Compliant Mechanisms: Principles and Design
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Lecture - 60
Static balancing method for compliant mechanisms

Continuing our discussion of static balancing, where we looked at using balancing techniques of a rigid body linkages with spring loads we were able to balance a complaint mechanism by taking the compliant mechanism as a spring load, now we will discuss a direct method where a compliant mechanism can be directly balanced by adding a few springs using once again the technique that we have developed or balancing rigid body linkages.

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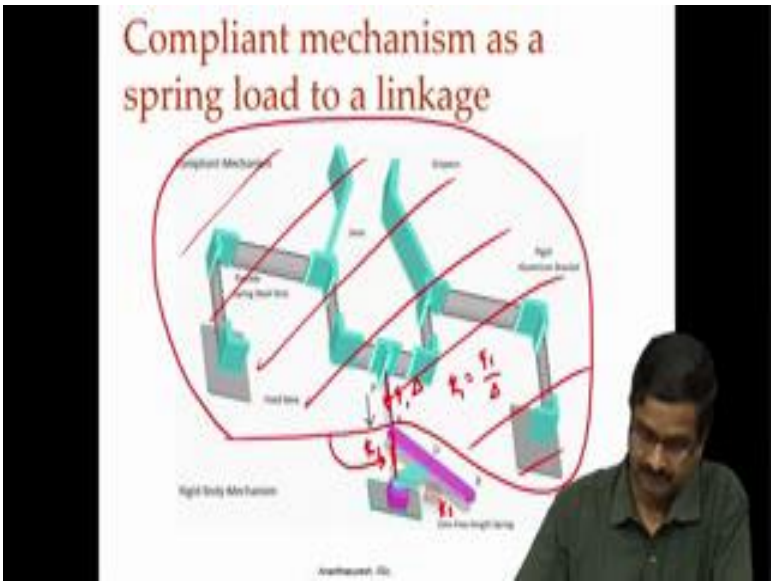

So, we discuss a direct method today, to discuss direct method that has a way of balancing a compliant mechanism with only springs added to it and no other linkage. Just to recollect what we discussed in the last lecture, if I have big complaint mechanism such as the one shown here we said that we can model that entire thing as one spring. So, from here to here whatever we have we model that as one spring again the approximation or assumption here is that, we say that this compliant mechanism range of motion is going to be see limited in, which case we can model that is a linear translational spring how do you find if I call this spring constant let say k 1, what you find k 1 we apply a force f here, and then note down some displacement it goes there and k 1 will be equal to f 1 by delta, that if we do it finite analysis that experiment of whatever.

Once you have this then you can forget about this whole detail of the complaint mechanism and focus only on this k 1 and this k 2, we know how to balance it and that is how we do it. So, a large compliant mechanism the reason we take the large one was that the range of motion even if it is large that is still linear for the mechanism.

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And this was the example that we had. So, we have the compliant mechanism here where this linkage is there just to our linkage and there is a static balancing spring, for us to do the work and then there is strength attached in the polish, this is what we discussed in the last lecture.

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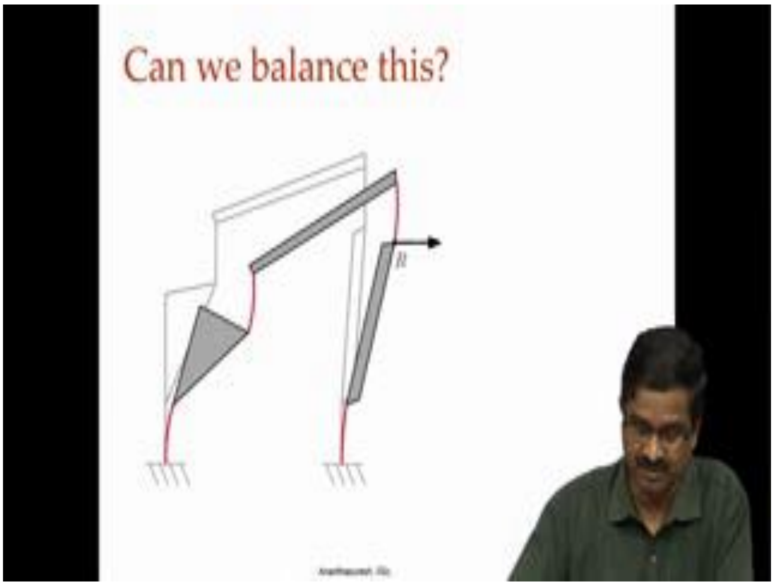

Now, we go back to the one that we have did not talking about, if I have a compliant mechanism un deformed and this is red one and blue one is the deformed one. So, as apply force it will deform like this, but the idea is that even after removing the force it should stay there rather the force required is minimised as much as possible, that is with little force you can put it wherever you want and it will stay there that is a static balancing can we do that.

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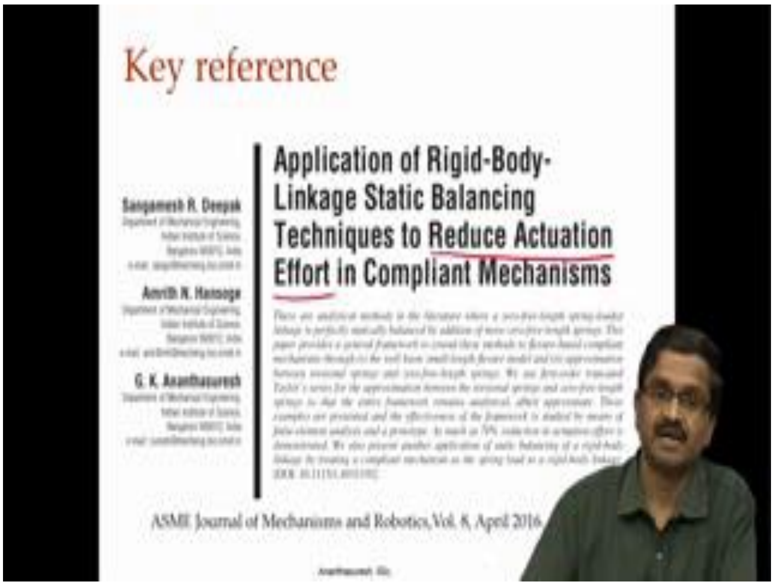

And there is of course, yes we can do it and that is discussed in this paper the details one can go through leisurely, I will just highlight how this trick actually works again our idea is to reduce the actuation effort in compliant mechanisms.

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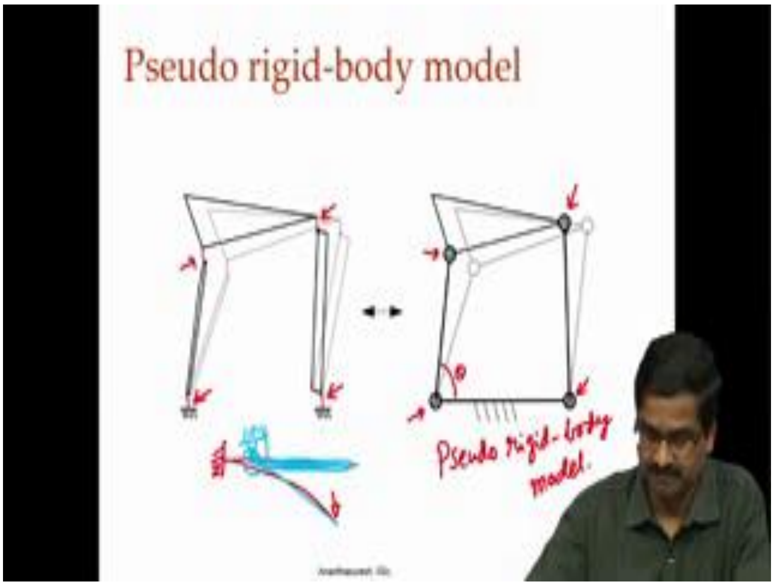

The first thing we do is we take that compliant mechanism and make a pseudo rigid body model. Here, is where we realise that there is a difficulty of course, when there is a small length flexure fluid we can come up with the torsion spring that is not a problem for all the four small length flexure fluids we can compete an equivalent torsion spring current.

But it turns out that balancing at torsion spring load with translational spring loads is quite difficult almost impossible, because this will have just a linear angle theta here whereas, anything you could translational is going to have lot of take terms sin and cosine. So, it would not be possible if you want to do it for phase substantial range of motion that what we will address now. So, if I have let say a cantilever beam if it is there what we said was that when apply the force it will deform like that you remove your force is going to go back, let say I do not wanted to go back then we know that a cantilever beam can be approximated as a rigid body, which is of some characteristic length pi over 6. So, that will be the rigid one so when it deforms it going to be like this and here we have the torsion speed.

But a rigid body with a torsion spring is very difficult to statically balance test that even if it is linear because this force are tor that we get will be in terms of the angle theta linear whereas, the springs that you add we will have trigonometric terms and they more do not match that is a difficult.

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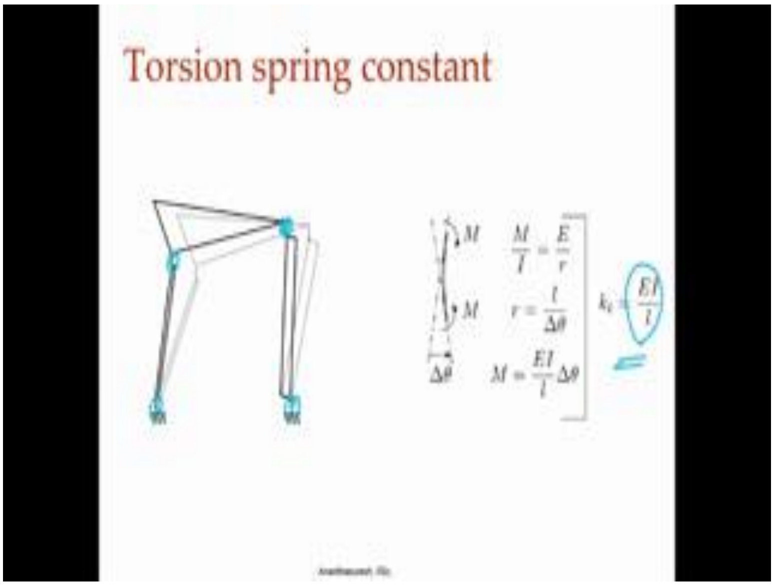

So, what is that equivalent spring constant has we had discussed with the very beginning of this course EI by L use youngs modulus i second moment of area L is a length. So, that is easy so when you put torsion spring here, here and here and here we know how to get this torsion spring constant.

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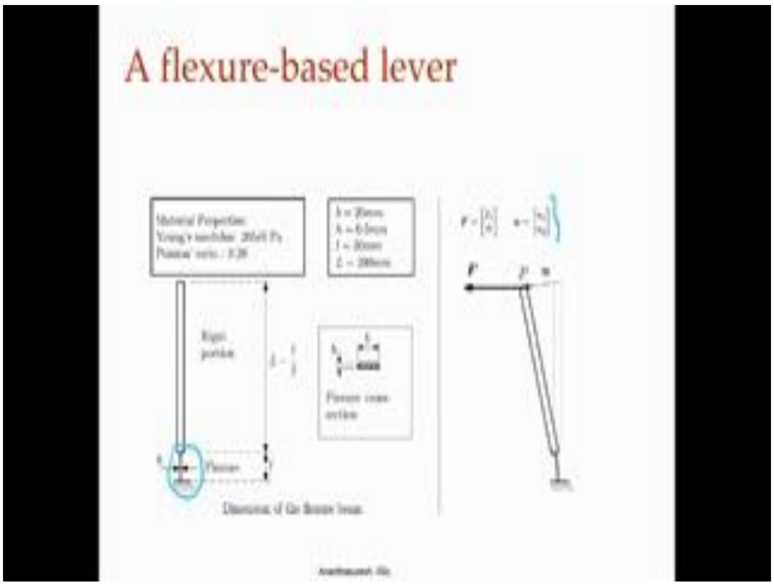

So, here what we do is if I have flexure based thing this is the flexure, we want to come up with a model what we have is the force effects, and 0 meaning that this is a horizontal force there is a displacement factor u x and u y.

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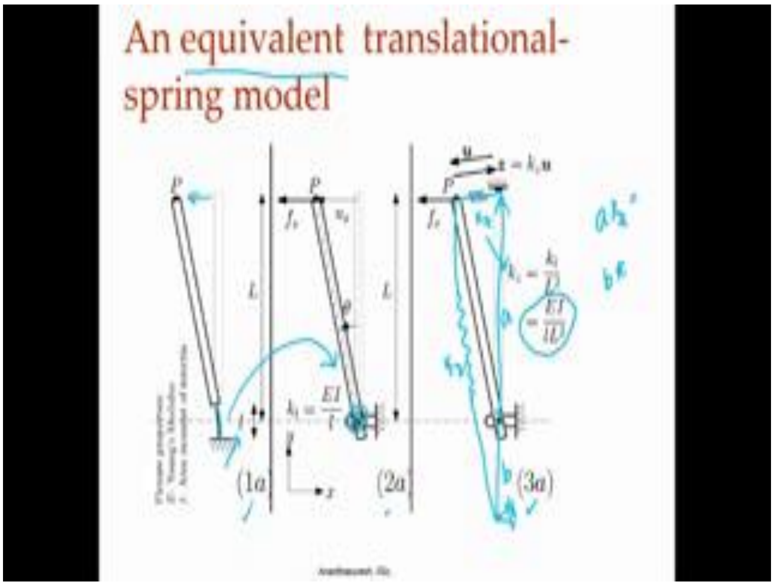

The triangular cross section whatever this is a flexure based lever is what we would like to discuss now the idea, here is that there are three cases shown case 1 a 2 a and 3 a, 1 a is what you want to balance. So, we have a flexure hinge when it is there we apply some force it goes there we wanted to stay there we want to attack something to this. So, that it will stay even after removing the force in all three cases we want that.

Here, there is a flexure, here there is a torsion spring, here there is actually a translational spring somewhere and all of these where to find equivalence we know how to find equivalence between this and this k t EL by L it turns that this k z that we talked about at distortion spring, that also can be got in terms of EI by small l l square, but small l a is the flexure length. So, one way to model this is model the flexure thing is to for a torsion spring that is a pseudo rigid body model, but that is hard to perfectly statically balance whereas, the same effect if we get it through this translational spring case that attached to the tip to a reference point then we can easily static balance, balance can be done all we need to do is if I have some case that I can take a spring that has some spring constant.

Lets I take a spring something. So, let say the length from here to here is a, and I have to make sure that a times k z equal to let say this is b b times k, where k will be from this point to this point and let it be also fix like this, now that becomes a spring to spring balance and there is a spring 1 k z and spring 2 k 2 and we can statically balance that is the idea there is a equivalent translational spring model, because that is easy to statically balance rather than a rotational spring as what is shown here.

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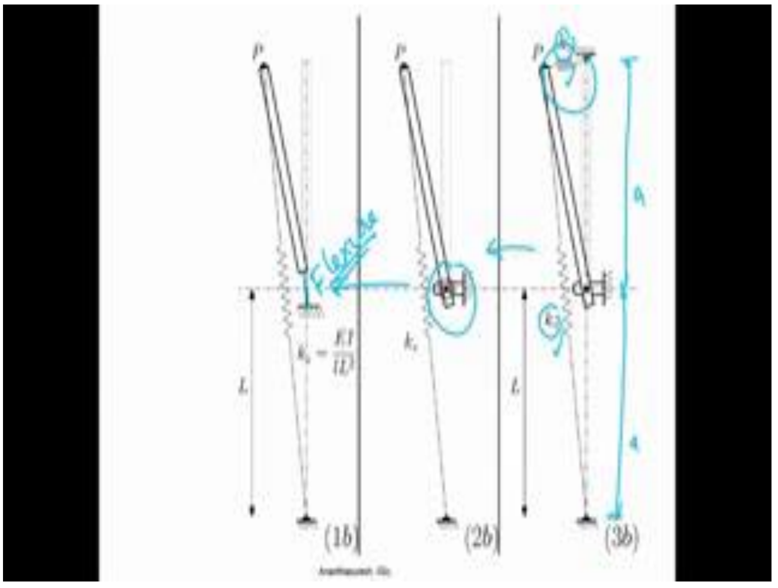

So, if I have this one, if I add that this spring and this spring will balance each other. In fact, in this particular case if I take this as a and this also as a; that means, that whatever case that is here is same case that should be here as well you can change it in, which case you have to make it smaller larger compare to that and get this balancing spring this is equivalent to having a torsion spring and this is equivalent to having a flexure having a flexure. So, we are coming backwards we went like this in the previous slide we are coming backwards after static balancing is done.

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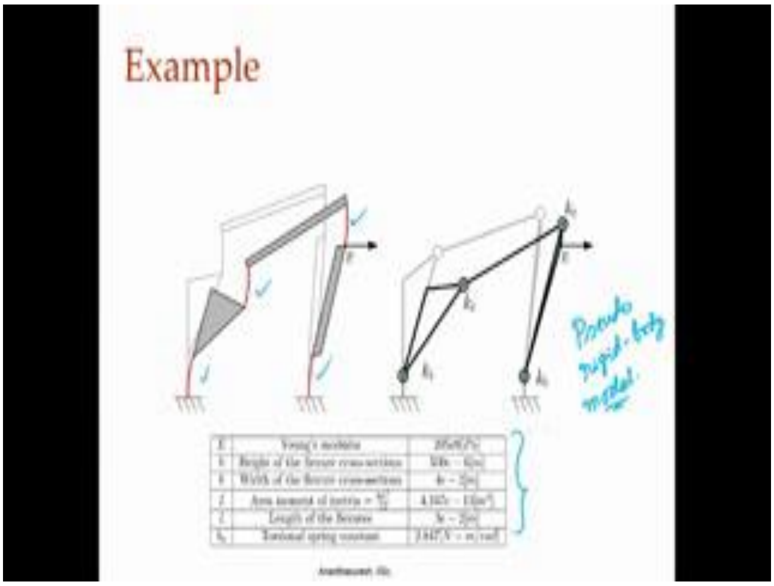

So, now if you have the same approach followed which we did it for one rigid body with a flexure, now what if there are multiple flexures in a mechanism such as this one. So, there are four flexures, and for all each of these four flexures we can do this pseudo rigid body model, but then we just said that torsion springs are difficult to be statically balanced and some data are pertaining that is given it is all realistic.

Now, what we do is we use the same approaches before the effect of the torsion spring is compensated by a translational spring, again let us go back to see this instead of having a torsion spring we have a translational spring that is all we are doing.

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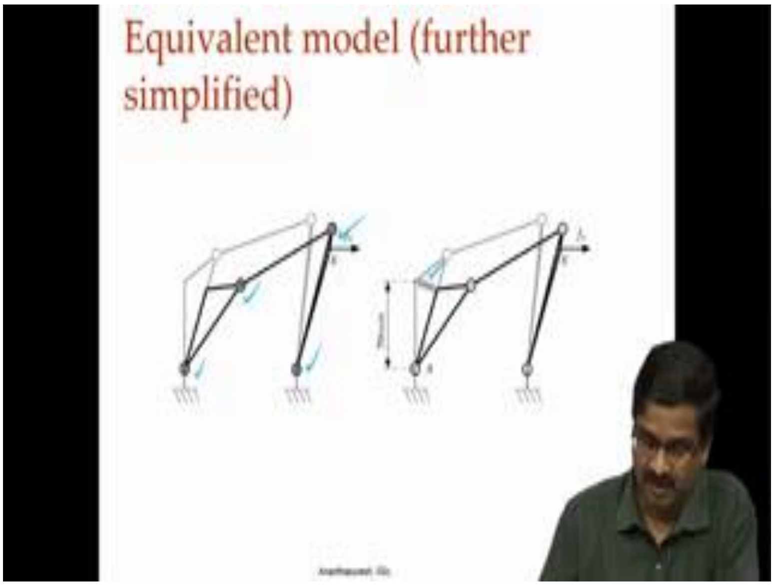

That can be done not only for one torsion spring here we have 4, all 4 have disappeared now the effect of all of that is come to one translational linear spring. Now, it becomes like a 4 bar linkage with one spring that has some load we can balance that.

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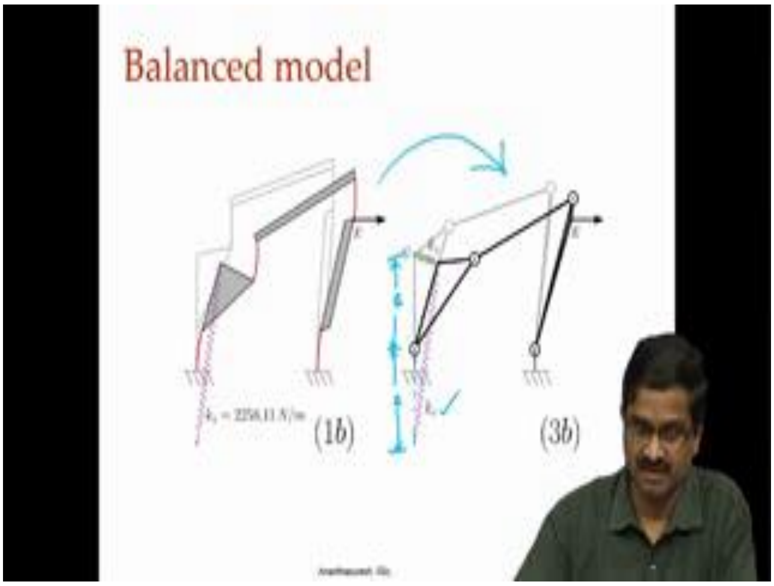

So, if I have this one and the spring, I can take this another one which is also indicated as k z provided that this length and this length are equal. If this is a and this is also a, according to our spring to spring balancing technique we know that k z times a should be equal to k z times a and since, a is a same in both k z is equal to k z. So, what we are doing is multiple things are also compiled by a single spring and that is spring can be a compressed by this spring because they follow a main result of todays lecture.

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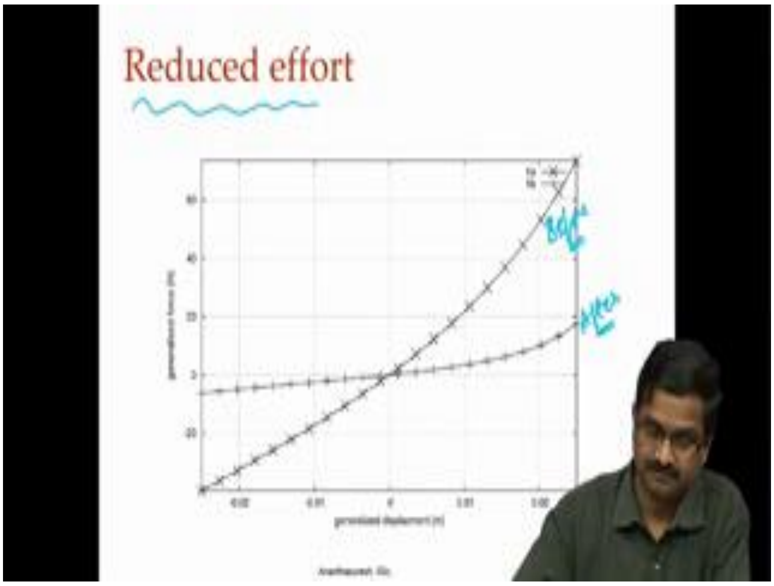

If we do that again this is before static balancing and this is after. So, you can see how much the effort has reduced it had become 0 reduced quite a bit, it has not become 0 because our approximation exists if that approximation removed it will be exact in which case it will be quite difficult to do because, like I said torsion spring balancing with translational springs is very difficult one rotation spring or torsion spring can come in to another torsion spring, but not with a translational spring.

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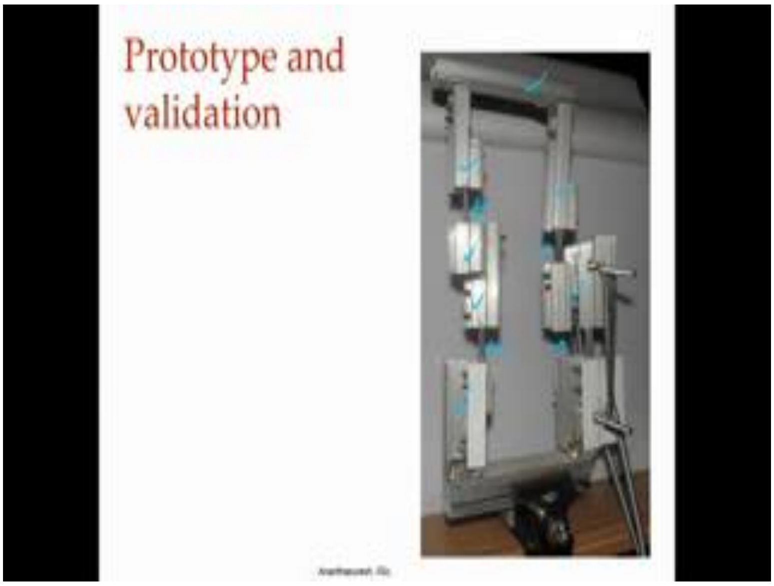

Again the idea here is reduced effort. So, here is a prototype that was built for that mechanism again there is there are spring steel strips and there are heavy duty aluminium parts, here and we are able to balance is you can position wherever in this in our law.

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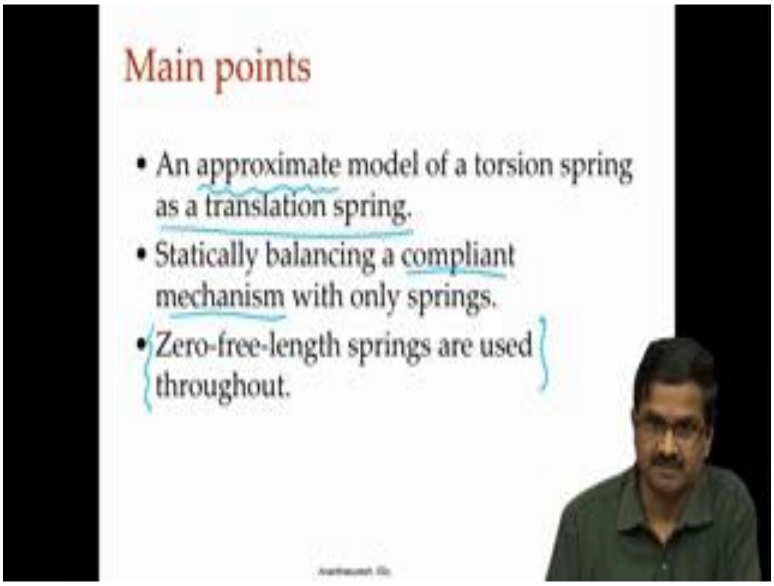

So, the main points are we have an approximate model for a torsion spring as a translational spring that is the key here, if we do that assumption then a compliant mechanism can be statically balanced only an with spring that is the idea and of course, throughout this talk we used a 0 free length springs.

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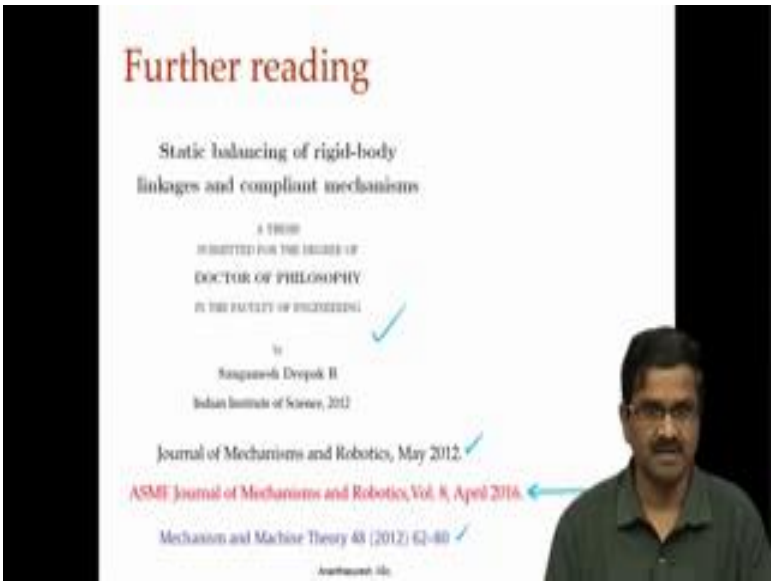

So, for further reading this red coloured one is the main paper; however, this page thesis Sangamesh Deepak, and this paper and this paper are also available to you to learn how to do static balancing of linkages with springs and in the later adapt it for compliant mechanisms.

Thank you.