Compliant Mechanisms: Principles and Design
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Lecture – 46
Designing with Kinetoelastic Maps

Hello, we had discussed in the last 2 lectures how non-dimensionalisation can be done for not just simple beams, but for the whole compliant mechanism. Today we will look at 2 examples to illustrate how we can use non-dimensional maps to design complain mechanisms or rather dimension I would say that is topology we already have something that from a data base which as I said in our lab you have about 80 to 100 of this compliment to topology you can take any one of them whatever size they may be, whatever material they it might be made of we can use that and then see if it can be used for some other application - whether it is micro or macro does not really matter because what we have is non-dimensional maps.

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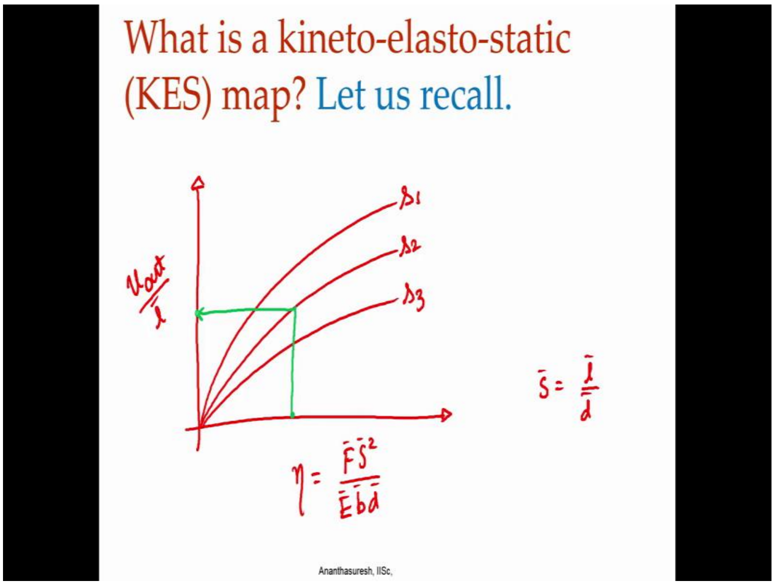

So, let us look at that first let us we call what Kineto Elasto static map is. So, we take any quantity let me keep the pen in some ink to daw this map were we have eta which is F S square by Ebd to recall S is slenderness ratio which is l by d by the way all these are average values which is do not put them after some time. But different S value we have a quantity could be so far we discussed displacement let us say u out divided by l bar that is not dimenasionlized, so we plot these things it may be like that for one S another S another S and so forth that is S 1, S 2, S 3 and so forth. So, that is the Kineto Elasto static map. So, what it means is that if I have a mechanism we can calculate eta value once we know forces (Refer Time: 02:24) ratio X modalus breadth and depth b and d we will know as let us say it is S 2 quickly we can find out what did non-dimensional displacement is since we know l bar, we will get the non-dimensional real displacement non-dimensional. Once you get this quantity that is non-dimensional multiply by l bar we get the displacement.

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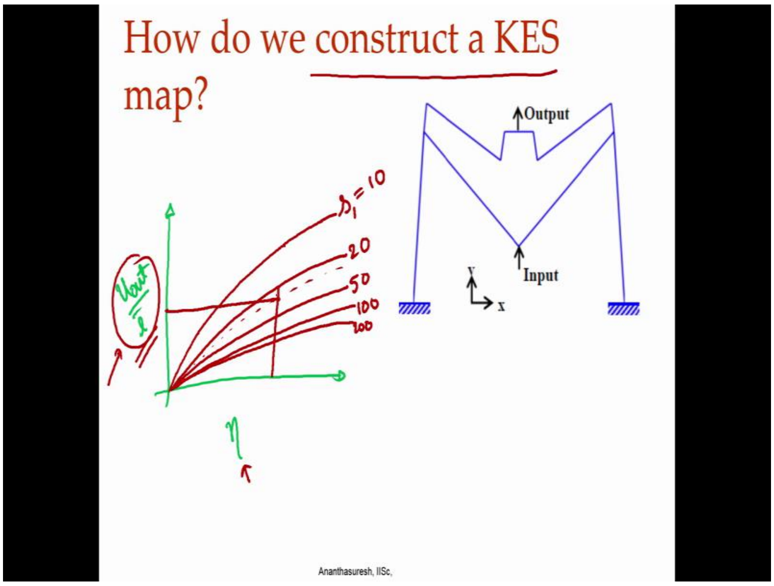

How does one construct this KES maps Kineto Elasto static maps? For that in order to plot any one of this curves let us say I have u out divided by l bar and then eta and if you to take any mechanism whatever dimension is it may have, whatever material it is made of does not matter.

We take whatever we have on hand and do a finite element analysis we have to do a non-linear quantum analysis within is still linear, but geometry non-linear 1 and we can draw they can basically get many points and if you take them close enough you will get something like smooth curve that will be for 1 s value let us call it s 1. That s usually we start from 10 because below 10 as we already discussed we does not obey the beam theory on with this non-dimensional analysis is based on so we take 10 and then increase the value do another finite element analysis and do it for 20 and then may be 50 because

30 will be too close and if you start doing you will see even with 100 you know it does not after while even if 200 it will come very close. So, whatever more than 200 it does not really make sense because become 2 slender.

So, if I were to do for 10, 25, 100, 200 I just need to do 5, finite element analysis it may look like lot of work it is actually only 5 non-linear finite element analysis is all you need to do for a given suspension that all for this non-dimensional displacement that you want. So, just that we did to recomputed the values in terms of eta and then this non-dimensionalized u out by l bar which is not a lot of work simple competition. So, constructing KES maps is really easy it is not a lot of grudge work it just few analysis or once we do it no need to go back to finite element analysis because let us say you are not done 30. So, you know were 20 and 50 are, we can actually intelligently interpolate back of the envelope calculation. So, you can easily do and find out what might be for this eta if 30 or not done in say what that is. So, it is as easy as that.

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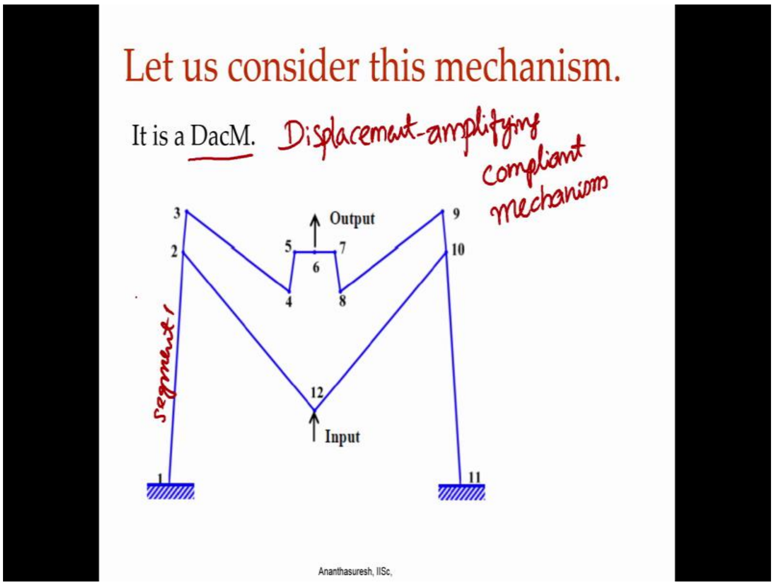

The first thing we are to do is once a complain mechanism is there here we have a DacM meaning this is Displacement amplifying compliant Mechanism, what we call DacM for short it is a acronym abbreviation. In this case segments this is first we have the nodes 1 2 3 and 4 and so forth and we also have this is segment 1, segment 2 and so forth.

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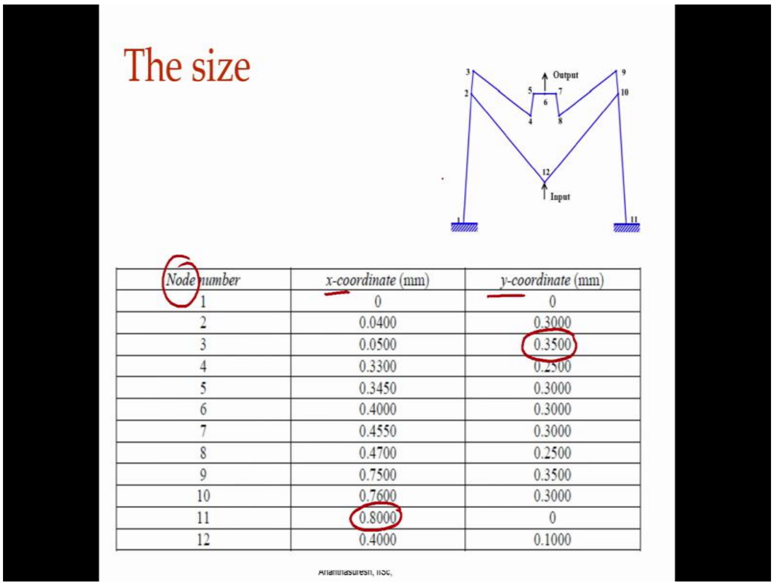

So, let us say this information is given to us. We have any data base a lot of complaint mechanisms each of them this is the node number and then x coordinate y coordinate, what size it is does not matter. The size of this is given here if you see the maximum here is 0.8 here and this is point of 3 5, this is 0.8 milli meters by point theta millimetres meso scale mechanism micro mechanism if you what to make this. But what you need may be a bigger than this smaller than this does not matter, it just the size of the mechanism that is in the data base using this you can draw the Kineto Elasto static map.

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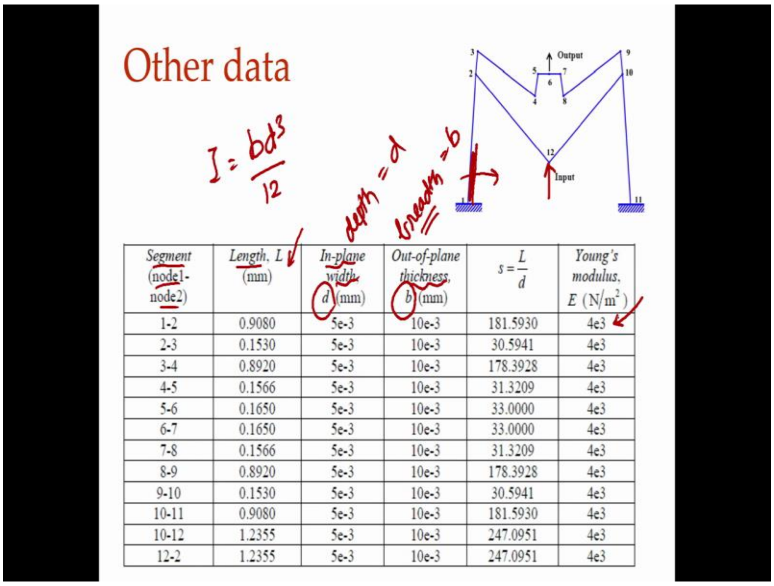

And for doing that you also would need to know once your coordinates of course, you can calculate length of all the things and segment connecting which vertices on nodes we need to know In-plane width we need to know out of plane thickness. This something to note this is the depth of the beam, there is the breadth of the beam and use depth and breadth indicate that this is d this is b.

So, that second movement of area for rectangle of cross section b d 3 by 12, how we decide this? The depth is the dimension in the plane of deformation. So, if have a complain mechanism let me just show then In-plane width here we is going to deform in this plane when you apply the force here. So, that becomes the depth. So, In-plane width is that depth of the beam and out of plane dimension which is the breadth here which is out of a thickness. So, thickness is actually breadth here b.

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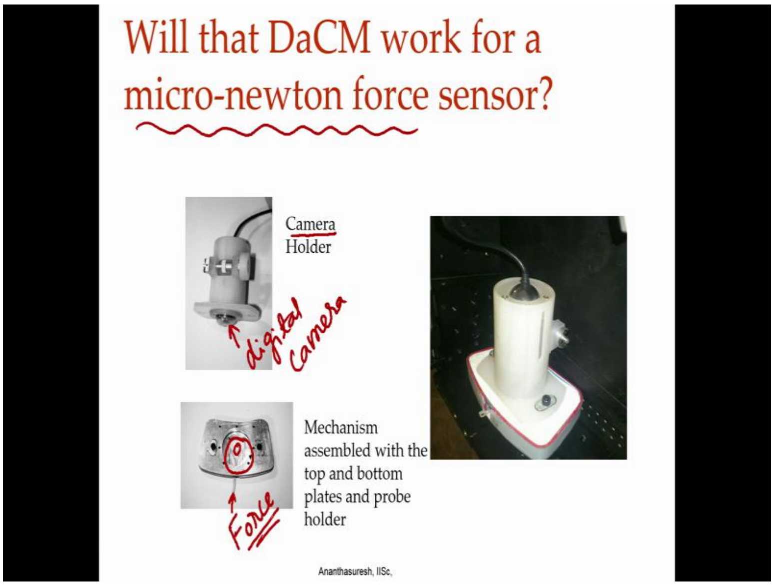

So, when you have this data you can draw the Kineto Elasto static map. So, in this particular things let us talk about how to design a micro Newton force sensor that is the force sensor that can dissolve up to 1 million of a Newton 1 micro Newton. So, that is actually made in or group couple of years ago were it looks like this, what it has is a digital camera is it a holder this is the digital camera. So, this digital camera looks at a compliant mechanism which is here will see a bigger view of that. It is not that small also it is something like a meso scale 1, but made with p d m s the very flexible material that will have a input here and that will cause output of a point amplified which the camera looks at it and then based on what camera measures as the output we can estimate what this force is. So, that is the principle of this micro Newton force sensor.

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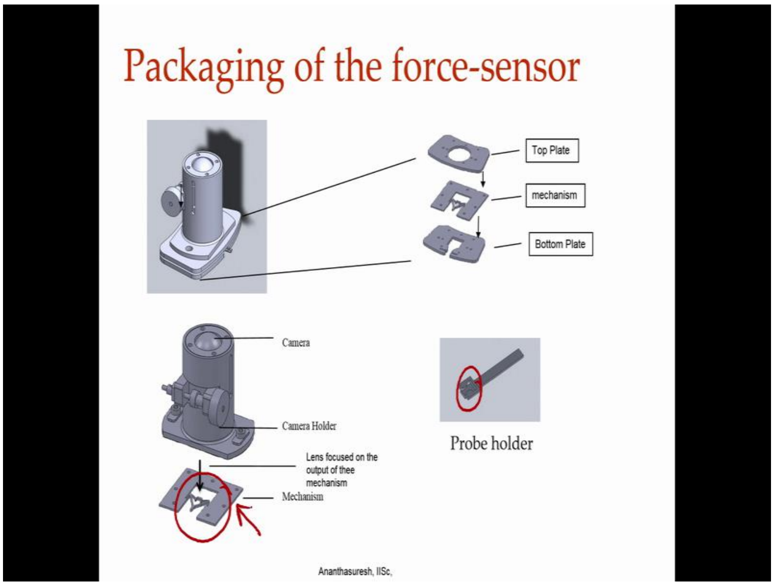

So, the packaging at this is the holder, whether camera comes this is the mechanism is the probe holder were the mechanism will be located, you can put the whole thing and it is more like a cartridge you can put that it breaks (Refer Time: 09:24) it does not break because make sure that when you design that it is strong enough.

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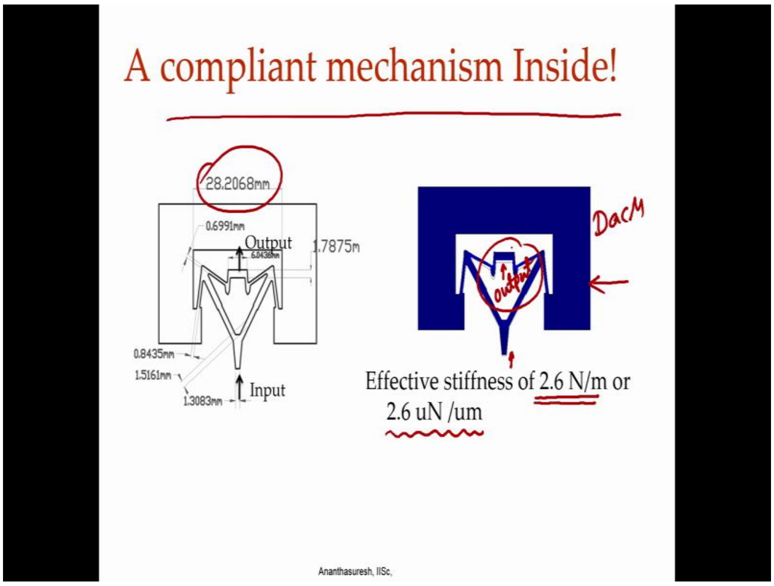

So, what is important here is the compliant when that is inside this force sensor there is nothing else you can dip in water we can put whatever feels it does not really matter and you can actually use this to measure forces there applied on the cells are other biological things were environment may not be suitable for other types of sensors. There may be expensive, but here the expensive part is at digital camera which also you can get for 5000, 6000 rupees these days and there certainly cheaper than some of the mobile phones that smart phone you have. After that it just the compliant mechanism our DacM that is you apply input force little line you can see it amplifies displacement over there that is the output. So, it designs such a sensitive one which is effective stiffness of 2.6 Newton per meter, the device if you see this is 28 millimetres, it is a centimetre size device 3 centimetres by 2 centimetres, but it is stiffness is 2.6 Newton per meter very low or 2.6 micro Newton per micron, it will move by 1 microns over here and over here it may actually move a little bit more because the DacM and we can measure that use the camera and that is how we get our micro Newton force sensor.

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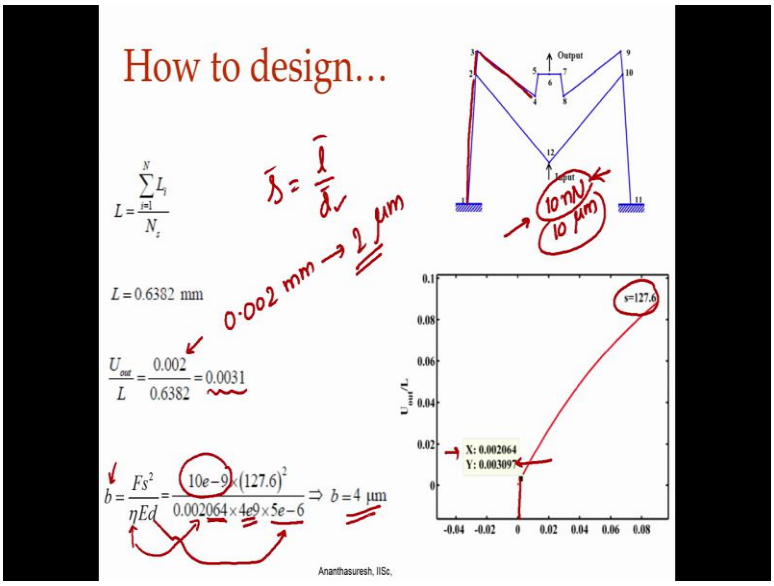

So, how do we design? The first thing is we are to get this l or rather l bar we have all this segments - we have length of this, length of that, length of this you take the average in this particular case, but l average for the one that is in the data base it 0.6382 millimetres we do not need. So, many decimal places, but since were there you have put in fact we are designing something very sensitive, so micron and submicron also matters here, that is the l bar and the once we have l bar you can choose s value you have once a l bar slenderness ratio which is l by d or l bar by d bar or s bar.

So, most of the time in micro fabrication the In-plane width it decide the lithography limit that in a particular process you can make a three microns 1 micron 5 microns whatever your capability is in this case we choose 5 microns conservatively. So, you can actually get that slenderness ratio s here by taking that l bar you have divide by d. After you do that you draw the curve that is Kineto Elasto static map and then what you want u out by L, L bar u out is taken as 0.002 millimetres and that is 2 microns why do you want 2 microns the idea is when you apply let us say 10 nano Newton's here or 10 micro Newton's here whatever is the force you want displacement. Displacement here we wanted to be at least 2 microns because the smallest force that you want to resolve should lead to a displacement at measurable by the digital microscope here or camera there.

So, there we thought that if we are 2 microns that microscope is able to measure. So, you have taken the u out l then we get u out by l non-dimensional number and that is the y coordinate here 0.003097 or 0.0031 and corresponding x here is the eta value which is very close to 1 that is 0.002. Once you have eta then we can find the implant width that view wanted should be the d that we had assumed. But breadth which is the out of length thickness here can be obtained because now we measured eta to be 0.002064 does not matter so many decimal places, but 0.002 and f is in this case we have taken 10 nano Newton's, s is 127 because we assumed d bar to be 5 microns which is here right this is d that is 5 microns e we have taken 4 gigapascals. In fact, I forgot to mention here in the data base over here for this mechanism e was for 1000 Pascal's that is just something that was put in data base does not really matter whatever it is what we want is the non-dimensional map that we now draw. So, in the non-dimensional what X modulus you take there does not matter as long as displacement everything we have taken the consistent units.

So, we have all of this now we get b to be 4 microns we need thickness is 4 microns, if it is 4 micron thickness sometimes could be 2 thin in which case there will be problems of mechanism deforming out of plane we have to increase and that may change this that is exactly what we had done.

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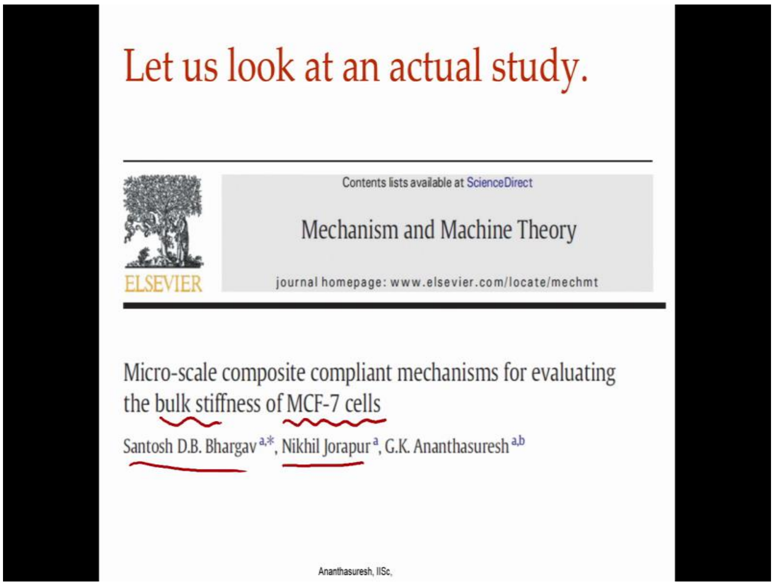

In another work Santosh Bhargav and Nikhil, 2 students had done this work for designing these mechanisms not for micro Newton force sensor the that I talked about, but actually to measure the stiffness of cancer cells breast cancer cells the cell line which cancer foundation 7 cells.

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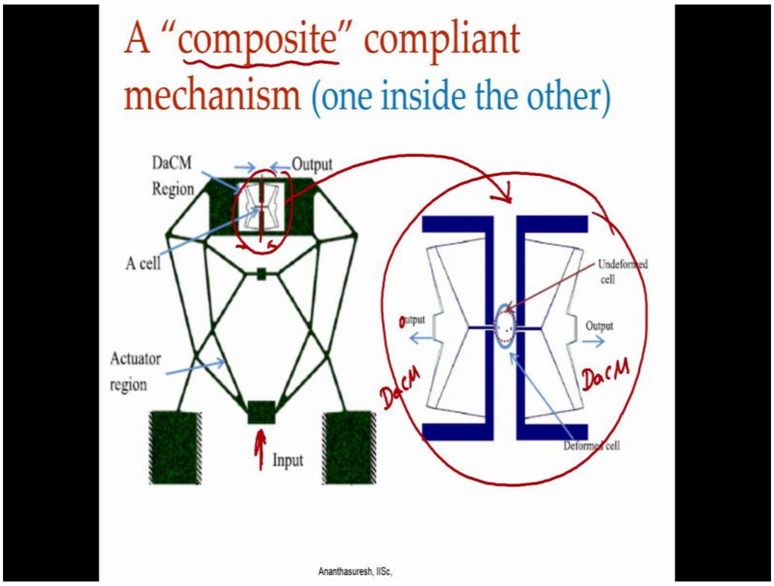

So, we want to measure the bulk stiffness as if you hold cell in your between your fingers and then see how stiff it is. For that what they done was they are taken a compliant mechanism which case a calling composite compliant mechanism meaning that there is a compliant mechanism inside a complain mechanism. This particular big mechanism is if apply input force here these 2 just you hardly see gap between them, but there is a gap there will just come together were it comes together the touch and that is when if there is in between, so this another complain mechanism which is grown up here that is a mechanism in 7 mechanism, in the composite complain mechanism here were a cell is cell was red circle now became blue when you do this.

And here is where we have DacM on the right side and DacM on the left side, you have 2 displacement amplifying compliant mechanisms in such a way that this probe if I put a cell the red one where the force is applied over here, that is force applied the big mechanism small one here use and then this force applied by the cell express by the cell would cause this output to move and this is where we would want to measure using microscope. Use any microscope take we have a field of u, now or felid of u should be this big that we can see both DacM and the cell that we are grasping that are the constraint here, based on that first looking at KES map for this mechanism. So, it will be like this.

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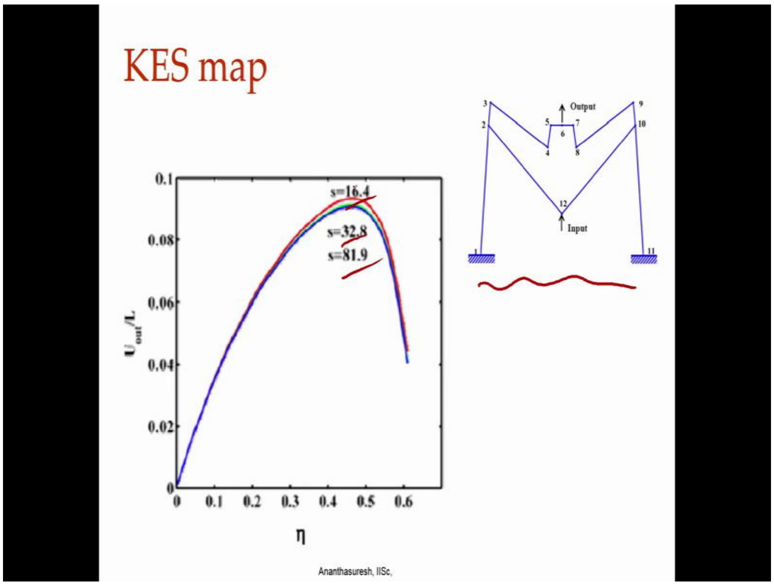

We have looked at you can in a earlier presentation also eta is up to 0.6 we have drawn and for s equal to 16.4, 32 and 82 and it as a maximum all the features are there.

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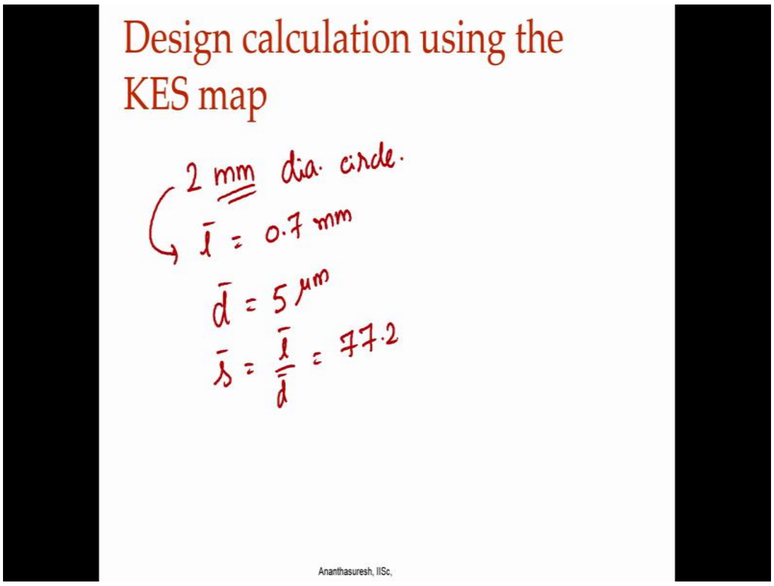

But our interest here is the particular set of specifications; that is we want to be able to do this in a way that the mechanism both mechanism and the cell fit in a 2 millimetre diameter circle that is what, I had just drawn that is this circle 2 millimetres. Based on that we can get roughly the l bar for this mechanism from that specification l bar for this is 0.7 m m, that is for in the data base we can get the average length of all the segments and scale up for what we need the 2 micron in that we want each mechanism gets 1 millimetres 2 millimetres 1 millimetre, so l bar average 0.7. And In-plane width which is the depth of the beam here that is we are taking 5 microns based on the causes then we get s or s bar to l bar by d bar which comes to 77.2.

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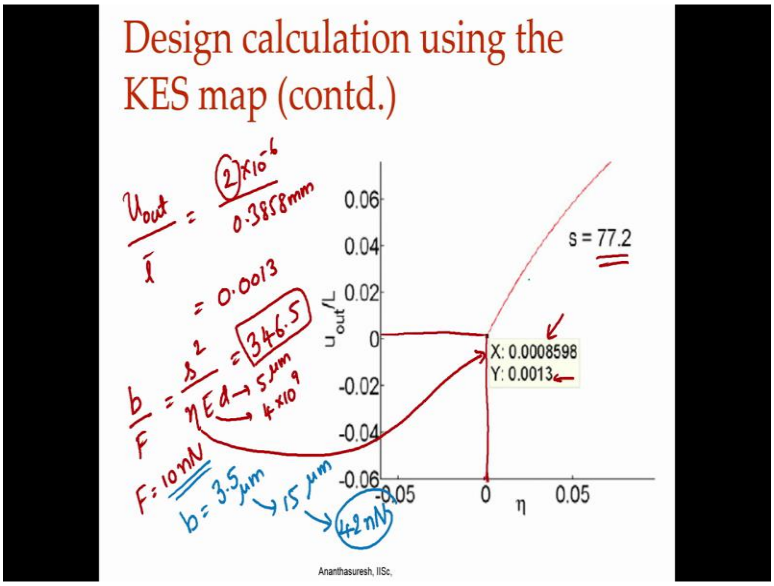

Now once we have this we can actually draw that. So, 77.2 we can draw this and then we want u out by l bar u out here you wanted to be I think may be 1 micron or 2 microns I think in this case let us say 2 microns we take and l bar we have taken this to be 0.3858 millimetres 10 power minus 3 if you do that comes to 0.0013.

So, that is what is the y coordinate something here there and then corresponding eta very close to 0 that is what it is 0.00085 once you have that eta it went to fast. So, once you have eta we can actually calculate that, b by F because eta is F s square by e b d you have taken b here f here if we do this b by F comes to 346.5 here, eta comes from that s in the wave we already e in this particular case is taken to be again I think 4 gegapascals again a (Refer Time: 20:19) material. So, E is 4 into 10 power 9 and d you had taken as 5 microns, if you do that d by F transfer to the this value and if I take F to be let us say 10 nano Newton's that is I want to be able to measure 10 nano Newton's so that I get a view out of 2 microns if I do that I get b to be 3.5 microns and this will be the thickness here, in that the breadth in the particular case it is a In-plane complain mechanism that would be in this is going too fast; that is 3.5 microns.

Other hand, if you think 3 point microns thickness is too small because material will go out of claim then this will an issue. So, we want to increase it let us increase it to 15 micron just. So, that out of plane stiffness is reasonable then if we recalculate this b by F and F will come to 42 nano Newton. So, if you want to have 15 microns as your thickness then minimum force that you can resolve become 42 nano Newton’s and not 10 nano Newton’s that 1 in 10’s.

So, this kind of calculation very quickly done because it is all in here in the Kineto Elasto static maps.

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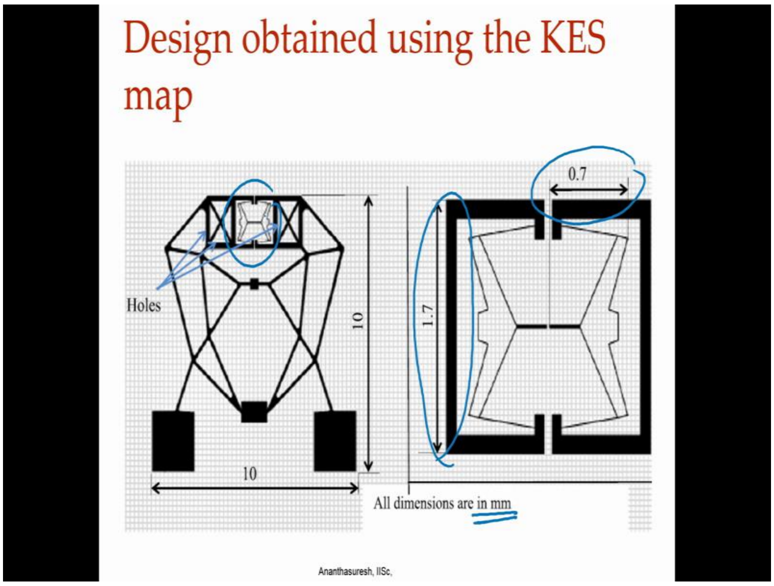

Now, let us look at how it was designed. So, you can see the 0.7 we had taken over all size of this is 1.7 millimetres, there all in millimetres and this happens to be a small part of a bigger complain mechanism, the whole think can be made and emerged in liquid to handle biological cells. So, you can design whatever size mechanism you have using this technique you can adopt it to the smaller one decide the size of the thing. Similar thing you have done for cement tester mechanism that is much bigger, much more force, we can actually estimate what should be the size or manufacturing limits are there we can say what is In-plane width, thickness and so forth.

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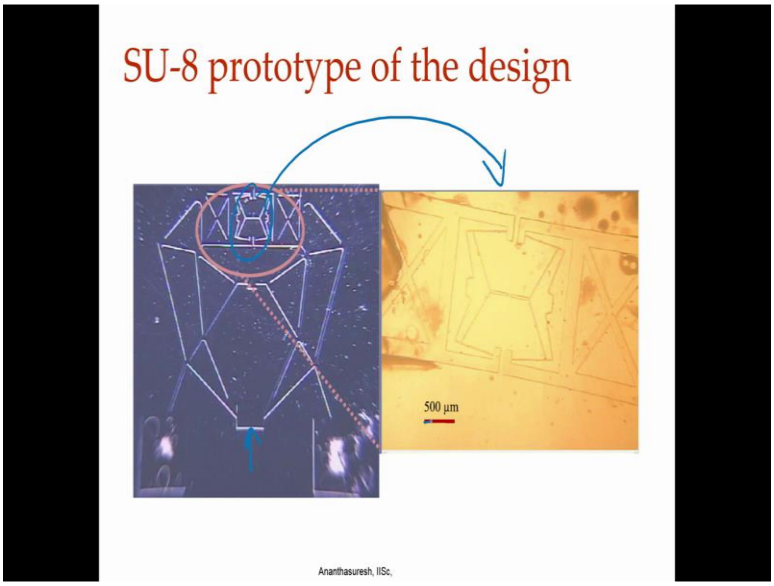

These are the SU 8 prototype that was done, again we have the big mechanism were the forces applied over here and this moves and this that blown up you of that were you can see this length here is 500 microns. So, that is half a millimetre.

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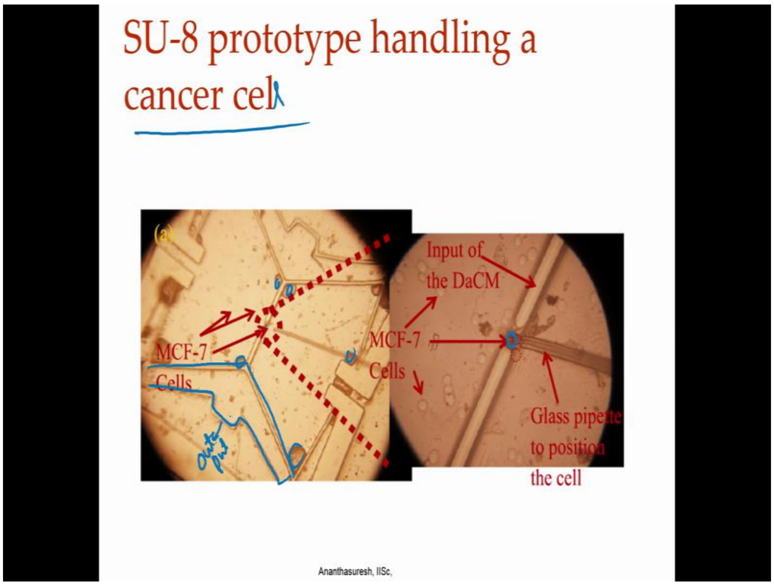

And this actually shows this cancer cell actually graphed you can see all the cells here (Refer Time: 23:01) and that is where this goes c c DacM.

So, this is where output displacement will be this is the output and that is what camera will in this case microscope will see and then estimate the force.

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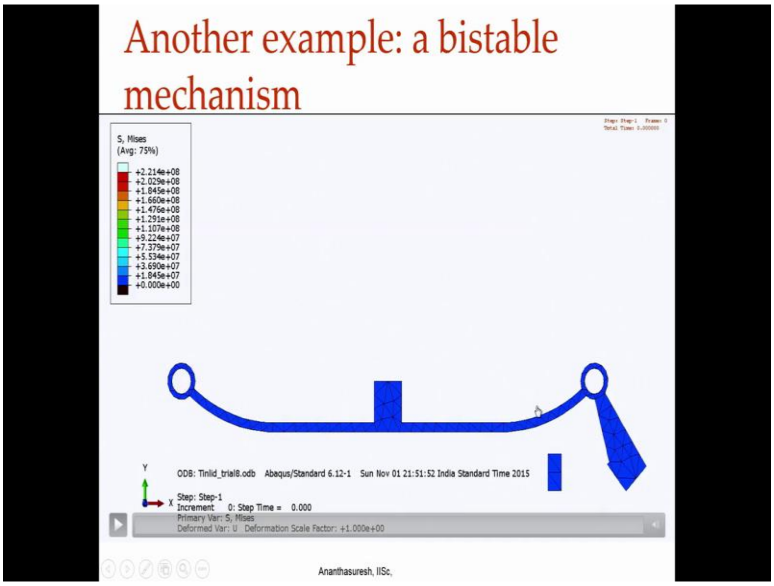

Now, let us look at another thing which are bistable arches they are highly non linier because at bistable in for that all. So, we can draw these Kineto Elasto static maps. So, in this particular case let us look at an animation.

So, how this arche works we are applying force here it would go there that is one stable state another stable state, and this arch shape can be many type can be guess a sign curve in this particular case we call it a tin lid curve because we have a tin lid here which is a lid that can go by stable it is a shell and I can place it on this and I can cannot do this now because I can place it.

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But it is the nice feature on the sides which we can press on the sides and it would go and then lid will be tight again. If you want to open it I just have to press it like this easily comes off, if I want to close it of course, I can do this I cannot do for the lid.