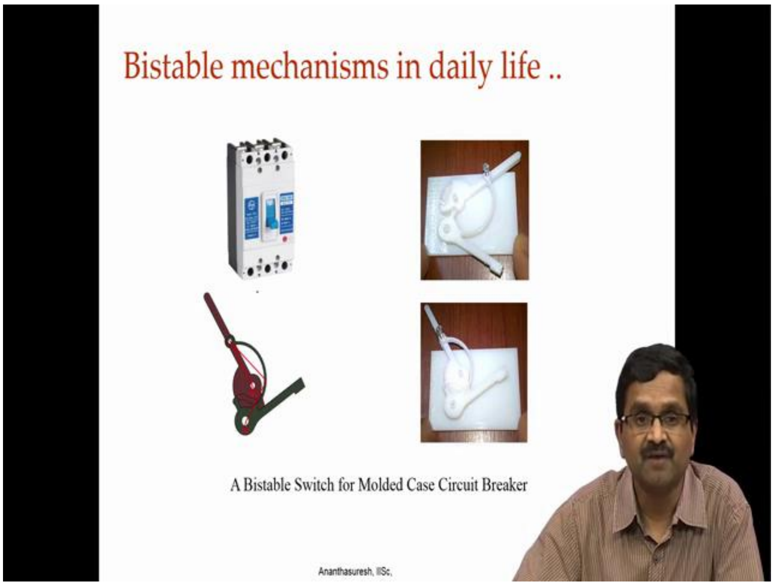

And that exist in many of the internal organs as well and there are this Qubicats m c b's mini circuit breakers, the lots of companies that do this they all have interesting bistable behaviour.

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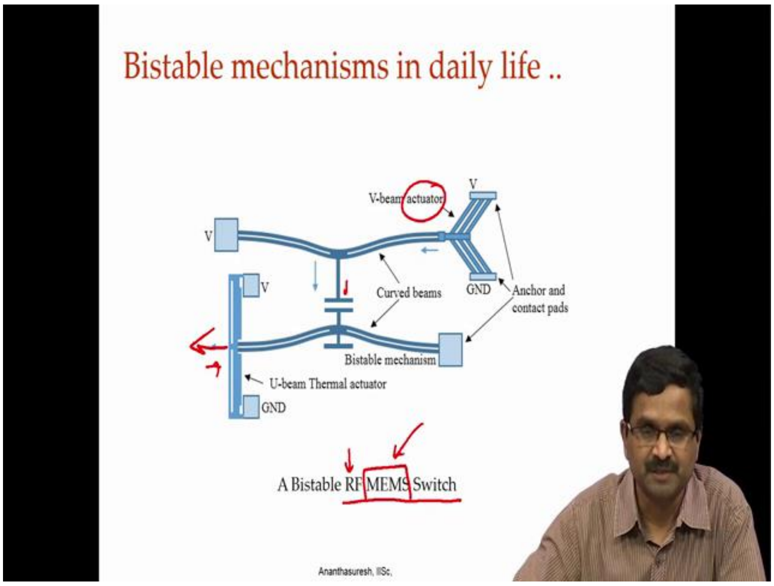

And at the small scale will be discussing the applications of complaint mechanisms in micro systems are what we call MEMS, micro electronics mechanic systems, the RF radio frequency switches are also bistable.

So, here is something that one of my students is working on now Nithish. So that can also have Bistability, there is an actuator here and if you apply the actuator you can make this thing move and make contact a push this that would make contact something else and then you actuate this here and that will actually arrow is shown that way, if we actuate that, it will come back to the state. So, there is a Bistable element will be talking about in next lecture.

So how to analyse what we call arch bistable mechanisms? So, in the MEMS field also there are lot of these bistable devices.

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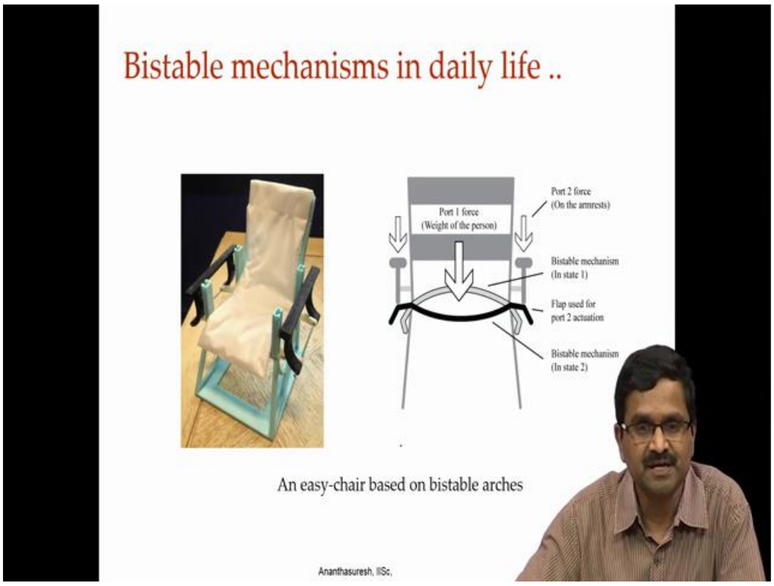

And we also have somewhere going on in our group right now, on making easy chairs that are Bistables, but are there is a state before the person sit, in other state after the person sit, is shown here before and then after is the black one.

So, you can have Bistable. So, you do not you feel comfortable in both states, the chair is comfortable before the person sit is and the person and the chair comfortable after the person sit is so that is also a possible.

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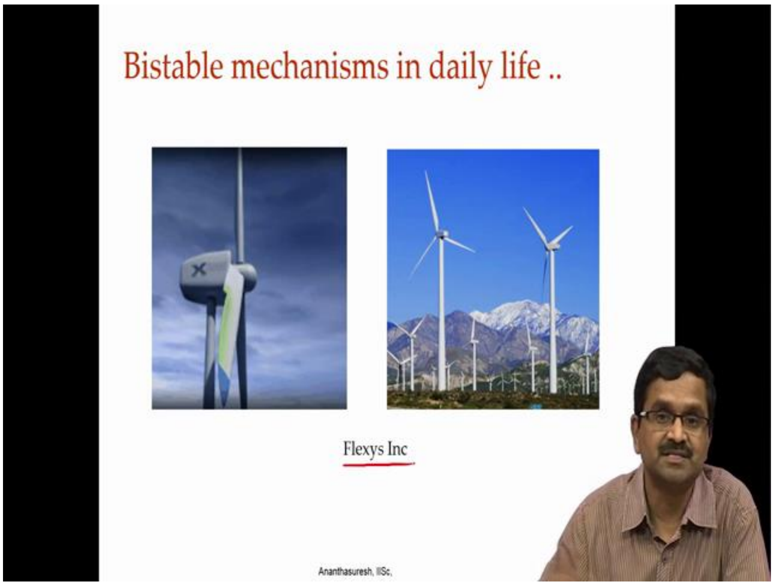

And even bigger applications we saw in a aircraft wings, that can also be applied to the wing mils or wind energy devices, depending on the wind condition we may want to change the profile of the blade, we can do that now with bistable as it is shown here a company called Flexys is working on it.

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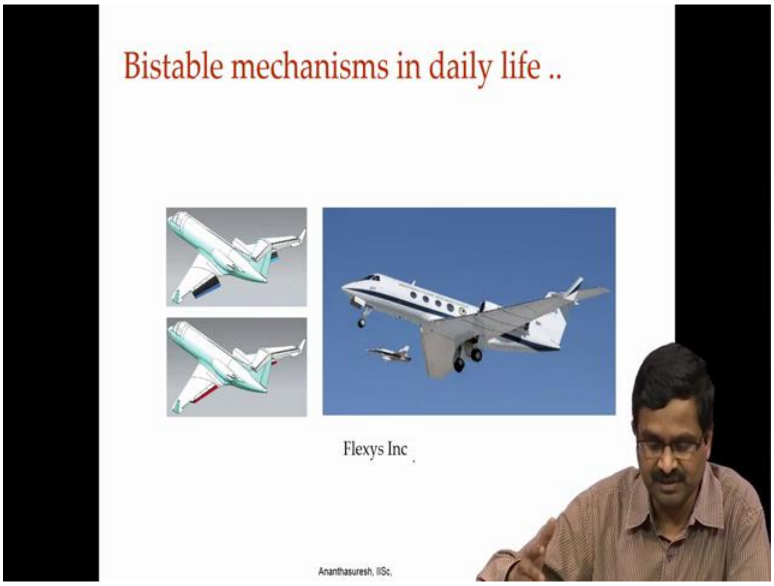

And so or many others and you can also do this with aircraft wings as we already discussed. So, instead of having flaps with hinges which are really disrupting in terms of arrow dynamics, we can have most smoothly changing like birds and insects do, we can change the angle of the wings, so that the flow will be smooth around it.

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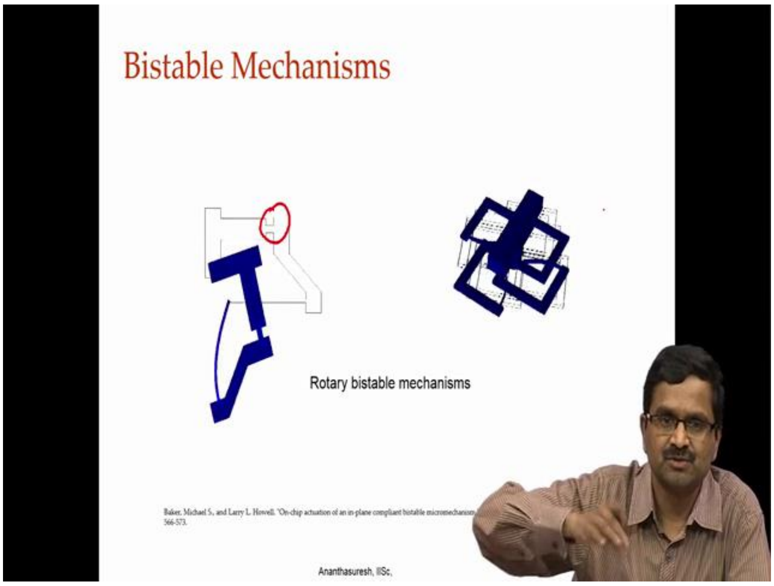

And is to have that we can make them rotation also, there not a transnational, here the two state of a it is say lampt and distributed compliant mechanisms. So, there are actually this flexural hinges there, we can make them, so they can go this way or that way. So, there are lot of different Bistable devices.

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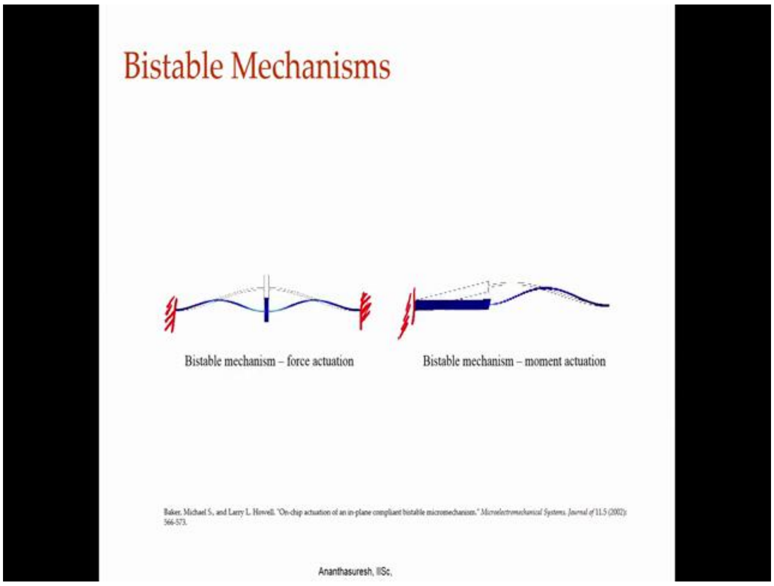

And is arches which will discussed more in next lecture, they are fixed in this particular case it is fixed this end and in this end and when apply force it has either this state or the other state and you can have a lot of things here also it is fixed here and fixed here we can have bistablity a number of them are there.

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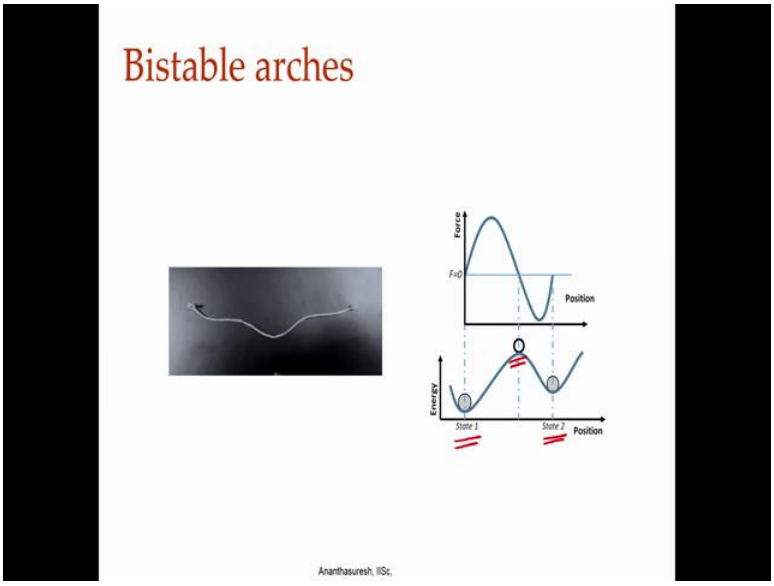

And here is one a prototype, that shows how we can we can hear the noise also, that is one stable state were we started out with and then another stable state the original one, we can move it that way or this ways and again what we need to remember in this lecture is that, the Bistable has two minima and then a maximum in between stable stable in between, there is an un stable.

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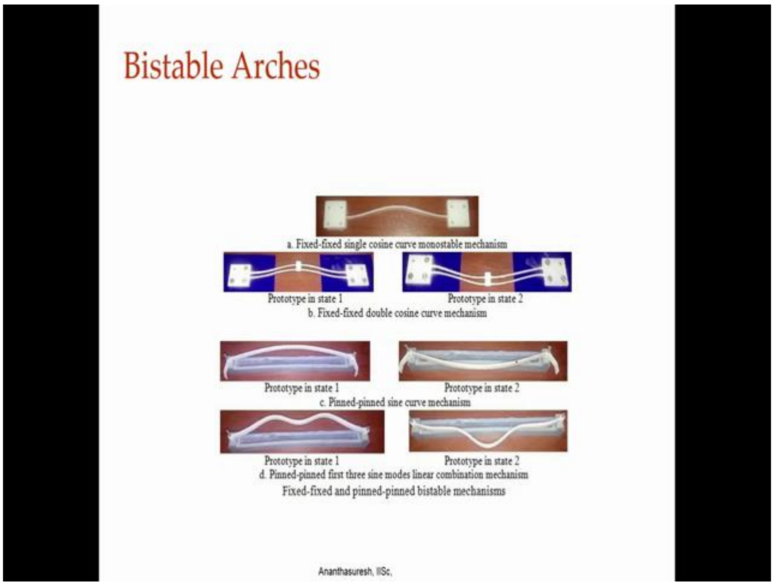

They are all arches, which will discuss, so there are number of them that we saw a movie of, number of these things that will see how to analyse later on in next lecture.

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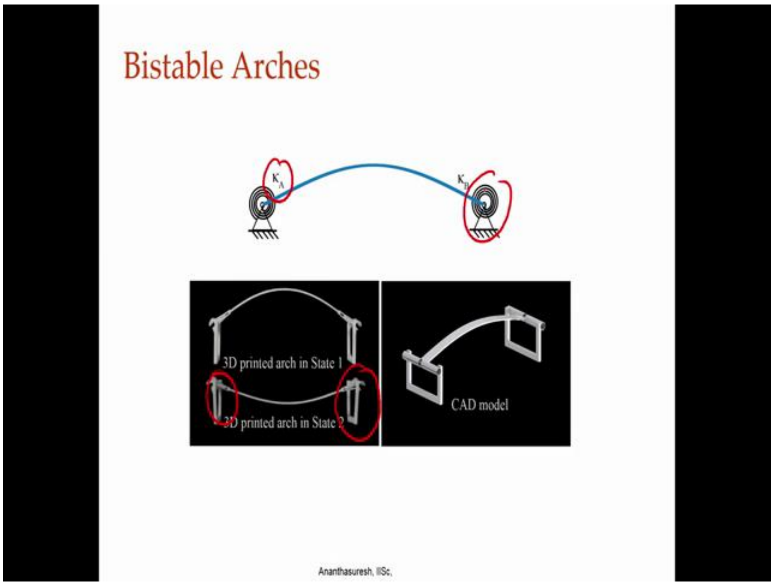

And the analysis is again we will use some kind of a model. So, where will tensional spring for a joint that has stiffness which is, if I have a flexural joint elastic pair, that we have discussed it very beginning of the lecture we can represent that with a torsion spring an either side, we have this and both sides, you have torsion springs and you can make them as one piece, but we can modelled as a an arch with them pin joint that has torsion spring.

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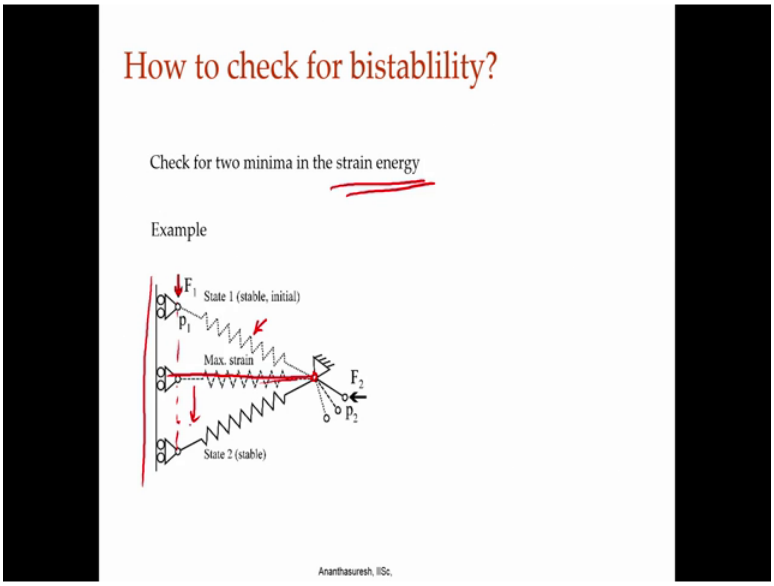

How do we check for Bistability? You have to basically look at the energy. So, we have to look at the strain energy of the system, so if you see, if I have a thing that slides on this direction you have a pin joint here and I have a spring, the spring let us say this is the state one which is stable there is no force. If apply force like this, when you go to this horizontal one the spring is compress the most that is all we want. Any of the Bistable devices, where they need to have Bistability their strain energy should increase and go to a maximum after that length increases between this point and the moving point here then it strain energy decrease again you have bistability, so that is how we should check.

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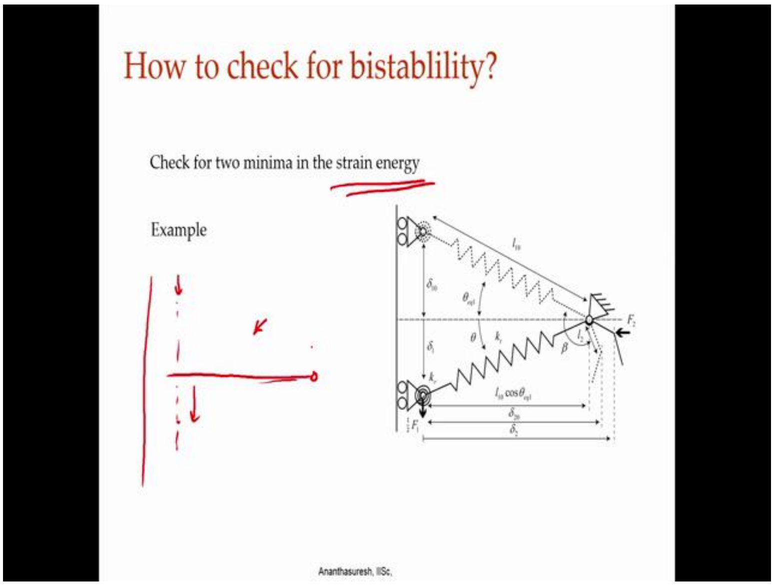

So, we need to have a mechanism where the strain energy decreases goes to a maximum and then decreases.

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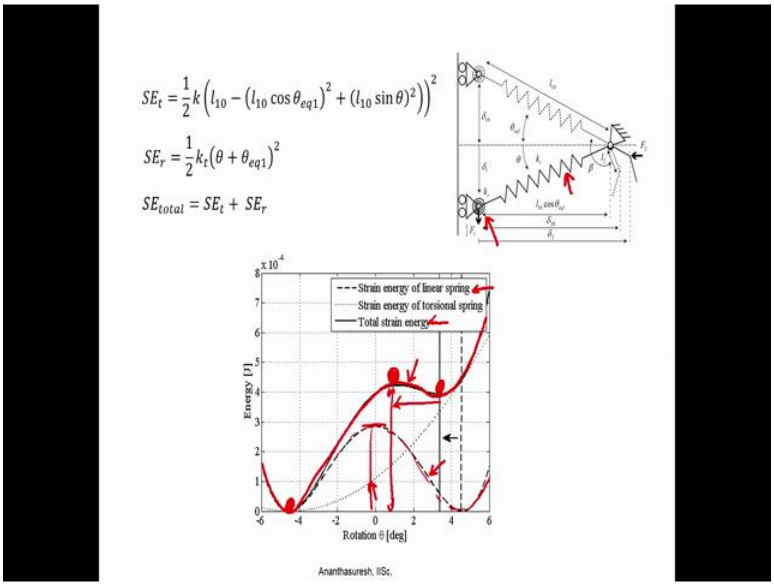

And that is we can write the strain energy expression, which will discuss more in the next lecture were we analyse this arches. So, that we get this total strain energy as it is shown here, this black line has a minimum and then there is another minimum here.

Strain energy with only linear spring is this dashed line that goes like this, rotational spring included. So, there is a linear spring transitional spring here and there is a rotation spring both of them are there. So this one is only with a torsion spring, this is only with the translational spring, this is in both of them, but what is important is that, there is a stable point there, there is a stable point there is a un stable point.

So, we can switch between two stable points by going over the hill. The hill if we do not have the rotational spring, so that the hill from here to here is very steep and now it is even steeper on one side, but other side it is easier going this way is harder coming back is easier. That is what actually we use in the easy chair that which we just discussed, will talk more about it in not the next lecture a lecture after that.

So, the main points here the bistability can be easily achieved in complaint mechanisms, in elastic systems in general by specifically complaint mechanisms because complaint mechanisms inherently have elastic deformed elements, as approach to rigid body linkages you have to introduce additional springs to make them bistable, here there already there so we can very easily do that.

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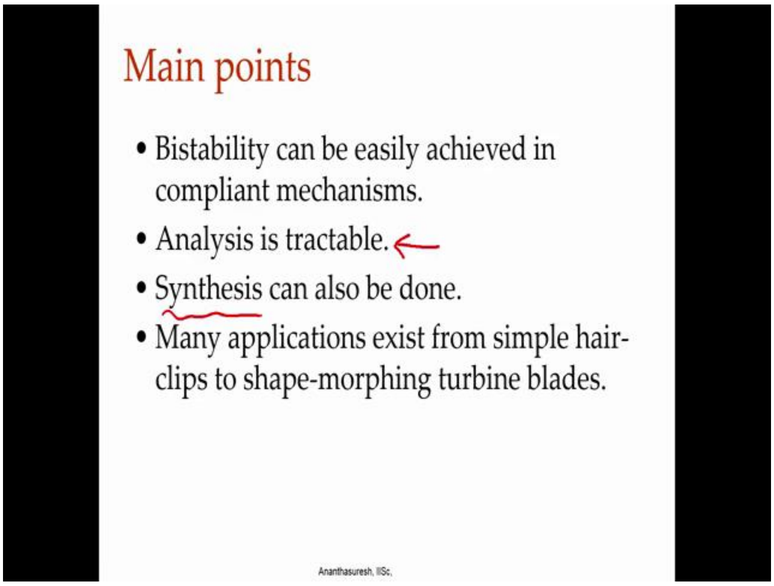

So, Bistabilty is an important aspect for complaint mechanisms, that is why a lot of work is been done on this and what we are not discuss in this lecture is what will discuss in the next lecture is that, analysis is tractable meaning it is easy to do not trivial, but it is possible to do and we can also do synthesis, which will briefly touch up on in the next lecture and one after that. Many applications exist that is something for us to remember from simple hair clips to shape morphing turbine blades and so forth.

So, there are lot of important applications and lot of consumer products which is actually economically has lot of impact. So in both ways this is a very important a phenomena.

Thank you.