A Brief Introduction to Micro Sensors

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Lecture – 21
Accelerometer – II

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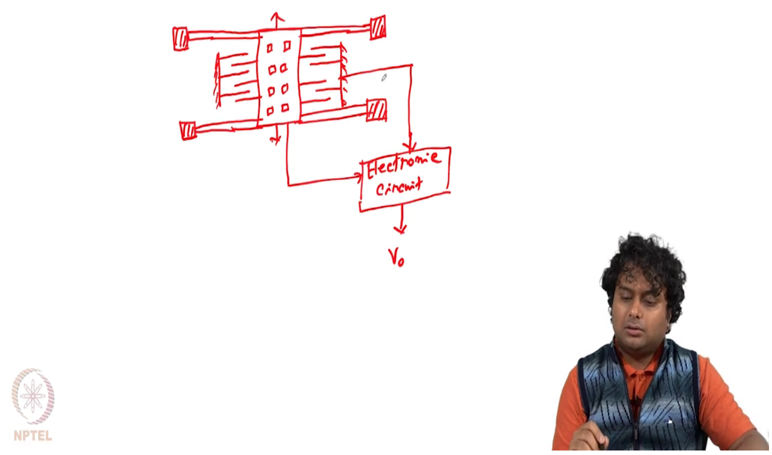

So, we are discussing about this Accelerometer, which is having like this kind of homes and using some electronic circuit, you can measure the change in the capacitance and can accordingly measure the output voltage. And, this output voltage is related to the deflection or the movement of this proof mass and accordingly acceleration of the body.

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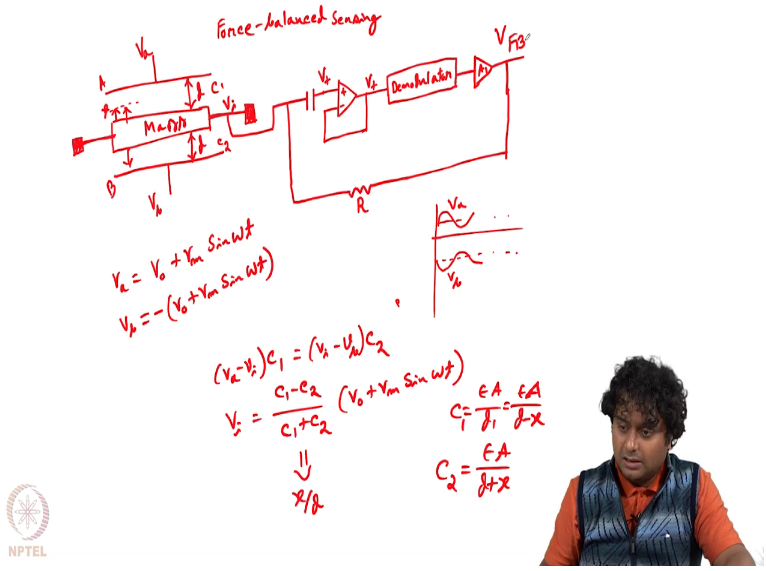

Now, let us say, we will see that, how we can use this kind of capacitive measurement for force balance sensing. This is force balanced sensing; means the force will be balanced. So, what does that mean? We will see. So, let us say that, there is this proof mass, which can move in on the vertical direction only ok. So, it can this proof mass can oscillate in this direction; in this direction.

And these two plates A and B are fixed plates, in between which we are measuring capacitor; capacitance between the proof mass and the A and also proof mass and the B ok. So, initially both the top plate and bottom plate are at the same distance from the mass. So, this is d; and the same from the same distance and that distance is d let us say. Now so, this is a complete circuit, how we can get force balance? So, that will analyze one by one using like what this kind of capacitive accelerometer.

So, let us say, we apply some voltage here: V a equals to V naught plus V m sin omega t. So, some ac signal I am applying with some dc bias right. So, this V a, V 0 is dc bias and V m sin omega t or V m is the like the amplitude; or the maximum value. So, 2 V m will be the peak to peak value right and omega is the frequency and V b on the another like the bottom plate we will use the same in magnitude; in the bottom plate, we will use the same magnitude but, negative voltage.

So, this will be minus of V 0 plus V m sin omega t. Now, if I consider this voltage to be; let us say, this voltage is V i. So, this voltage is V i. Then how much is the V i? While the capacitor; while the mass is not moving; it will it is from the same it is at the same distance from the top plate and bottom plate, then the capacitor on both the sides are same. So, it will be like 0 because, it is like plus V 0 plus V m sin omega 2 t 2 minus V 0 plus V m sin omega t. And how these signals look like?

If so, let us see, if this is V naught then, if this is my V a; then the. So, if this is V a then this is V b right. So, this let us say V a and this is V b. It is same in magnitude, but opposite in sign. So, it is same in magnitude, but opposite in sign. So, the V i will be 0 initially, right. Now, if the tip if this mass moves, then the capacitor like this distance will be different and let us assume that, it has moved towards the top by a distance x. So, let us assume that it has moved to the top by it by an amount x ok.

So, the gap between the top plate and the mass is now d minus x whereas, the bottom plate and the mass or the proof mass is d plus x right. Now, if the voltage induced in the central mass is V i, then V i; then the charge at the top plate because of the top plate will be: V a minus V i into C 1 where, C1 is the capacitance between this plate and C2is the capacitance between this plate.

Now, the charges have to be conserved right. It will be the same charge of the both sides of the central mass. So, V i minus V b into C2 and from there we can write that, V i is equal to C 1 minus C 2 divided by C 1 plus C 2 into V 0 plus V m sin omega t plus V m sin omega t.

Now, here, we have put that V a equals to V 0 plus V m sin omega t and V b equals to minus of V 0 plus V m sin omega t right. So, this we have put and we will get this expression.

Now, this signal; before we go there. So, what is C1 minus C2 by C1 plus C2? So, C1 equals to epsilon A by d 1. And what is this d 1? d 1 is like epsilon A divided by d minus x; and C2 is epsilon A divided by d plus x right because, this is the distance between the central mass and the top plate and bottom plate.

Now, if we calculate this then C1 minus C2 by C1 plus C2, we will get as, this term will give as, x by d; x by d where, x is the displacement of the mass and d is the initial gap between the central mass and the, central mass and the top or bottom plate. Now, once this signal passed through the capacitor then, capacitor blocks the dc only the ac is passed through. So, this signal once it goes then this V 0 will get cut because, the capacitor will block this V 0, the dc part only the ac will you go, ac will go.

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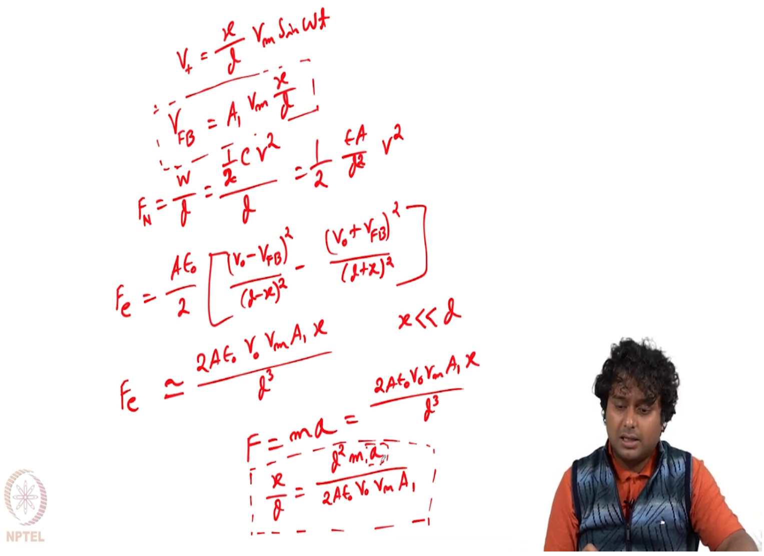

So, this let us say this is at this point if it is V i; let us say V plus which is going at the positive terminal, then we write that plus equals to so, C 1 minus C 2 divided by C 1 plus C2 write x by d to V m sin omega t right. So, this is capacitor blocks the dc and now this signal is coming as like the V positive is the is by d V m sin omega t; and this is going through this operational amplifier which is connected as a buffer amplifier.

So, here also it will be same V plus right. Here also it will be same V plus. Then we are using a demodulator circuit which will actually kind of block the higher frequencies and only the lower frequencies will pass; it will be kind of used as an envelope detector ok. So, the outside, the output of the demodulator what we will get? So, let us say this signal what we call V FB. So, that is feedback because it is again connected to the input side. So, that is the feedback signal. So, the V feedback or V FB will be equals to A1 V m x by d.

So, where from this A 1 is coming? A 1 is coming because we are using here and amplifier which has a gain factor of A 1. So, that A 1 will come right and where this, what does this sin omega t go? So, this omega usually we keep it higher frequency. So, we choose the omega such that, that is very high value and then it gets blocked at the demodulator circuit. So, only the ac part is there only the sorry, only the dc part or the magnitude part is there.

Now, if this x is already a time varying signal then, we will be able to detect that. So, let us say this x itself as a like with time it is changing right. So, then we feedback also will be like that. So, it is not like that that we are chopping off all the time varying signal but, it is only we are only blocking the high frequency. So, that we can see exactly how the x is changing right, how the x is changing with time; as the mass has moved to the like the upper side, now the distance between the top plate and the bottom plate is different right.

And, because of that there is a charge imbalance and because of that, there is one, there is some electrostatic force. Now, how is the how much is that electrostatic force? So, electrostatic force necessary normal force between two parallel plate, can be written as like w by d where because this is known to us right that w at the energy divided by the distance; we usually gets the force right. So, like electric field is dv dr or V is the potential or work done; here also w by the distance.

So now, in this case what is the w? w is like the energy stored in the capacitor and how much is that? That is half C V square, from electrostatics we know the energy stored is half C V square divided by d and d is the distance between the two plates. So, again C equals to; C equals to epsilon A by d. So, and then there is this V square and because of this another d. So, it will become d square right because, 1 by d is coming from the C and then already there was a d. So, it is epsilon A by d square into V square right ok. Now, this is the force in between two parallel plate like the normal force.

Now, in our case, what will be the, what will be that force? So, that electrostatic force equals to A epsilon naught by 2 where A is the area of the like central mass as well as the top plate and bottom plate, it is all same into V 0 minus V FB divided by d minus x whole square; minus of V 0 plus V FB divided by d plus x whole square.

So, see here, we are only taking V 0 minus V FB or V 0 plus V FB. Why is that? Because, the V m sin omega t or with respect to the negative part it was already in like the central mass was already symmetrical right; and while the mass has not moved, while the mass has not moved then, at that time V i was 0 because, both the side capacitance is same that the charges are same and the force is also same.

So, there was no net force in the vertical direction thus, at the as this move then, as this move then, what happened is there is a dc level shift right. There is a dc level shift and because of that; because of that, this V 0 minus V FB and V 0 plus V FB is coming because, one side it is like plus V 0 another side it is minus V 0. And accordingly, the distance also between the top plate and bottom plate is one side it is d minus x and another side it is d plus x.

So, while the V FB is coming from the top side it is V 0 minus V FB whereas, from the bottom side it is minus V 0 minus V FB. So, it becomes V 0 plus V FB and both are these forces are opposite. So, the net forces will be we can simplify it to 2 A epsilon naught V 0 V m A 1 x by d cube; and here we have considered; here we have considered that, the deflection of the central mass is very small compared to the gap; compared to the gap. So, this is the electrostatic force.

Now, some this body, this body or this sensor accelerator has been kept on some body which is actually accelerating and because of that this force has applied right. So, if the body is accelerating with an acceleration let us say small a then, the force applied is actual force applied is mass into acceleration right; where, mass is the m is the mass of the sensor of this central mass this central mass is having a mass of m.

So, when the force is ma and this force is equals to the electrostatic force because, it only has a least amount of force only has been its only able to move the proof mass to its top position or bottom position. So, ma is equal to; so, now, you can see that this x by d is directly proportional to the acceleration. So, once we measure, once we know that how much is a deflection x then, we know that how much is acceleration because, this d m capital A A 1 all these terms are already known to us.

So now, if we I am telling the sentence again. So now, you see that the x by d is equal to d square m into acceleration divided by all this constant terms right. Now, this acceleration according to the acceleration this x will change. So, once we can measure the x then we knows that how much is the acceleration; and this d m capital A epsilon naught or let us V 0, V m and A1 all these terms are already decided by us.

So, we are deciding we know that what is the geometry; we have designed for the sensor is. So, accordingly we know this area, mass and other things the gap and all and also we know that how much voltage we are applying. So, these terms are also all known and we measure the distance and accordingly, we can get the acceleration. Now, how we can measure the distance? Because, we know that this is x by d and this x by d is again related to V FB.

So, we know that how much is this V m we know, this A 1 also we know and accordingly, we can calculate the x by d because, V this feedback voltage what we are actually connecting to the input again was feedback that we can measure here. So, we can measure the feedback voltage from this point. And accordingly, we can calculate what is my x by d is and accordingly we can calculate how much will be the acceleration.

So, in using this circuit, we can using this kind of system, we can measure the acceleration. So, with this, we like finish this module as well as this course and before ending so, we will just revise it once that, what we have learnt in this course. So, initially in this course we have first studied about like we have seen, we have that what are MEMS sensors, what are micro scale or nano scale sensors and why they are important right.

And, then we have also discussed about the scaling effect; like while you are already we are using some similar kind of sensors in macro scale, what does it like how does it change when we scale down to micro scale or nano scale. And, there we have seen that the physics remains same, but the phenomena might change.

Because, like some forces are dominant, like the volumetric forces are dominant in 3D scale whereas, like the surface forces are dominant in micro scale; what we have seen in scaling that the volumetric forces are dominant in the macro scale like in bigger scale right; whereas, the surface forces or one-dimensional forces are dominant in like micro scale or nano scale and accordingly, the phenomena changes.

Then we have seen like the simple mechanics and we like how the force and deflection is related and for measuring a force or in any pressure or similar mass of some particular body then, we actually use some kind of moving structure like cantilever or membrane. And, as it applies some kind of force, then the structure deflects and accordingly we measure the deflection by electronic way by or optical way and accordingly, we calculate the force.

Now, how this force and deflection are related for cantilever or for membrane that we have already discussed in the module 1 and 2. And, then we have also seen that for complicated structures like, if we have more than one beam like two beams or three beams then we can use the parallel like we can use the spring mass system like where two parallel spring or two springs in series and can calculate the equivalent spring constant and can accordingly calculate the force right.

Then, we have also then we have discussed about coupled electro mechanics and there we will have seen that; how on a body we are applying both the electrostatic force and elastic force are applied together and how they act together. And how the deflection changes with different kind of voltages and what is cooling voltage. And then stiction and how this kind of cantilevers or membranes are made. We have learned about silicon etching then, also some material deposition in very short way we discussed some material deposition. Also very important lithography like how do you make actually this kind of nano patterns right.

Whether you want to make a micro scale pattern or nano scale pattern; how you can use a like an e beam like a pen or a UV light for that purpose. And finally, we have discussed two specific sensors: one is pressure sensor and another is accelerometer. And, we have also like seen how we can use this kind of system for measuring pressure and acceleration and also we can we can mount it and in very small area because, these are also very small sizes right. So, these kinds of pressure sensors or accelerometer are the product of MEMS technology.

I hope you have enjoyed this course.

Thank you.