Design of Mechatronic Systems
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Lecture 11
Smart Sensors Concept

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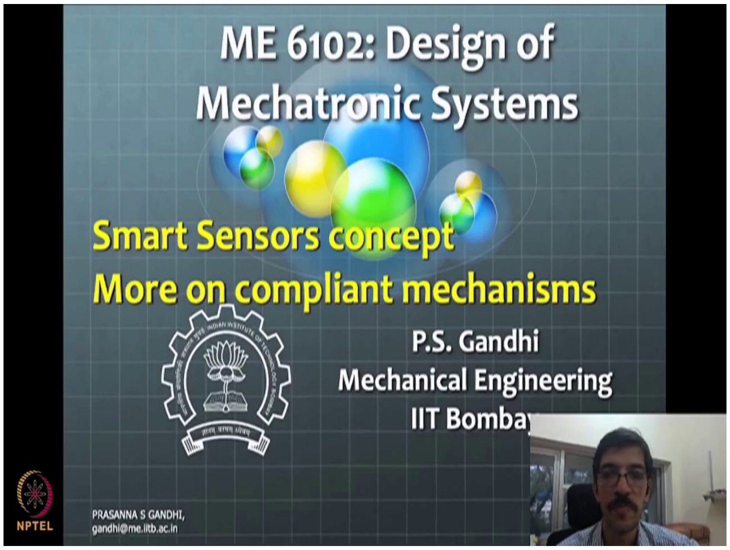

Let us start our next topic that is on Smart Sensors Concept. So, I will tell you what it is and how it is very useful for many different sensors. And then, we will talk a little bit more on compliant mechanisms, it is a little bit of its analysis and things like that for mechatronic purpose, there is mechanisms that we have seen in the CD-ROM drives and things like that. So, let us begin with the concept here for the smart sensors.

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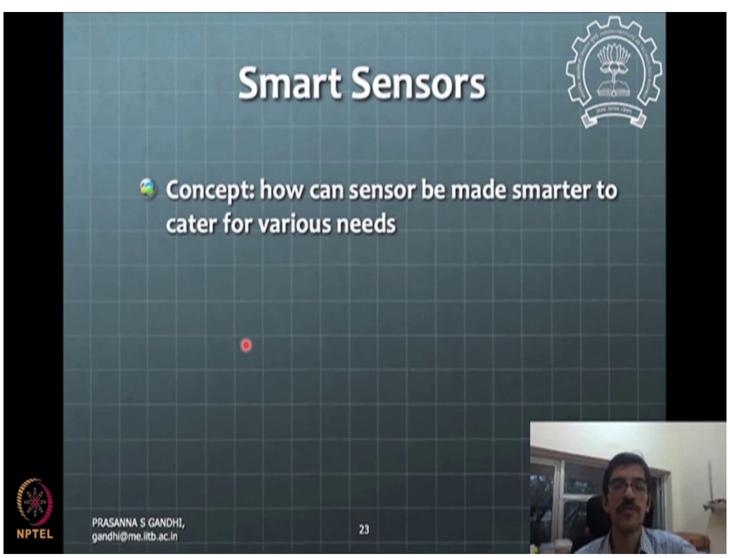

Let me get a pointer right. So, you need to think about how we can make a sensor which can be smart in some sense in the sense like, so it can self-calibrate itself or maybe it can have a range and resolution in tussle, usually there is a tussle between the range and resolution sensors that can measure at a very large range their resolution will be typically low sensor that can measure at a smaller range their resolution can be high. So, this tussle between resolution and range is always there, you cannot have something which is measuring very large quantity at very, very high resolution.

I will give you an example, you have seen, say we talk of measurement of the weight. So, if you go to the, if you want to weight gold, for example, you go to this goldsmith or jewellery manufacturer and you give the jewellery to weight, you will have this small little microbalance which will give you very, very accurate weight of the jewellery that you are measuring.

Now, if you talk of other extreme, there are this weight bridges you might have seen in the, what you call some, there are these vendors who are like having this weight bridges which can weight the cars and trucks they can measure. So, you will find like the way you have these gas pumps or the petrol pumps like that this weight bridges will be there. If you ask them like what is the accuracy of measurement of the weight, it will be in hundreds of, or if not 10s of kgs, mostly hundreds of kgs they weight tons of material there.

So, there is a huge difference in the resolution of measurement or the accuracy of measurement on one side if you go for very small sensor, very small range, a gold measurement versus a car measurement. Of course, one sees the need, weather there is a need for such a high accuracy. We do not need the car weight to be known to such a high accuracy. But the point here is that the things which are made to work with a larger range typically give you lower resolution.

And if you now demand, I want both little bit exchange the range of measurement. Say, for example, microbalance can go up to maybe 80, 100 grams weight they can measure. But if you want to measure up to 500 grams, with the same resolution or up to 1 kg with the same resolution. How can we make it possible? That is a question here.

So, think about it, what a thing comes to your mind to do that. So, we will talk and discuss a little bit more about this example. What ideas that can be incorporated to enhance the range of, so let us talk specifically about this weight measurement? So, how the weight measurement principle is done, think about that and we will come to that in a minute.

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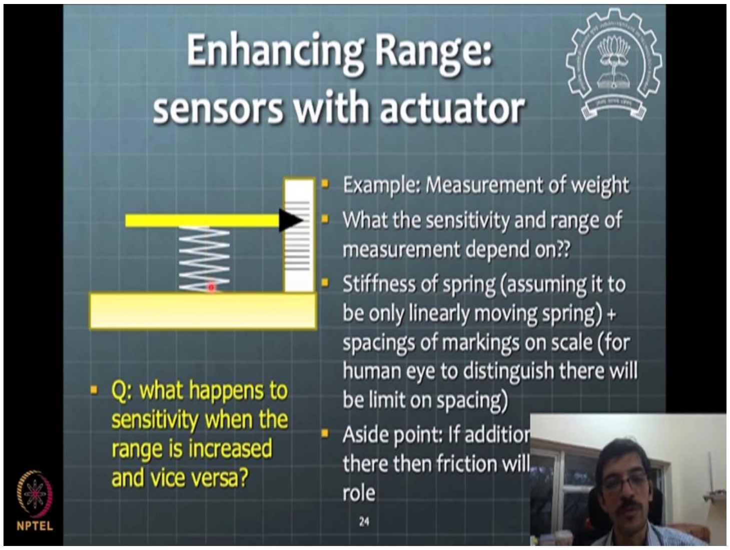

So, let us say you have to enhance the range of the sensor with this specific example of weight balance. The weight balance typically has a spring, you put some weight the spring will deform, and it will go down, and typically on the scale, you will see some weight measurement done. One of the ways of measuring weights. Other way, you may have this balance that your subji vendors they use, but right now we will just focus about this system for weight measurement.

So, the markings here are typically 1 mm marks which we can identify from one to other, maybe 1 mm we can identify. Now, if I want to weight very, very small quantity or very, very small resolution measurement, then I use a spring which is a little low flexibility, a little lower rigidity, highly flexible spring. So, even for a small weight, it is going to get deformed and I can see its marking on the weight scale.

Now, if I get the spring to go smaller in stiffness or higher flexibility, then you see that from this point to this point if the pointer can move, say this point being a limit that spring gets completely compressed here and this is a starting point. So, the range that you will be able to measure is proportional to the stiffness times displacement. So, that will be the range.

So, this is our whole displacement that can be possible for the spring and then stiffness times that will be a small range because normally the stiffness is very, very small. If I increase the stiffness, then the range can be increased, but then what happens is still for a moment of 1 mm, I will have to see that larger weight needs to be put. So, that means my resolution for this 1 mm measurement is going to be little lower or higher stiffnesses.

So, this is a point, can you all see this point? So, now, we are not right now worried about that there is a friction that will also play some role and all these things are going to be there. So, we are not right now bothered about those things. So, the question is then how do you make enhance this range of measurement even for a small resolution, I mean even for a high-resolution or small stiffness scenario in this particular case. So, let us talk about that.

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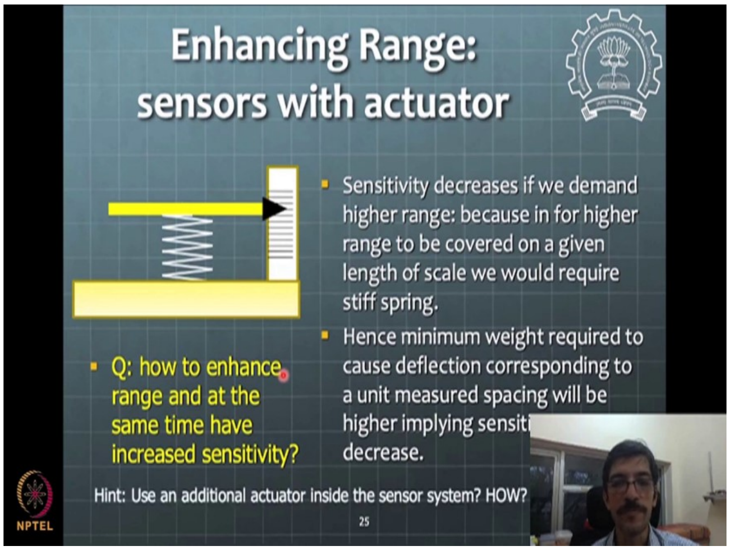

So, you appreciate this point that the sensitivity would decrease if we have a demand for high range resolution will be low for higher range and vice versa. So, if you want to increase weight then I propose that we put an actuator in the sensor. Suppose we put an actuator in the sensor. So, I formed a little small feedback system around this sensor such that, the actuator is now giving you additional force.

So, I measure these on the scale, take its feedback to my actuator, and then actuate the actuator such that this reading always points to 0. So, if I, even if I put some weight there then actuator will come in place. So, look the sequence will happen like that, I put a weight on the surface, then this pointer is going to go down. That means there is some error that is produced far from away from the 0 position, and then that error is feedback to the actuator and actuator gives some force and brings it back to 0. And this way you can always maintain some small, some 0 as a balance it is called null balance.

So, you null balance the system always no matter how much is the weight I am putting, I mean my system is always balanced. And now, depending upon what is the strength of your actuator you can get now the higher forces possibility. So you can use a spring still lower stiffness, but now the spring has no deformation at all because actuator is providing the force to balance the weight. So, that is a idea that is utilized here to enhance the range by using an actuator.

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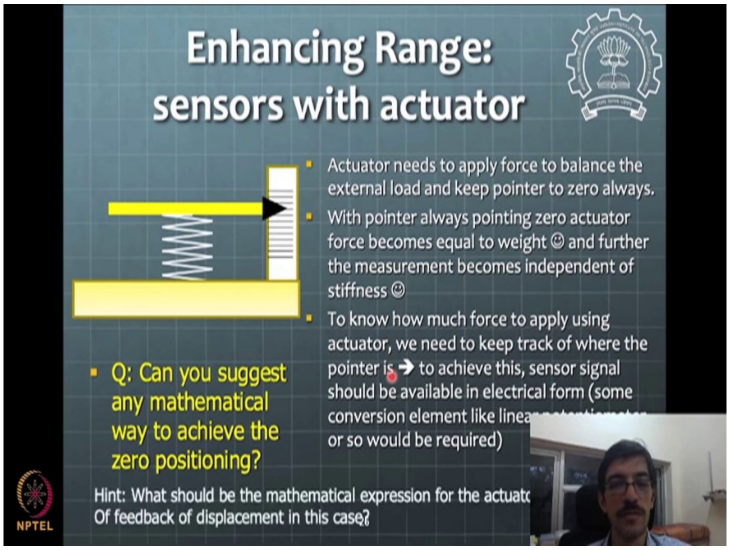

One can think of what kind of actuator, how we can put it, and all those things we are not now worried about, but making sure that, the actuator also does not have somehow any additional friction force anything like that. So, can you see this idea? So, with this idea, one can enhance the range of sensor and keep the resolution same and you get some additional advantages, any non-linearities that are existing in the system, they will not bother you here, sorry about my mobile.

As non-linearities in a system, for example, a spring as you deform more and more it would have, it might become non-linear, instead of your scale is linear, but spring is behaving in some non-linear fashion because of the large deformations. To compensate for that you would have, this marking also put in some a non-linear way. But because we are doing this null balance with actuator here, we do not need to do that. You see, this is a big advantage that you get, by doing this.

So, now one can think about okay, a little bit more detail about this concept and say, okay look, if I am doing this, putting this actuator here, how do I know what is actuator force I should apply. So, that will come from some feedback control law, one can think about what feedback control law you can put here. So, you have studied some PD control, PD, PID controls, or proportionate control, one can employ that and say that, oh look, if I apply the actuator force proportional to the error, with some gain constant, when slowly, it will go back to make error 0. So, that is how I can determine the actuator force.

So, you might have like some other ways, just proportional algorithm may or may not give you great advantage of those things can be discussed more, but the basic concept is essential to capture here, is that I will always maintain null balance or 0 reading on the scale. And, then the question, look, I am maintaining 0 there, but how do I know how much is my weight that I am putting on the surface? That can be then calculated by just seeing, how much is the extra actuator force that you need to apply to maintain that balance.

So, when I put something on the weight balance, I will have to apply some actuator force which is happened through some a feedback control strategy. And finally, once it is settled in the final position, whatever is the value that, bias value that I need to apply I will get to know from that value what is the weight that I put on the surface, that is how one can get the actuator, based on actuator force what is your weight that is put on the surface.

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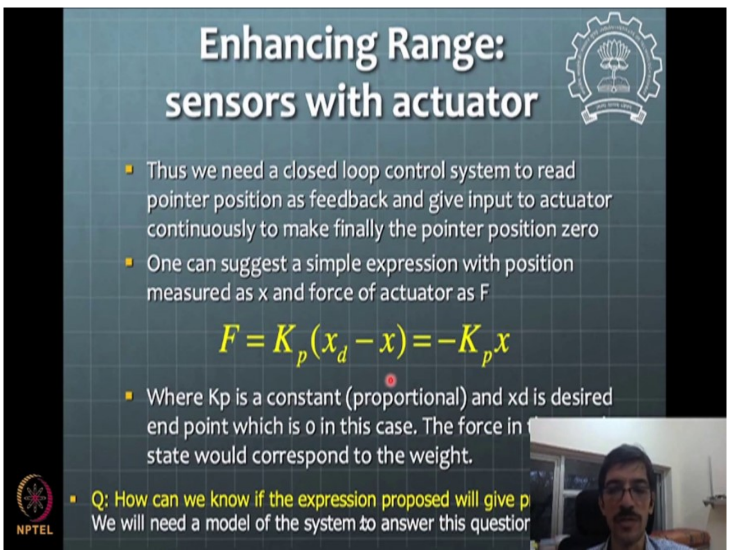

Now, one can do some mathematics to do that the actuator force is proportional Kp control we can do, then how do you analyze this system and things that one can do a lot of this mathematical jugglery beyond these to find out, what proportional constant I should use or do I need in addition some derivative also probably you will need a derivative control also to make sure your system settles into the final position rather than oscillating in a steady state.

Typically, that friction will be there in these practical systems. So, even if you do not put the derivative controls in place there will be a natural damping that will happen because of the friction in the system and your system will finally settle down, it is not going to continue oscillating forever.

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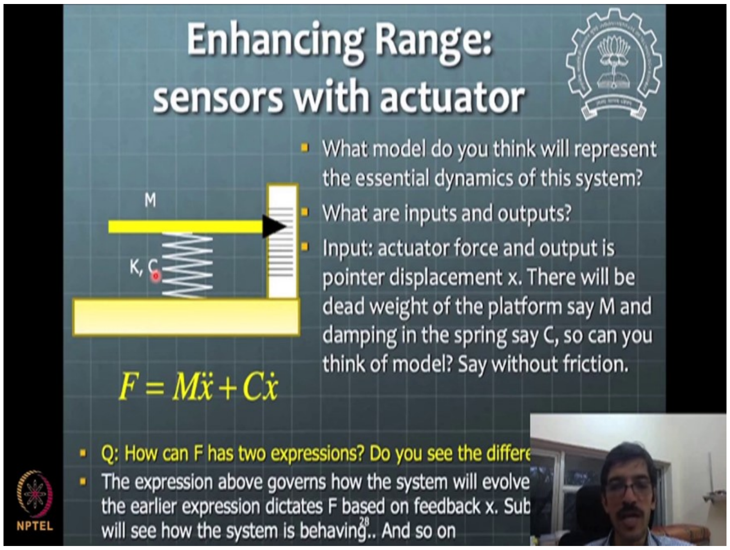

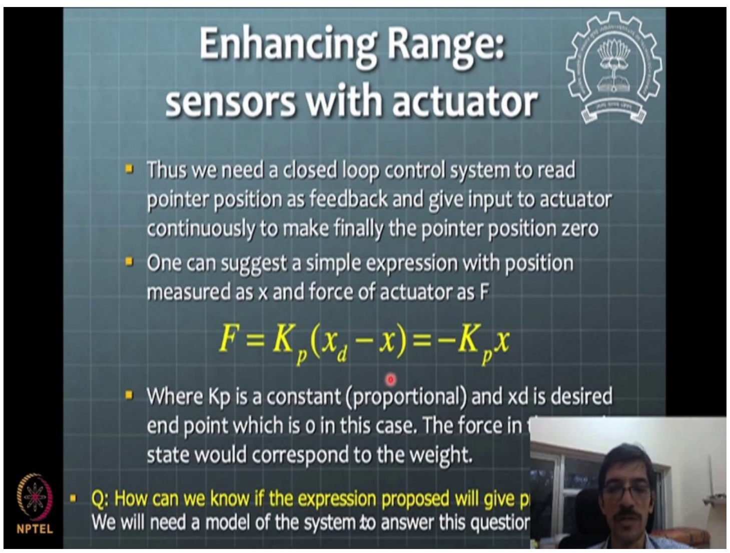

So, you can think of this mathematical model to the represent these dynamics of a system and then formulate control strategy and validate how your error behaviour happens and things like that. So, maybe you can try this exercise yourself and then look at some of these developments that are given in the slide.

So, for any system we will come to this in more in the detail when we start modeling different, different kinds of systems, but typically for modeling any system says you have understood this system, you know actuator there is some mass that will happen for this, the stage, the dead weight of the stage itself and then there is a stiffness and then some damping you can consider here and then this becomes like a simple spring-mass damper system and for which you know very well known equation, which is the force that I am applying on the system will be,

$$F = M\ddot{x} + C\dot{x}$$

and plus Kx will be there in addition.

So, this F that we talk here, this F is a force of actuator that has to balance finally, dynamics of a system. So, the steady-state value of the force will give you the final reading. So, the expression, so these are the two expressions for the force one is based on the dynamics of the system, and other expression is what you would develop as a control strategy based on the feedback.

So, the previous expression that you saw here was we are considering that we will apply the actuator force to be equal to this amount. That was our feedback in some sense for the system. So, when x_d is null balance or 0, then you will get this as a feedback expression for the force. And then this is a system dynamic, I think there is a term corresponding to the spring missing here Kx also will be coming as an additional term here, but and then we will apply some proportional control $K_p x$ as this force. That is how the things are going to happen.

So, right now the friction in the system is neglected. So, when you do analysis, how this control would work or how this control will take care of or settle the system into, then you need to substitute this value of force from, as you are proposing as a control here in the expression of dynamics. And then do the analysis and then you will be able to find out the details of how these force is going to, how this proportional feedback that you are proposing is going to affect your system or affect your state or x of the system or you can convert the state x into the error dynamics and study what will happen to the error. How will it go to 0, will it go to be 0 instantaneous, it will oscillate.

How I can have the settling time of that oscillations controlled, all those things one can talk about in lot more details. So we will come to some more analysis of such kind as we progress. You have done something already, but now we will see from a little bit more practical's perspective when the friction and other terms are there or if you want to model the motor also, the actuator also in the system in some way. How do you take care of some of these things that will be seen here.

So, by the way, to balance this if we use a screw system to drive, actuator means like motor and a screw-type system, then since it is not back drivable that will not work here. So, anything which is having a friction a lot amount of friction will not work for such thing. So, we need to employ here a non-contact linear actuator which will drive the system to make these things 0. So, you need to be aware about this, right now we say we have seen linear motion means we will prove some rack and pinion or this screw actuator. If you start putting that it will certainly balance this through null balance. But now, the kind of force that I need to apply the system is locked in this place, anyplace you take the system will be locked. So, even if you now say if it is at 0 and I place some more weight on the system since it is not back drivable, I am not going to get any deformation up here.

So, the screw actuators will not work here unless they are very smooth back drivability is there. So, typically screw actuators will not have a back drivability. So, here we need to have non-fiction, non-contact linear actuators to drive the system, then things are going to work here much better.

So, you can think about and see whether yourself are able to do this error analysis here with one control expression and some other a control expression. And, we can talk about that in more details later.