Compliant Mechanisms: Principles and Design
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Lecture – 61
A catalogue of compliant mechanisms

Hello, we are into the 11th week of the course on Compliant Mechanisms: Principles and Design. Today we are going to do something different; we talked about compliant mechanisms derived from the basics of mobility, analysis and design method, six of them and in some final features we talked about such as mechanical advantage by stability, static balancing but now we will move into more realistic aspects of compliant mechanisms where you actually have to build something and design based on practical application. Towards that, we are going to show you today a catalogue of compliant mechanisms; when a catalogue I mean like catalogue of things that you buy in a market, in a similar way you can actually pick what you like from a catalogue.

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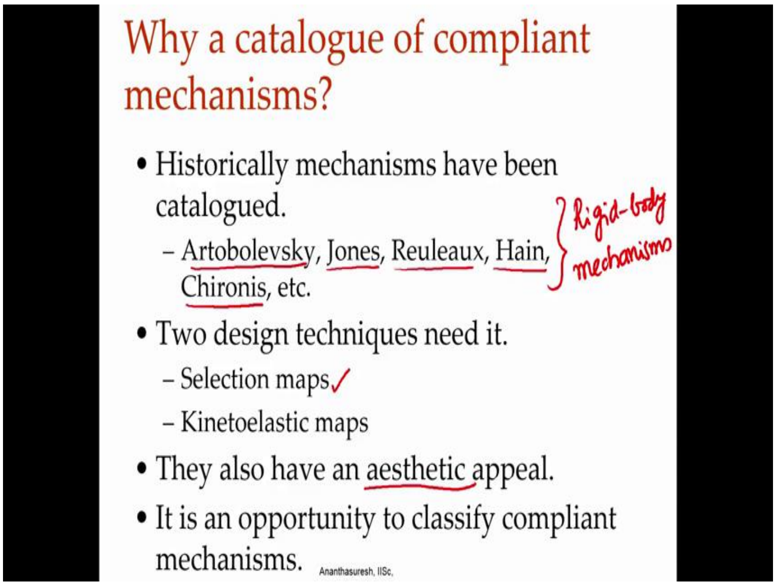

Now, we have a catalogue of compliant mechanisms which we will show today. So let us look at that, we have a catalogue of compliant mechanisms that we can actually use. So, first thing is why do we need a catalogue of compliant mechanisms, what is a purpose, why do you need to have; it is not a market place to choose but why do we need it. One reason is that historically mechanisms have always been catalogued. There are famous catalogues that are attributed to Franz Reuleaux, Artobolevsky had actually books cataloguing linkages and Jones - four volumes are there; which are basically there with any mechanisms, designer or an academic who works on mechanism design.

And Kurt Hain also had a very large catalogue of mechanisms that he had gotten built over a period of time and in modern times Chironis has a catalogue also; it is also a book. So, these are all the thing that existed in mechanisms and all these word, for all these are or word because there all survive; they are for rigid body linkages. So, if somebody wants to design a mechanism for a particular purpose, we always turn to this catalogues and then see what is available and then what could be used for a given application.

So based on that historical reason, it makes sense to have a catalogue of compliant mechanisms because as we have being saying in this course, this in a way is a new type of mechanisms which were not there in all these catalogues. Although they had thought about them and they do say for example, Kurt Hain's book they say that at that point of time when the book was written, they could not consider elastic deformation and that is why the limited themselves to rigid body based mechanisms.

Not that they could not consider, they could of course consider but not in terms of computations especially with advent of finite element analysis, compliant mechanisms analysis has becomes simpler and lot more methods have been developed. So for historical reasons, it makes sense to catalogue compliant mechanisms. The other reason is that we discussed two design methods that actually need this catalogue; that is a database. So, in the selection maps with design technique that we always discussed, we need to have a database of compliant mechanisms from which one can select based on this stiffness and inertia maps that we discussed, where we can show all compliant mechanisms as if they are materials, just like as this method enables people to choose a material. The selection map technique inspired by hash piece material selection lets you choose a compliant mechanism for the application.

In fact, there was a little extension compared to material selection here based on the user's specifications, we could show a feasibility map on which these mechanisms are super imposed as dots or curves if we consider large deformation effects. So, we need a database for that selection map technique. In another technique we discussed, another design technique is kenito elastic maps, where we had captured in non dimensional charts the complete characteristics of compliant mechanisms. From the displacement, mechanical advantage, geometric advantage, stress, natural frequency and so forth all of those captured in kenito elastic maps and if you have a catalogue of compliant mechanisms for which such a map is also appended or set of maps pertain into various performance characterises of compliant mechanisms, there will be useful for people to choose them for an application that is of any size, any material and any shape and cross section shape and so forth.

So, that is another reason why one would want to have a catalogue of compliant mechanisms. A third reason is that they also have an aesthetic appeal, mechanisms always are thought to be scientific sculptures because when mechanisms move many people like that motion because there is a co-ordinated motion of various parts of rigid body linkage that has an aesthetic appeal and so is the motion of a compliant mechanism. And to quote Lord Kelvin apparently like these models, whenever he sees that he would actually hold it in a hands and try it and then say that unless he sees a mechanical model; real mechanical model, he was not satisfied; he always like to look at these things.

So, they always have this scientific appeal or general appeal for people who may not even care about what they do. So, for that purpose also we need to have a catalogue or compliant mechanisms. In our own lab all the walls are decorated with these compliant mechanisms and many of them are going to be shared with you today. And when you have a catalogue, it also gives us an opportunity to classify compliant mechanisms because whenever something grows in number; it is important to classify so that everything has it is a right place when we consider them, so that is another reason why I want to catalogue compliant mechanisms.

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So, this is Franz Reuleaux collection of rigid body mechanisms, not compliant, Franz Reuleaux did not consider compliant mechanisms; rigid body mechanisms and they are all colourful today because one professor at Condell University has resurrected them in digital form; otherwise they all look like this.

They all turned and they still work from the early 20th century or may be even before that when these where built and they all work even now when you turn little bit oil you put and they turn and they work. And all of these are now made like digital models; they are extensively used in education, in teaching kinematics and mechanisms. In fact, that is the fifth reason why we need to have a catalogue of compliant mechanisms so that one can teach them by showing these things and find patterns. So you see this little picture here, this is the part collection of Franz Reuleaux mechanisms such a collection is there in Condell University higher state and a few other places in the world; these are all rigid body mechanisms.

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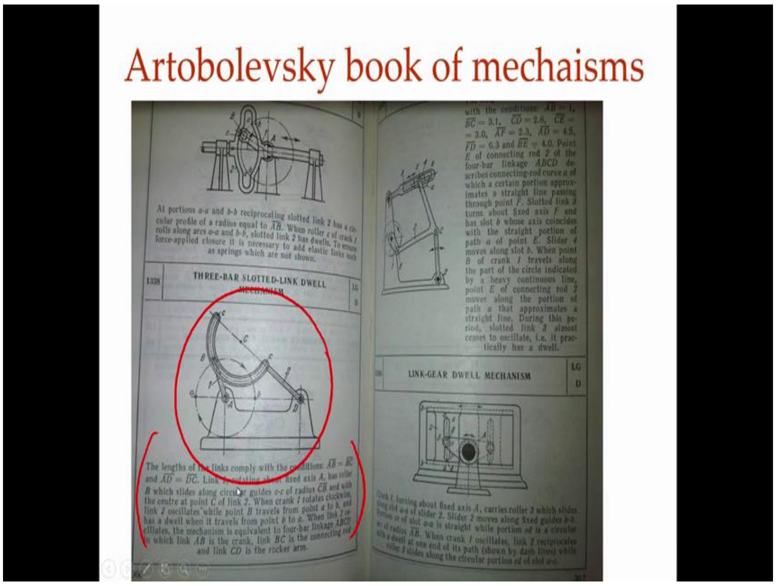

As oppose to that Artobolevsky has a book where this type of drawings are there, some description of what the mechanism does is also there. By flipping through this book the thick volume; two volumes, one can actually get lot of inspiration for designing compliant mechanisms for the problem on hand. Similarly Jones has four volumes of mechanisms, they are all classified properly, but all of these are rigid body linkages.

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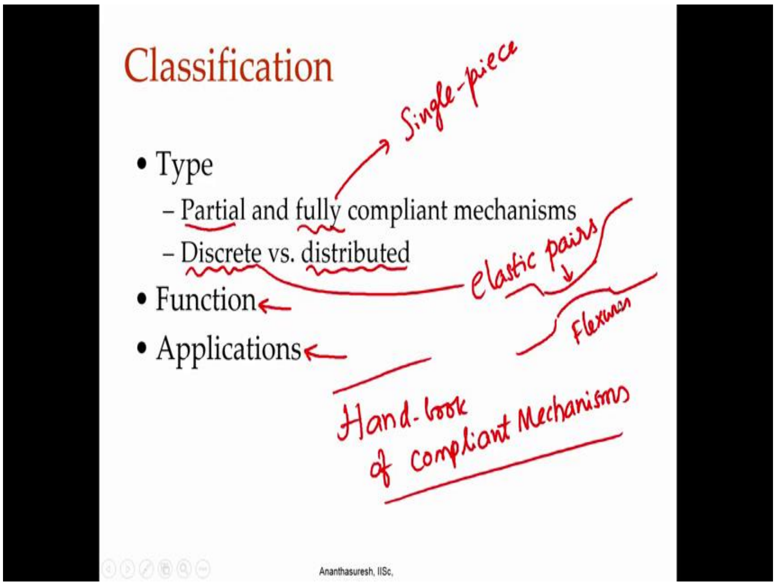

So we think about classification of compliant mechanisms; one can do it in various ways, first is type. We can say there are some partial compliant mechanisms where all members are not compliant, there are kinematic joints; there are some rigid or relatively rigid parts and compliant and elastic elements that mix it like a partial compliant mechanism. As oppose to fully compliant mechanism, where the entire mechanism is single piece; one continuum mix up the compliant mechanism that way we can classify. Another classification we have discussed during the course is at very beginning is discrete compliants versus distributed compliants.

Discrete compliants we have elastic pairs as we had called, these are basically flexible joints; such as narrow necked things like this and when there is a rigid one layer; these are elastic pairs or flexures. So, that is one thing but then we have emphasis that distributed compliant mechanism is important in fact most of the thing that we will see today are all going to be distributed compliant mechanisms. Another important way to classify is based on function; every compliant mechanism has a particular function, some other on multi function; they can be used in more than one function, but function base classification is a good idea.

Another useful way to do this is based on applications as well. Recently there was a hand book of compliant mechanisms that came out of (Refer Time: 10:33) group at Brigham university; that hand book does this based on applications also. So, that has deep description of each one of them and by looking at the pictures one can get inspiration for a problem on hand.

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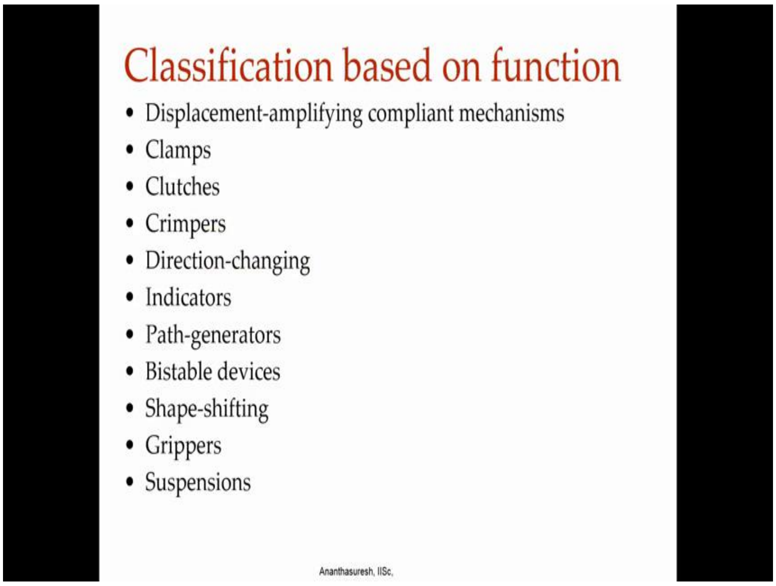

What we have today are classified compliant mechanisms or compliant mechanisms classified based on functions, we look at examples of each of these.

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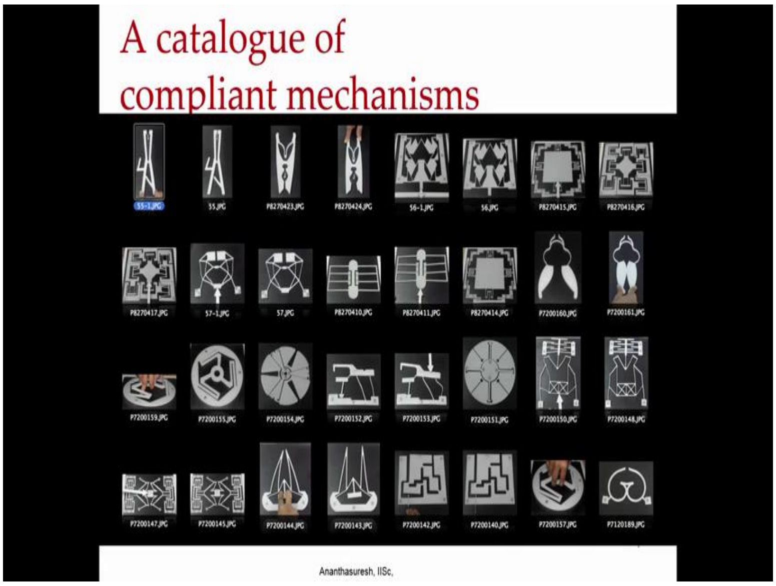

And there are pictures of this looking at this pictures is one thing; lots and lots of them, that all there in your lab on the walls and so forth. The other is to actually look at the real one, since we are able to communicate using this video based method. I am going to show all of these mechanisms so that you also get inspired to design a mechanism for your purpose, we will begin with displacement amplifying compliant mechanisms.

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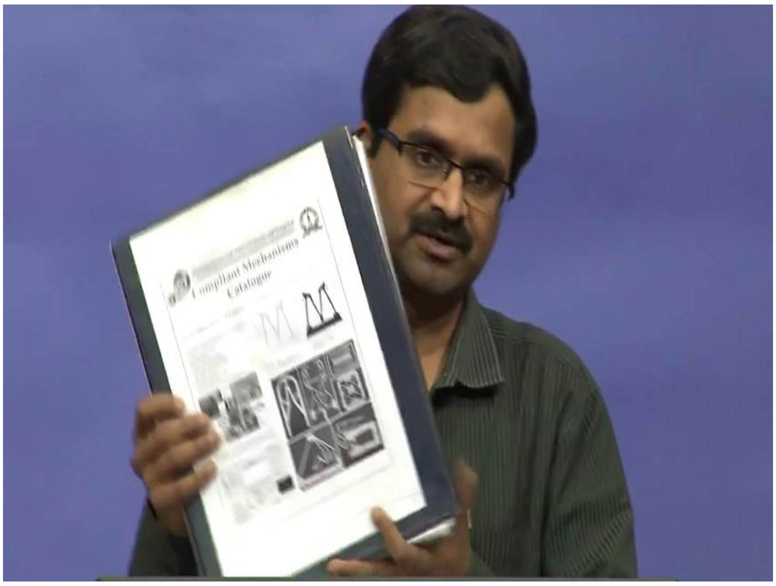

Before that let me actually show that a catalogue that we actually have like this book, these our labs catalogue of compliant mechanisms where there are a number of these sketches first, you cannot probably see the sketches clearly, but you will see the real mechanisms but what I would like to tell you is that there are all classified based on functions.

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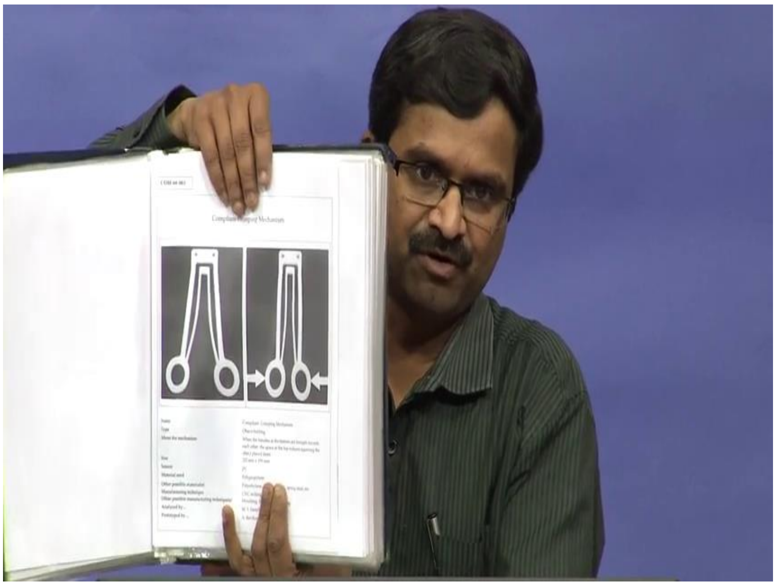

And each mechanism in which at three pages are there is going to be just a picture in its un-deformed and then deformed configuration where the force is to be applied, where the output should be and some description of what it does.

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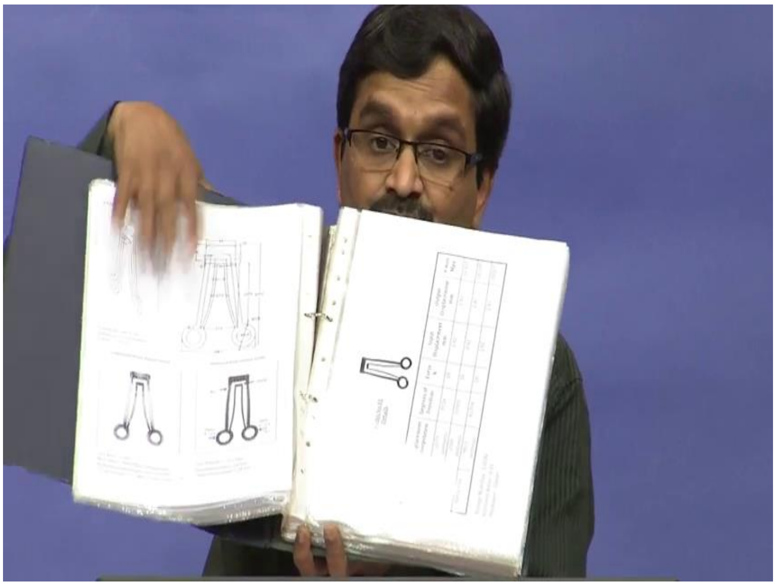

And then the drawing that is even if you do not have a cat file, if you have book like Jones and Artobolevsky and Chironis and others; you can have the geometry complete details of the geometric model of the thing and some information about the finite element model. So, one can also have downloadable finite element model, geometric model all that information is there and then each of them can also have the Kineto-Elastic map, for various characteristics such as geometric advantage, mechanical advantage and stress, maximum stress and so forth. So, let us look at some of the mechanisms starting with displacement amplifying compliant mechanisms.

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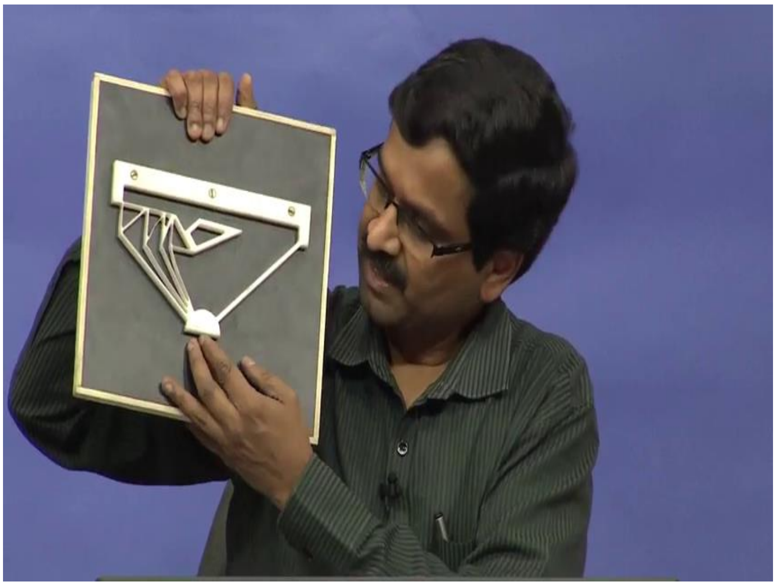

Here is one - this is the top portion is completely fixed, there are screws and then all made with polypropylene, these just the material we used to make this model, but because of our Kineto-Elastic maps the same design can be done with any material, any size, any cross section; as we will also discuss later about what materials could be use for compliant mechanisms and what manufacturing techniques will be used to make compliant mechanisms.

So, this particular one is displacement amplifying compliant mechanism that we call it DaCM, when apply a force here it moves a lot. You can see that I am pushing here not very much, but output over here is doing its job, this is displacement amplifying compliant mechanisms. This we ourselves have used in at least four different applications in our research.

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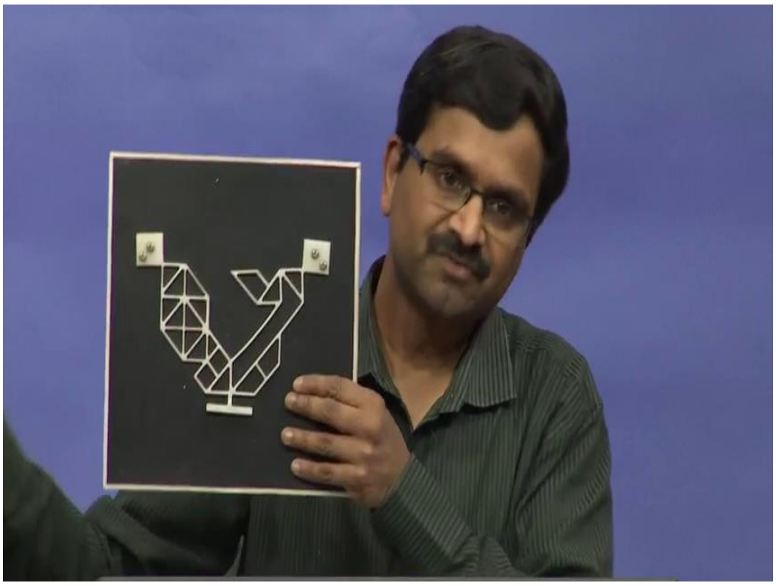

And here is one that was the basis for designing what I just showed. This was algorithmically designed, so here amplification is there by about a factor of 7, but not as much as the other one. So, that was inspired by looking at this; this was designed using topology that mention algorithm by Anupam Saxena; who is now a professor at IIT Kanpur, but this itself has inspired several applications for us.

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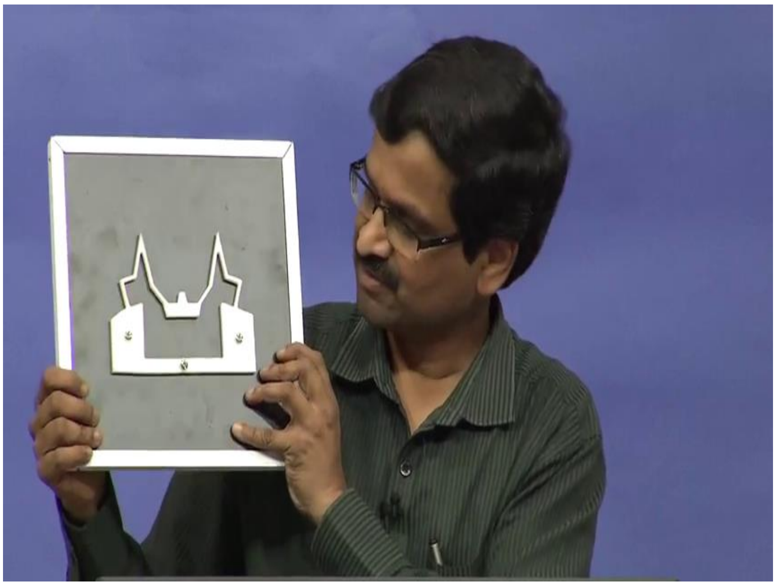

So, how we can move and how it amplify this present the output over here and here is one more, this was also done using optimization algorithm. This can be used like a gripper, but also in other direction it is actually amplified. So, each one of them we can see how it goes like this and more over this was designed by Girish Krishnan who is now a professor at (Refer Time: 15:10) this has, this thing about which we had actually discussed when we talked about building block based method for designing compliant mechanisms, where we can move it in x direction; moves only x direction, into y direction; it moves only y direction, but not (Refer Time: 15:26) like a gripper, so this is also a displace amplifying compliant mechanisms.

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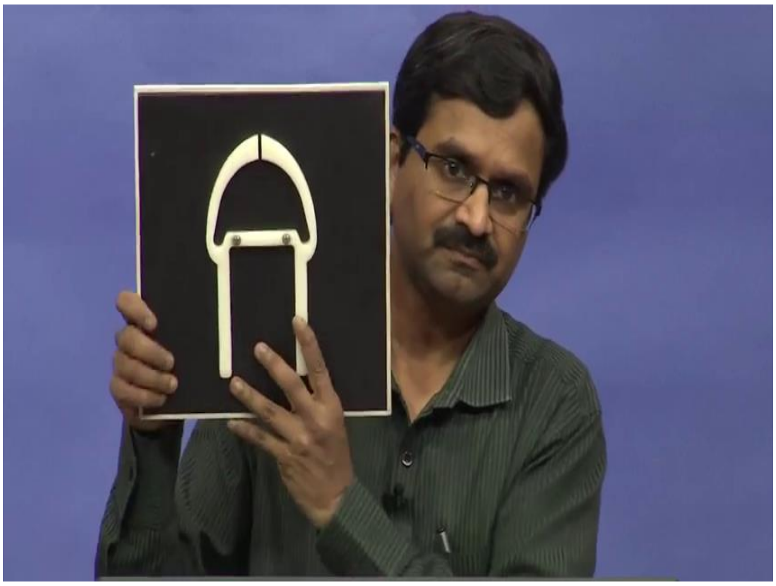

Now, let us move on to clamps, so clamps are there everywhere. So here is one, where I press like this; it opens up, you put some object over here and then remove it; it holds basically even the board is held by just my hand now because it is gripped. So, it has such a good clamping force; so this is like a clamp and that can be used.

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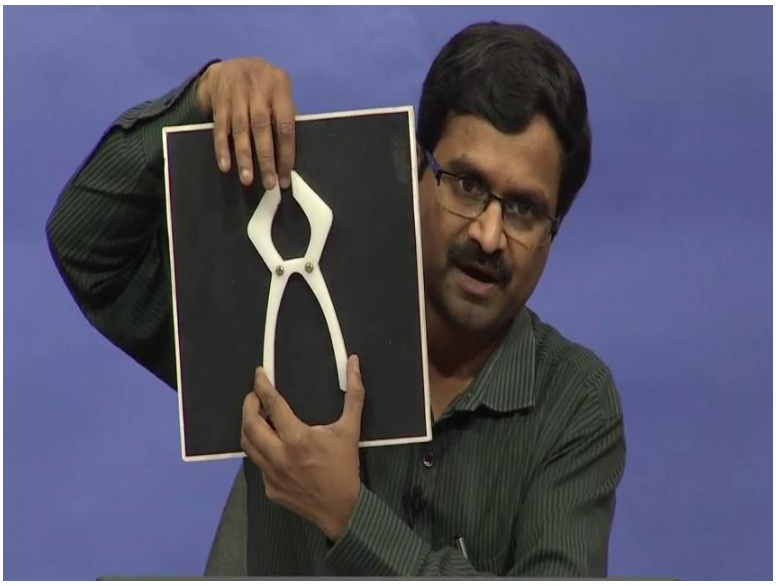

Here is another one, so similar to that but slightly different shape, different characteristic for a bigger object where apply a lot of force to open it up and put something it will hold just like the other one.

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Here is another one which is actually quite interesting, this is a large version. So, whatever I am showing, they are not a real size; this particularly it is a really a scaled up model of something that holds a micro electro mechanical systems chip. They are basically silicon dice, they will be very small sometimes 2 millimetre to 2 millimetre, 1 millimetre to 1 millimetre and compared to electronic chips which do not have moving parts and no delicate mechanical components; MEMs chips have delicate mechanical components and sometimes they have through holes as well, which electronic chips do not need to have in fact usually they do not have; mechanical insert through holes.

So, when use vacuum or anything else they actually get damaged, so we face that probably in our own work. So at that time; Ramu one of my students actually designed it and made it a micro scale, this square section in the middle that is where we can put the chip and the idea was when we apply force. So we apply force this way, they come together, when I apply force the other way; they open up. They open up slightly, you can actually hold it in your hand it is a small one; you can hold it in your hand and press this like this opens up then you put your square die there; silicon die and then leave it and it holds it.

At the time for transportation storage and it is a very convenient thing, there is no need for vacuum holding; even put it like this under microscope or a probe station one can easily do, that is application where you have to make really tiny and when I opened this and put it; I do not want the chip to break because of the tramping force. So, one has to design it carefully which is all done and these are the proportions for it.

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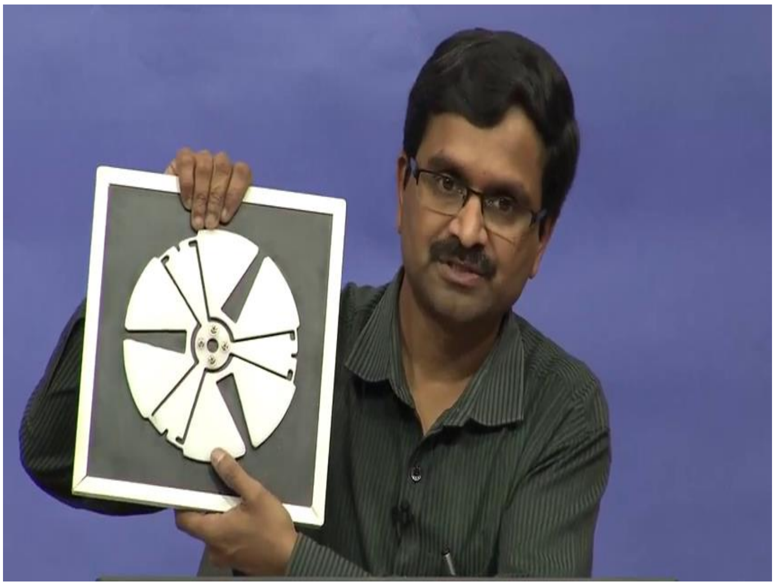

And next thing is an example of a clutch, the clutch this particular one is a clutch that was reported in a few papers by (Refer Time: 18:24) Hovels group, where it is a centrifugal clutch. If the whole thing shaft rotates because centrifugal force each of them will go; this is very stiff to demonstrate, at high speed all of this will go and stick to something around then the start transmitted at the torck after thresholds p d is reached. So, this is a centrifugal clutch and there are some bicycle clutches that over done and several of them are there; that is one class of mechanisms.

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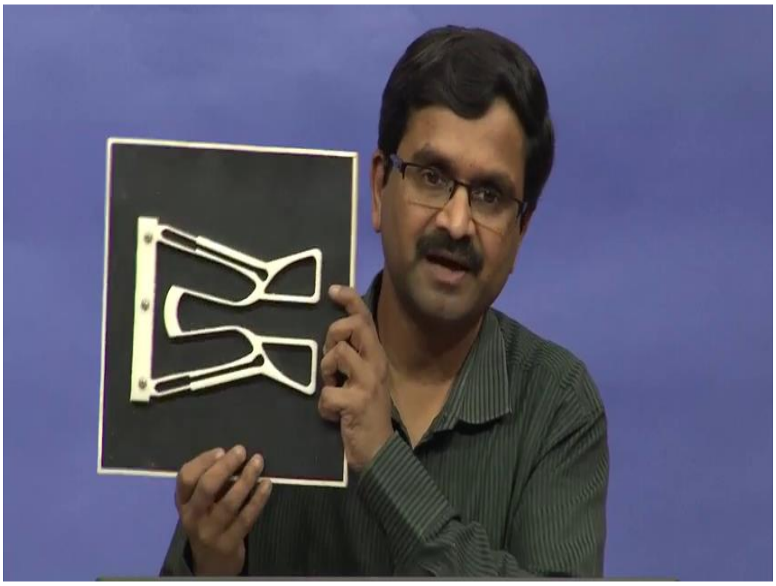

And then there are these crimpers and these crimpers are actually historically important to compliant mechanisms because professor Ashok Medhas group had actually started with a crimping mechanism. This one is very close to the one that they had designed; that was partly jointed and partly compliant but we have made a version. In fact all the divisor I am showing; all of it is not our labs work, it is something that we have taken from the literature and of course, many of them or from our own group. So, this is from inspired from that published work of Professor Ashok Medha when he was at (Refer Time: 19:37) University.

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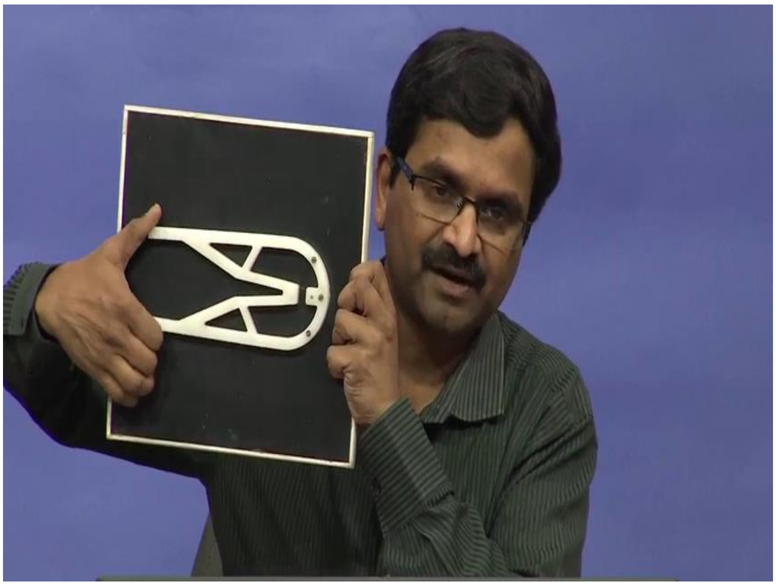

So, this is a crimper meaning that when you apply force; this one is going to move here and crimp a wire and in fact the next one I am going to show is something that they had considered there for crimping. So, if I do this it goes you can see here how it closes the gap and it will have enough mechanical advantage and force to actually crimp of wire. This was a m p incorporated in pencil even your state, I had work professor Ashok Medha and professor Ashok Medha always says that crimping mechanism is the one that started compliant mechanism.

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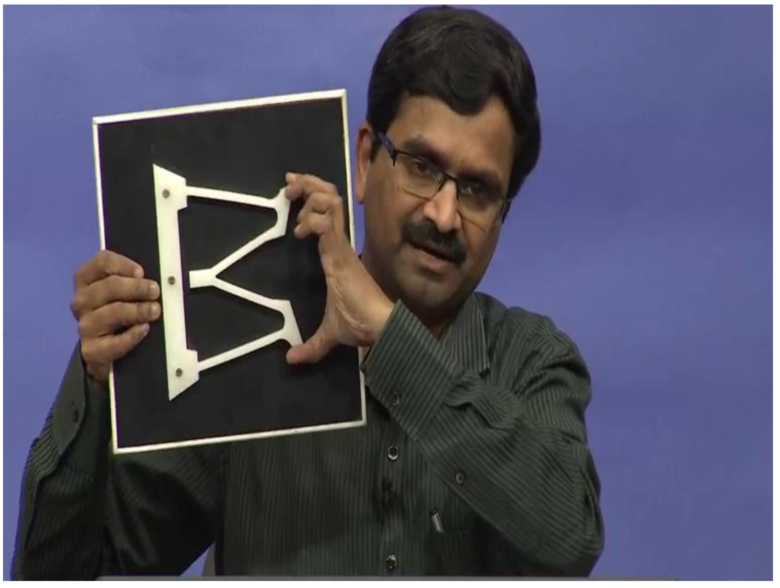

And here is another one; another crimper they all have different topologies or shape and so forth. So, this particular one has a lot of mechanical advantage, in fact if I put my finger here and press actually I can feel that pain, so it is a very good mechanical advantage that this particular thing has.

Next one that we will show are direction changing compliant mechanisms.

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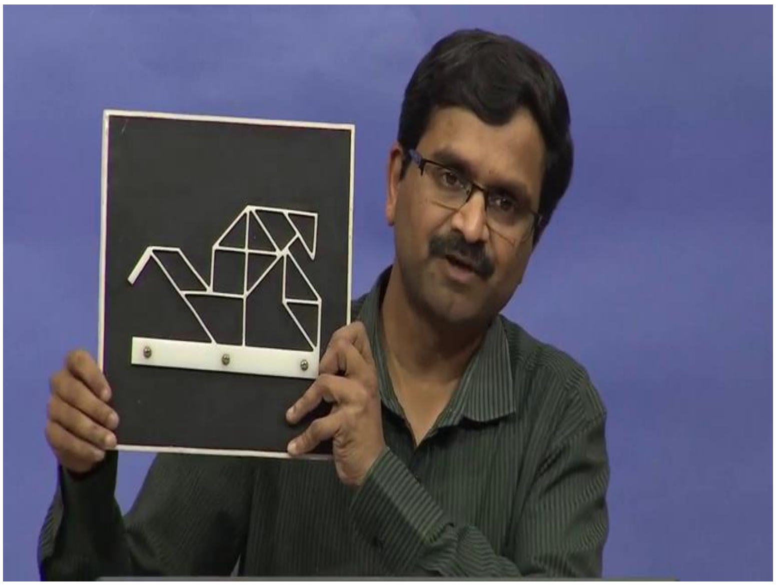

So, let me start with one over here, but direction changing what I am mean is that apply force in one direction and the displacement will be some other direction. This one was designed using an optimization algorithm again by Anupam Saxena, who is at IIT Kanpur now; he is professor there. So, apply a force in the vertical direction I am pushing it down, see where the output goes, it goes in that direction.

So, we call it peacock mechanism and it is defeating because where Anupam Saxena works in IIT Kanpur campus, there are lot of peacocks; so that goes like that.

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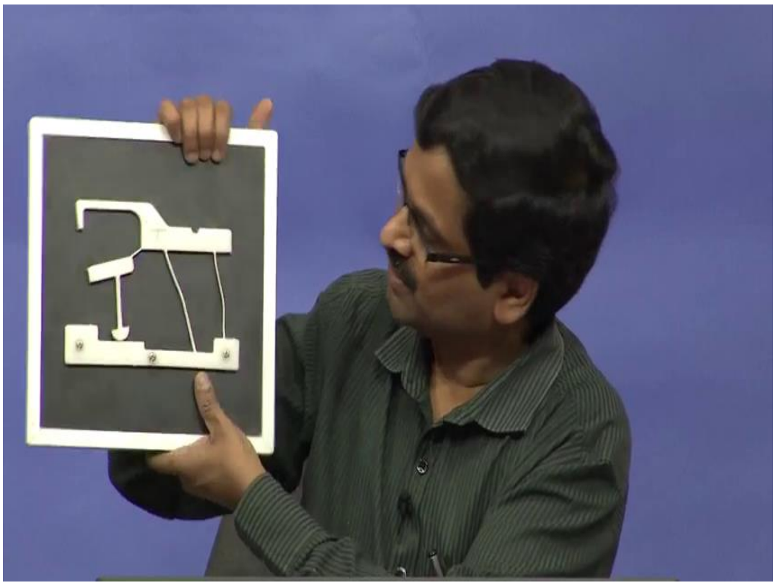

And here is another one; which also has a contact aided feature that when you apply a force here. So, how it works; it moves; it is a little difficult demonstrate it because it is going like this, if I apply force and in one direction it goes like this, so I can change the direction from input to output. When it touches here and then it will have a sudden change or a non smooth change in the path of the mechanism.

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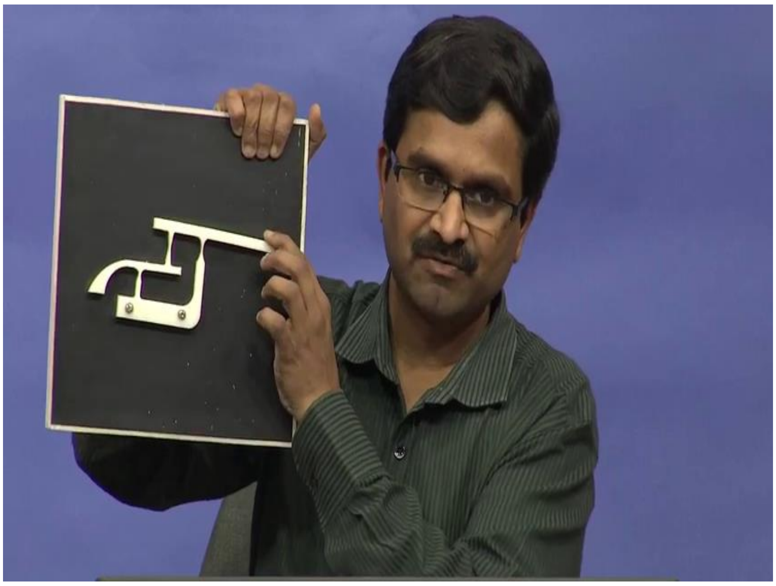

It is another one; when apply a force; it probably looks like it will loose; may be screw is loose. So, when you apply force this actually goes down and presses further; that is direction actually is not changing here, but that is the interesting feature of it; you are pushing down this also pushes down.

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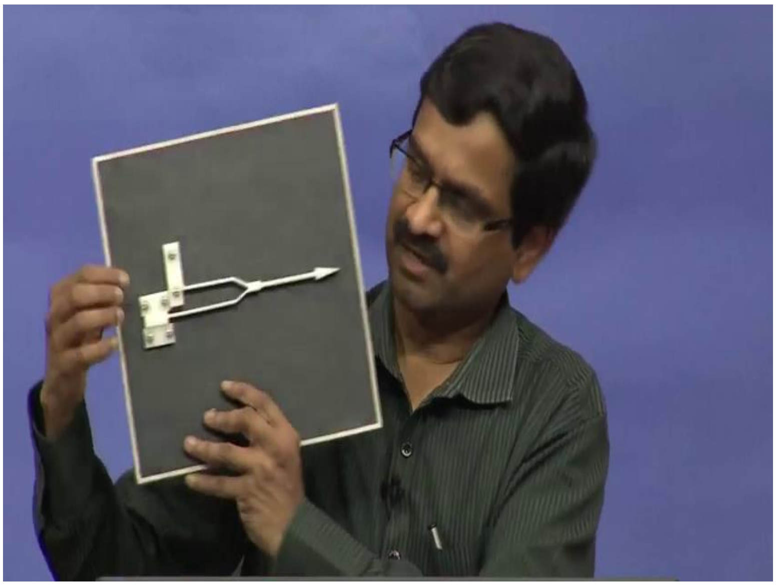

Next thing we will take on indicator mechanisms, so here is one indicator mechanism which if we apply a force over here; it moves like that, it will like an indicator. So, this we have used in a soil moistures sensor that does not use any electrical power or any external power. So, what pushes here is a super absorb and polymer which absorbs moisture and then swells; when it swells it expands of course, (Refer Time: 23:00) mean by swelling and if you put that mechanism next to it, that swelling force which will be very small is enough to push it and it show like an indicator to a former. Of course, this is not the mechanism we use there, a scaled up version of it, material is different, cross section is different, we can adopt to that such a small force where the amount of deflection we got was almost like this; we can show 1, 2, 3, 4, 5 levels that indicates we have former how much water we need to put (Refer Time: 23:33) field.

So, that was the inspirator of for this, in fact this particular mechanism was taken from a mechanisms book by S Molian, so we have taken from books as well. Here is another one which is also direction change a mechanism.

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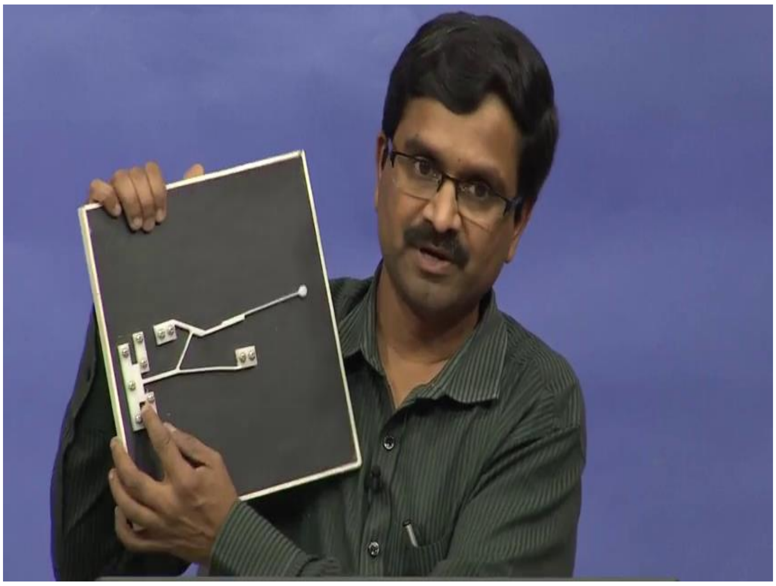

Again it is from a book by Molian, so before all the modern mechanisms scheme people used to do this a lot with mechanisms, this also a direction changing sorry not direction changing indicator mechanisms something that moves here; that will make this move this thing to indicate a particular level.

Next, move on to some path generating mechanisms.

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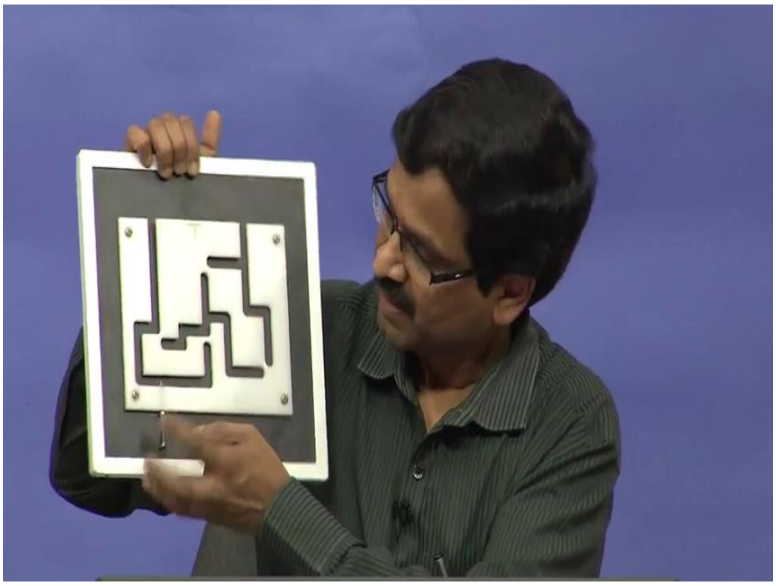

Here is one this is actually what we can call discrete compliant mechanism as oppose to distributed something that I do not recommend because the weakest links are these joints and in fact, rage of moisture be quite limited. So, here where supposed to push up here; it moves like this, this path generation because this is inspired by a straight line generating mechanism and actually (Refer Time: 24:45) mechanism when I push here, this supposed to move like this.

It does not really do that for a small range of motion it does, if I put large motion it moves somewhere else. So, this is a path generating mechanism that is based on discrete compliants.

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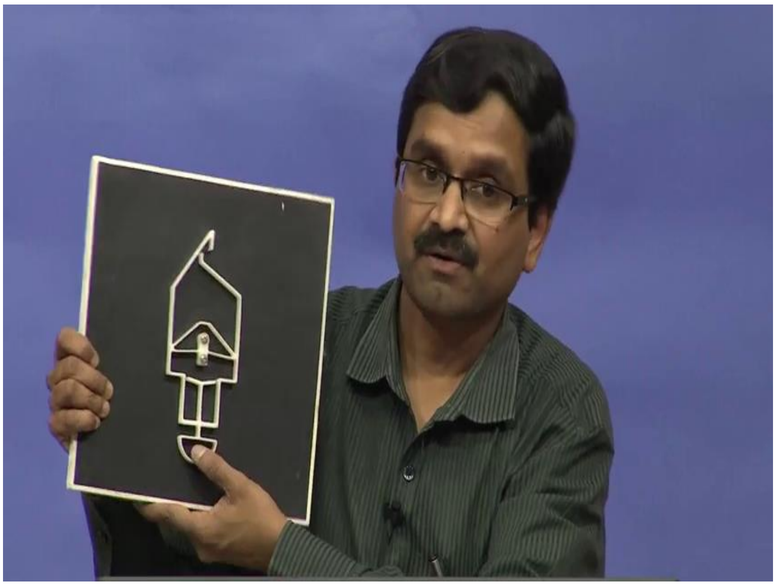

And this particular one is something that had non smooth path generation; we just need to apply force in this direction all through. When the contact take takes place between this part and this fixed part, it is fixed in the middle, the contact takes place there and there is a little thing here; there is a gap over here and there is over here, if you look closely there will be a gap as I pull they contact here as well as there. Then the output points path actually changes, that is a path generation not smooth paths with smooth input, so that is the feature of this particular compliant mechanism.

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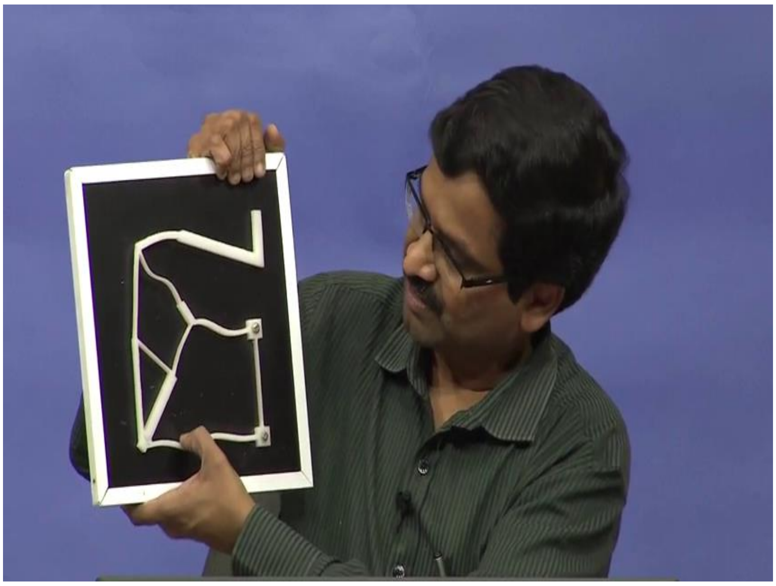

And there is one more this is actually the work of Professor Anupam Saxena of we use genetic algorithms to make these things. So, we there will apply a force some place; this must be the output point when apply force I forget where; it is probably straight line mechanism also as I moving this seems to moving almost like a straight line.

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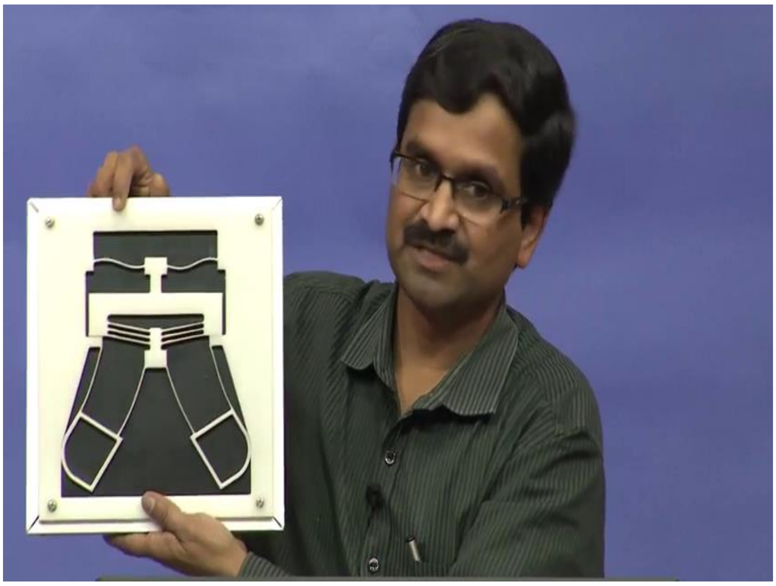

So, he has a number of designs that have this and we also bistable devices; there are a number of bistable devices, we had three lectures on bistability and there are number of mechanisms and here is one. So, let us see it is probably we have to push it down that is one state, so it opened up and then do this another state.

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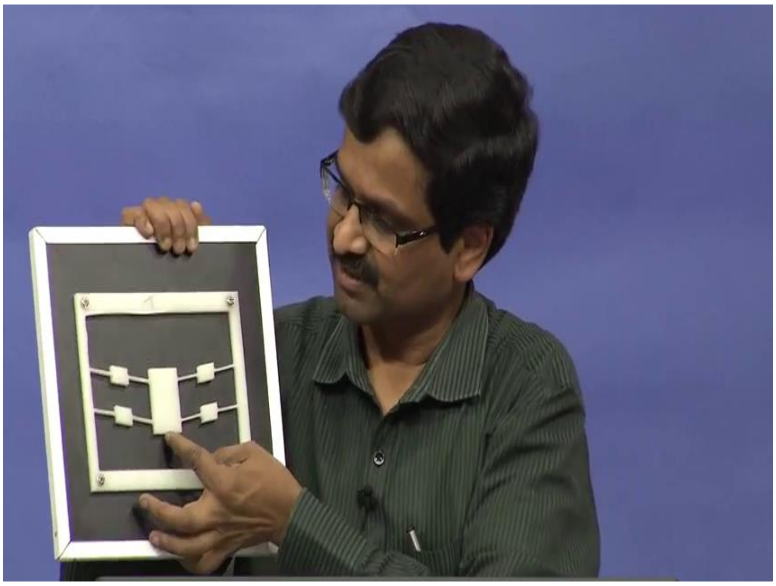

So, we have a number of bistable mechanisms also, but I am be just showing couple of them here; this is also one state, this will another state.

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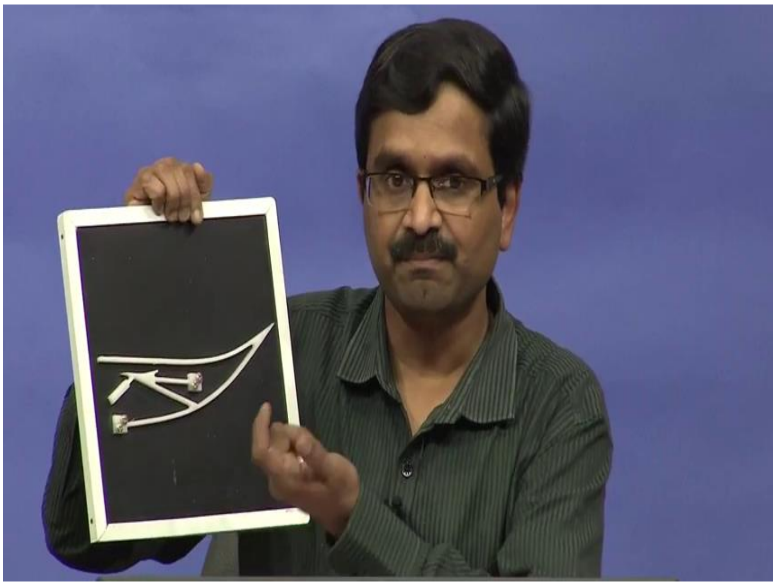

And shape shifting, this is one other interesting applications of compliant mechanisms, where if this is like a aircraft wing or something or a turbine blade shape you want to shift it based on the conditions of the environment, we can actually do that this particular one; if you push it like this, you can see how the shape of this is actually changing.

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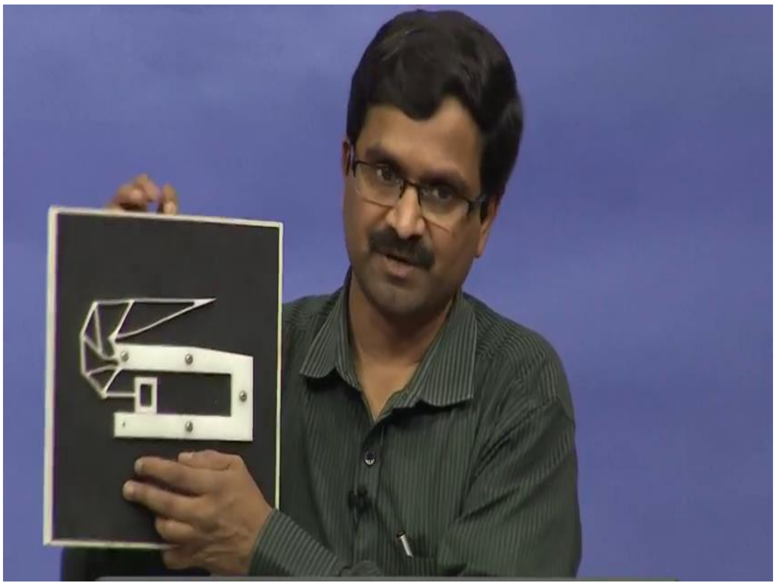

And here is one where you can see it more dramatically, if you have a piston cylinder or something like an actuation when I put this, it shape change like a flap of an aircraft you can change it like that.

It will be much more smooth, it is smoother than having a hinged flap here, this is also a lot of application in shape shifting compliant mechanisms. Finally, we have a number of grippers in fact the gripers that we have are probably two dozens or something, they all have lots and lots of design.

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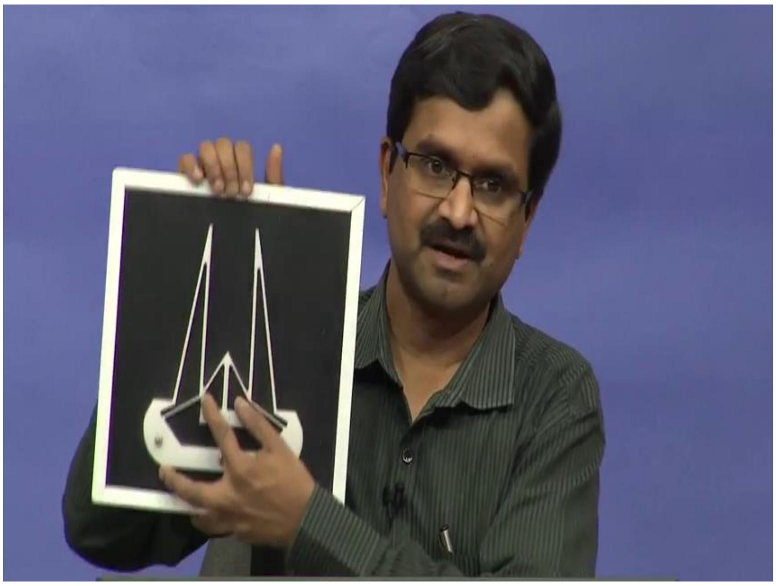

So, it can this is one type of gripper when I am just pushing it down, it does this. We will talk about grippers later on, but I will just show a few.

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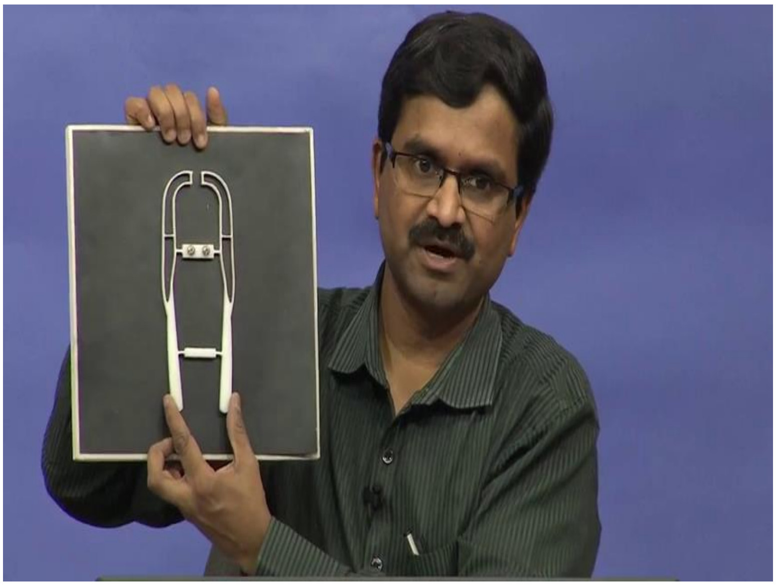

This is a parallel motion gripper when I apply equal forces at these two points and these two things will go almost parallelly without rotating. By that I mean they go like this; not like an arch motion or going like this, they can actually go like this without this tilting or this motion, they just go like this.

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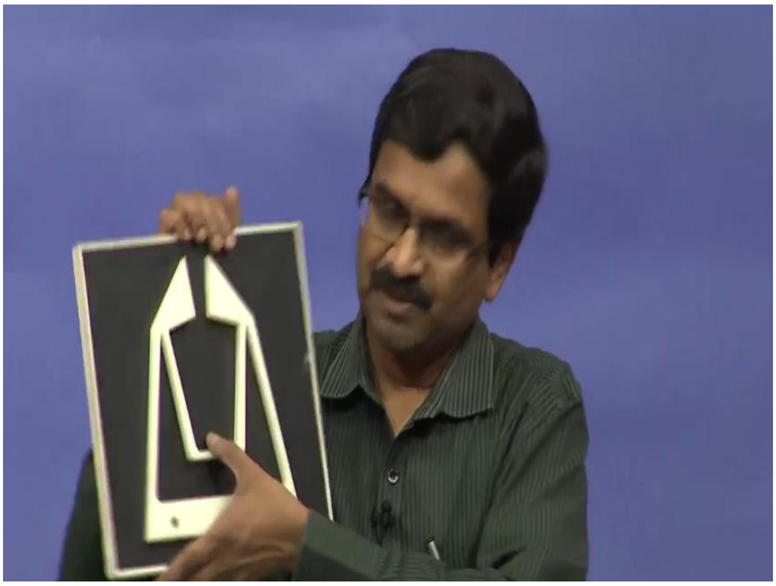

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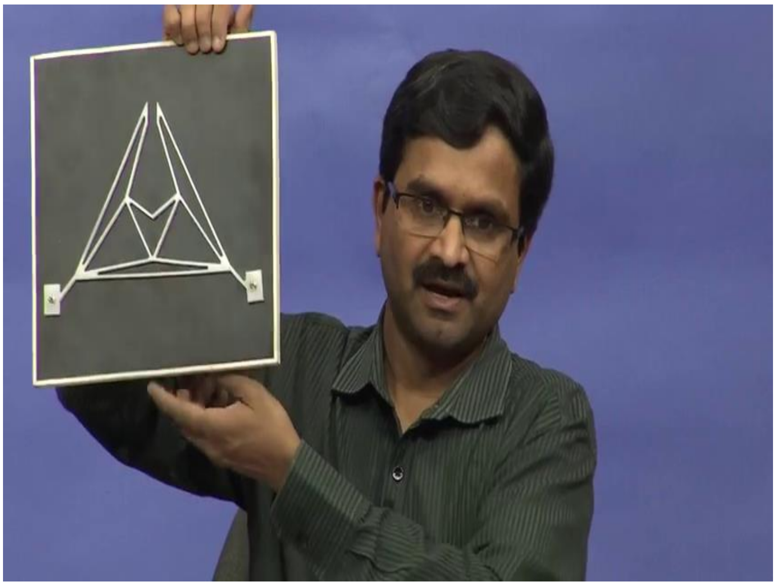

And this was probably my first gripper, so simple topology like gripper and here is another gripper, so where we apply a force it goes like this like a ITC company logo.

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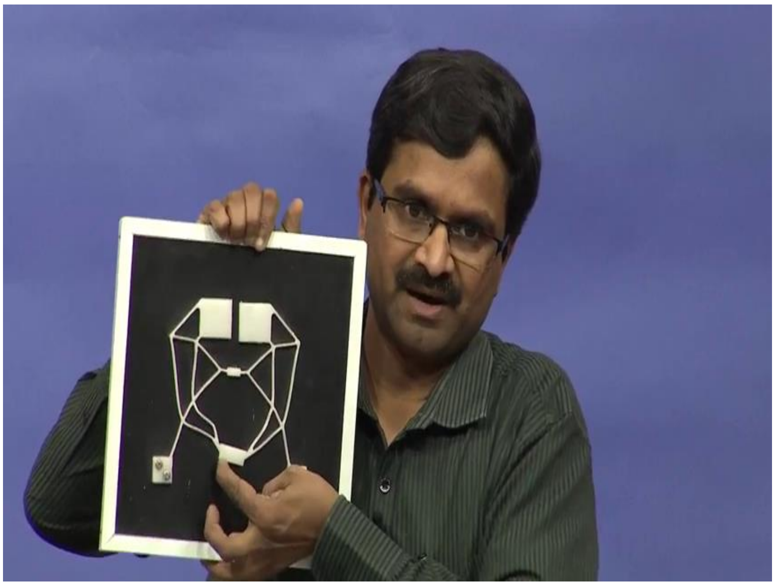

Here is another one, this was ole segments design this also has that feature of going when I push it up, they go parallel to each other I have to push it with lot of force and it goes like this.

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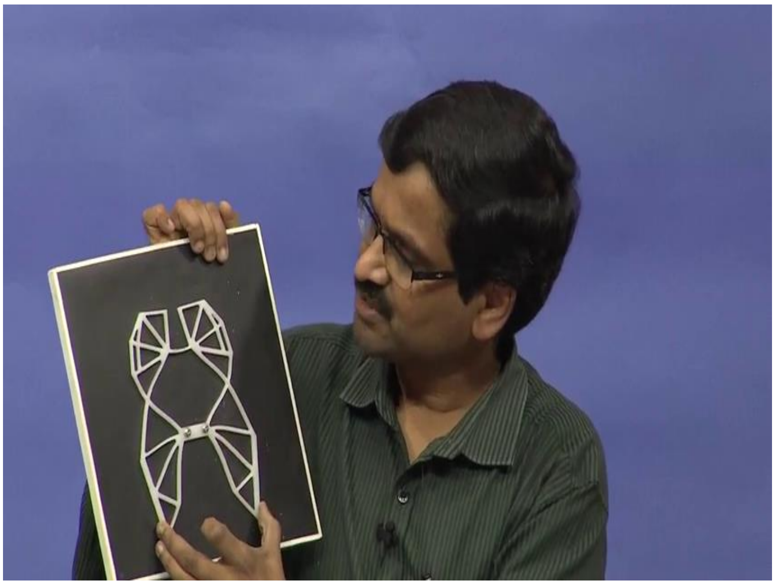

This was topology optimized design and this was also a topology optimized design that actually grabs and pulls it as you can see, when I am applying it grabs and then pulls it.

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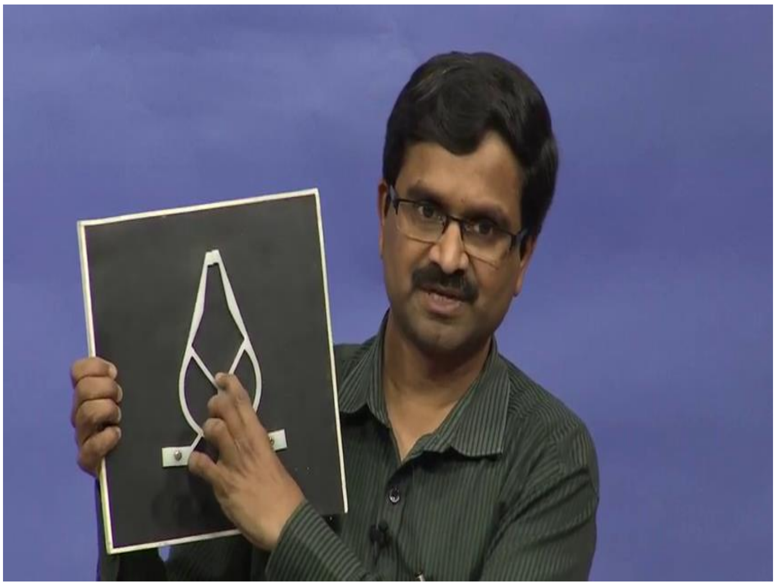

And here is one more, it is actually endless you know when we push here; it comes like this.

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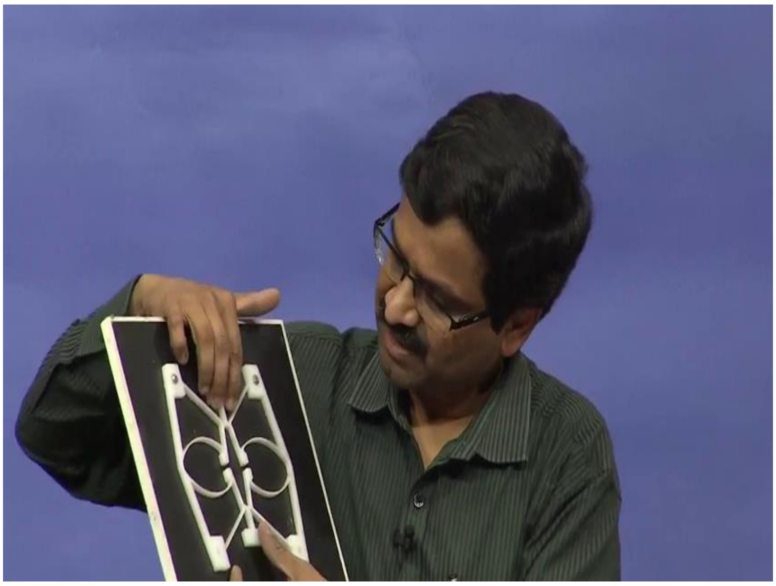

Each of them has a slightly different characteristic especially, if we look at the Kineto-Elastic maps then we would see how it does. This particular one is something that grabs and pulls, if I push it here; if I put a little wire there in between this gap and this gap as I push, they come into contact and then they actually pull it, so will see more of it later on.

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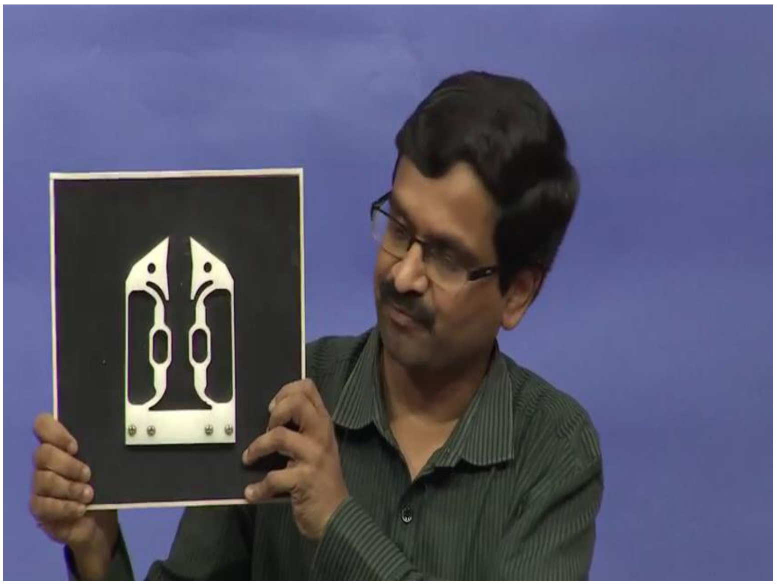

There are a number of other grippers; this one is again one of the very first compliant grippers that came from professor Ashok Medas group, where there was a little gear here to pull them together to make parallel motion. So, this was one of the first that inspired me to take up this compliant mechanisms, so this is very special for me personally to have this gripper. So there are many many other types of grippers, I think we probably showed enough and in the next lecture we also look at a few more which are actually suspensions, which are important for micro electro mechanical systems.

Thank you.