Microfluidics
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Lecture - 32
Microvalve (Continued)

Okay. So, let us continue our discussion on microvalves, we have been looking at thermo pneumatic microvalve. So, in thermo pneumatic microvalve, we basically we have a liquid present in a sealed volume and we go for pay change. So, we supply heat so that the part of the liquid gets into vapor phase so, there is an expansion of the volume and the expansion of the volume basically actuates the microvalve okay. Let us now look at an example.

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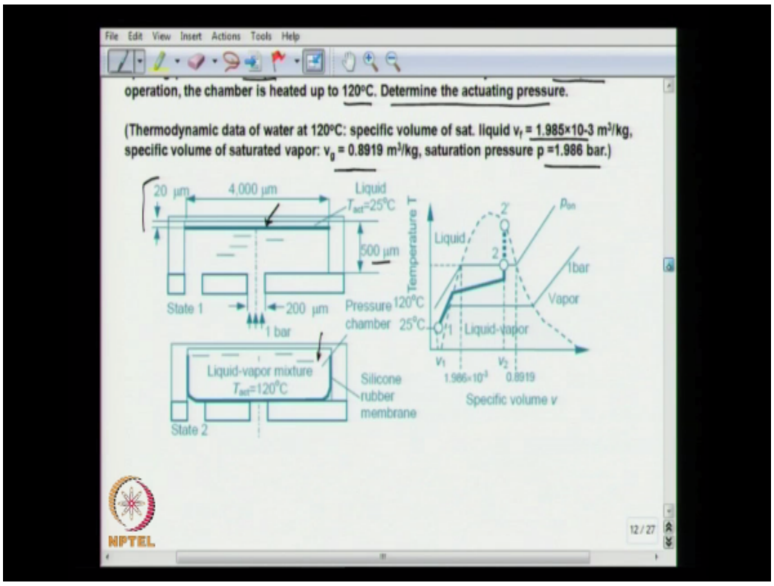

So, this is the example, the valve that we have seen in case of the pneumatic microvalve example has a small actuation chamber and large gaps for minimum pressure drop in the opening state and the membrane is made of silicon rubber and the spring force is negligible. The initial actuating chamber height is 20 micron okay. So, that is the actuating membrane height initially as you can see here. The gap at the opening position is 500 micron. So, this is the gap okay.

The water is filled and hermetically sealed at1 bar 25 degree centigrade. So, inside here, we will have water okay. In that20 micron gap, we would have water present at1 bar and 25 degree centigrade. And while operating, the chamber is heated up to 120 degree centigrade and we are interested to determine the actuating pressure okay. The pressure that we have in these state and we have the thermo dynamic data for water at120 degree centigrade.

The specific volume of saturated liquid is given and specific volume of saturated vapor is given and the saturation pressure is also given which is 1.986 bar. So, we are going to look at how we can find the actuating pressure okay. So, the first step we have to find the mass of the water inside the chambers. We have to find the mass of the water in the first step.

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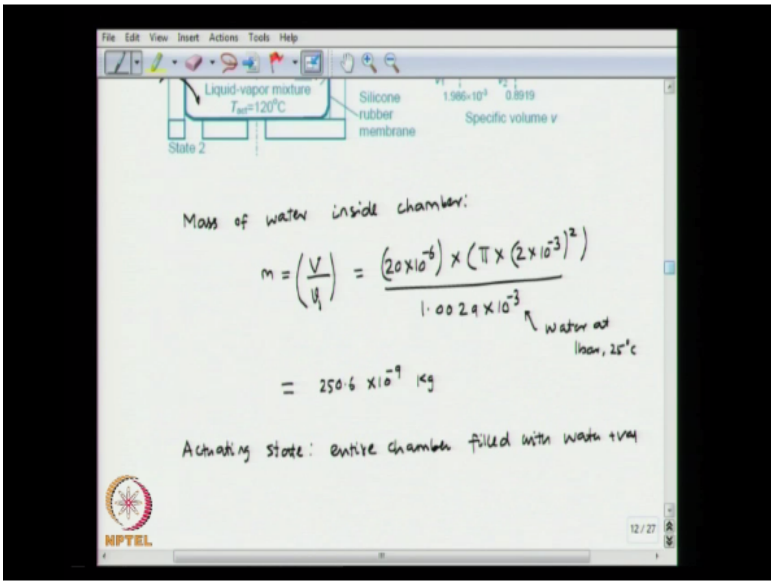

So, the mass of water inside chamber can be found so, m will be = V over V 1 okay. So, the volume will bE20 micron is the height, 20*10 power -6 and*pi r square, r is 2*10 to the power -3 so 2 millimeter square. So, that is the initial volume of the chamber here okay divided by the specific volume, which is given 1.0029*10 to the power -3. So, that is water at1 bar. So, this is for liquid water at1 bar and 25 degree centigrade.

So, the mass is going to bE250.6*10 to the power -9 kg. now, in the actuating position okay, let us say the entire chamber is filled with liquid + vapor okay. So, if that is the case, we can say that in the actuating state, the entire chamber is filled with water + vapor okay. So, if that is the case, we can find the specific volume.

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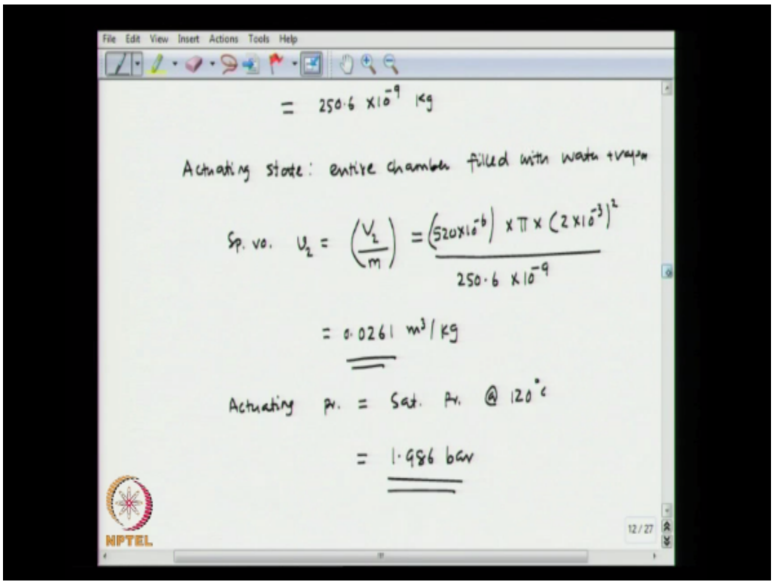

So, the specific volume V 2 is going to be V 2 divided by m. so, the mass is not going to change. The volume has changed. So, total volume, the total height here is 520 micron. So, this is 500 micron gap + 20 micron. So, this will be 520*10 to the power -6 is the height*pi*2*10 to the power -3 square divided by the mass which is 250.6*10 to the power -9. So, this will be .0261 meter cube per kg. now, if you look at this specific volume, is higher than the liquid specific volume but < the vapor specific volume okay.

So, what we say is that, this is a mixture okay and so the actuating pressure will be the saturation pressure okay. The corresponding saturation pressure at this condition okay. So, the corresponding saturation pressure at120 degree c. So, the actuating pressure will be = the saturation pressure at120 degree c and which is given by 1.986 bar. So, this is going to be the pressure at this condition. So, the inside pressure is going to bE1.986 bar okay.

So, wit that example, let us move on to thermo mechanical valve. In thermo mechanical valve, the principle is based on the difference in the thermal expansion coefficient between the actuating membrane and the base okay. And when there is a temperature change because of the coefficient of thermal expansion difference, the actuating membrane is going to expand okay. And the supply of heat to the membrane is going to actuate the membrane because of the expansion and contraction okay. So, let us look at thermo mechanical actuators.

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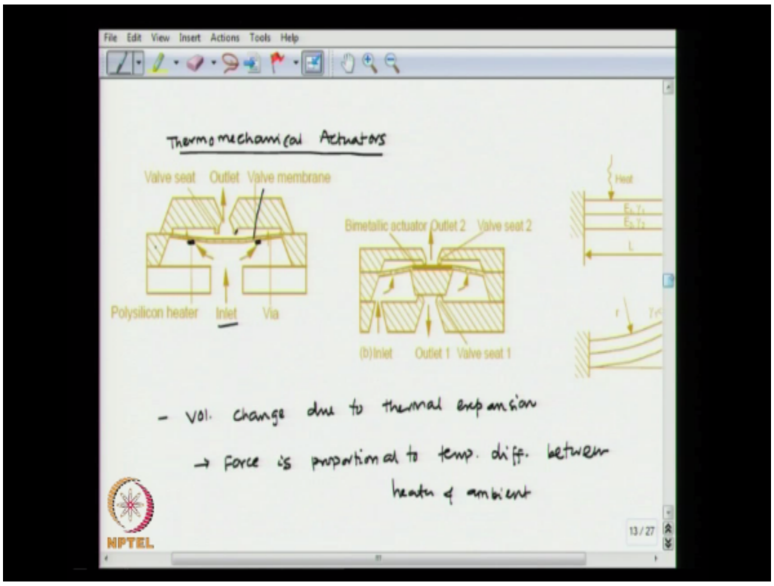

So, let us look at thermo mechanical actuators okay. So, here you can see the example, this is the inlet and this is the valve membrane okay and on the valve membrane, you will have some heaters present okay. So, the heater will be present on the valve and when the heat pulse is supplied, because of the difference between the thermal expansion coefficient of the membrane and the base, the membrane is going to expand okay.

And initially, the membrane is contact with the valve seat here, this is the valve seat so, the valve is closed. Now, if the heat pulse is supplied to the heater, the valve is going to expand so the valve here, that is going to be a gap between the membrane and the wall seat. So, the valve is opened okay. So, what happens in thermo mechanical actuators is that there is a volume changed due to thermal expansion.

So, there is a volume change due to thermal expansion and that force that develops because of thermal expansion is proportional to the temperature difference. The heater and ambient okay.

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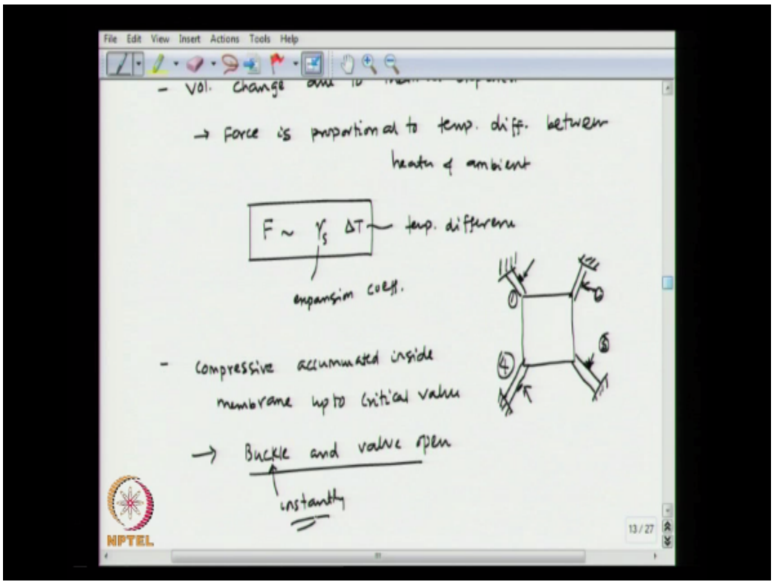

So, that force is going to be proportional to gamma S, which is the expansion coefficient*delta T okay. So, this is the expansion coefficient and this is temperature difference okay. Now, typically we would have a membrane which is square or rectangular incur section and the membrane will be inched at 4 sides okay. And so the membrane is going to be hinged on 4 sides and the heaters will be mounted on these structures okay. So, initially this plate is going to be in contact with the valve inlet.

So, the valve will be closed and when the heat is supplied to this heaters, then there is a compressive stress that develops within these 4 members okay. And at some point, the compressive stress exceeds a critical value and then the valve pops out okay. So, the valve is open okay. So, what happens is the compressive stress accumulated inside membrane up to critical value okay and this is going to be buckled and valve is open. And this buckling process happens instantly okay.

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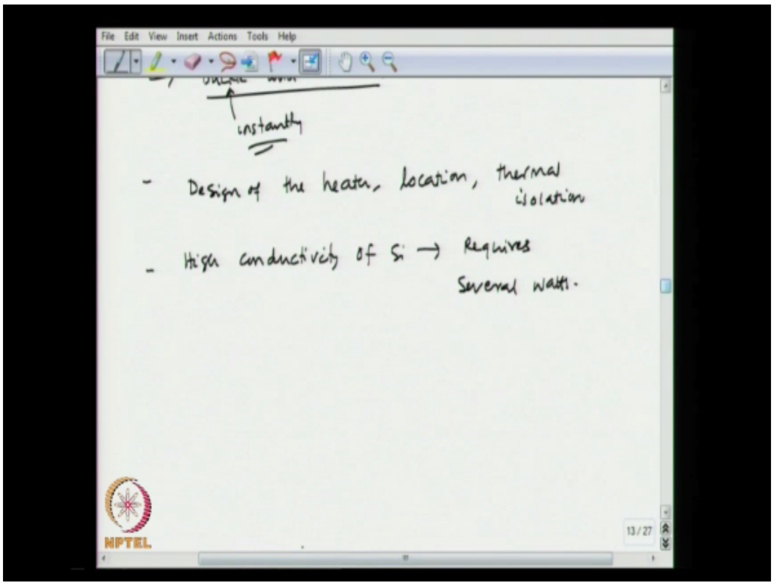

So, the design of thermo mechanical valve would involve design of the heater, its location and also thermal isolation. So, these are important design parameters okay. And because the thermal conductivity of silicon is quiet high about150 watt per meter Kelvin. The amount of the energy that is required is also very high okay. So, the high conductivity of silicon, so, this requires several watts okay. Now, let us look at a bimetallic valve, so this is the membrane itself and we would have a bimetallic actuator mounted on to the membrane itself.

So, these bimetallic actuators will havE2 different, so, this is the membrane and here we havE2 metals okay. So, that is why it is called bimetallic actuator. And when the heat pulse is supplied because of the difference in the thermal expansion between thE2 different metals, the membrane will buckle to 1 side okay. So, in this case, here the valve is in closed state when the membrane is in a buckling state and when the heat pulse is taken out, the membrane will return to its original position and the valve can be opened okay.

So, this is the scenario we have, we would havE2 different metals bundled to each other. So, they cud have different thickness and when the heat is supplied because of the difference in the thermal expansion coefficient in this case, gamma 1 is < gamma 2, the bimetal is going to deflect. So, there is going to be a maximum gap at the tip of the bimetal and there will be an actuation force F okay, which can produce equivalent deflection okay.

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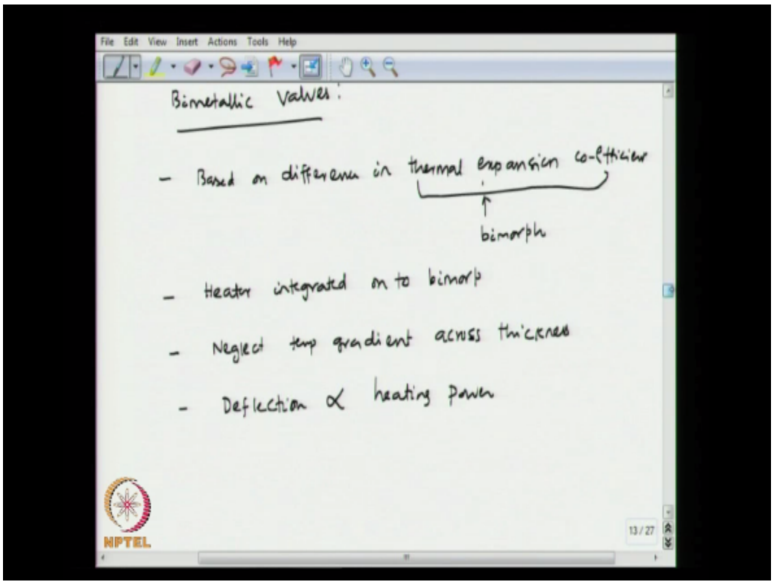

So, we talk about bimetallic valves. So, the bimetallic valves is based on the difference in thermal expansion coefficient okay. So, difference in thermal expansion coefficient between 2 metals or it is also known as bimorph okay. And we would have a heater integrated into bimorph. Here we would neglect temperature gradient across thickness, because we are talking about thickness of the order of micron and we would have linear dependence between the heating power and the deflection okay.

So, the deflection will be linearly dependent to the heating power okay. So, we can write the force would be proportional to the thermal expansion coefficient. So, the force that develops at the tip F will be proportional to gamma 1- gamma 2*delta T okay.

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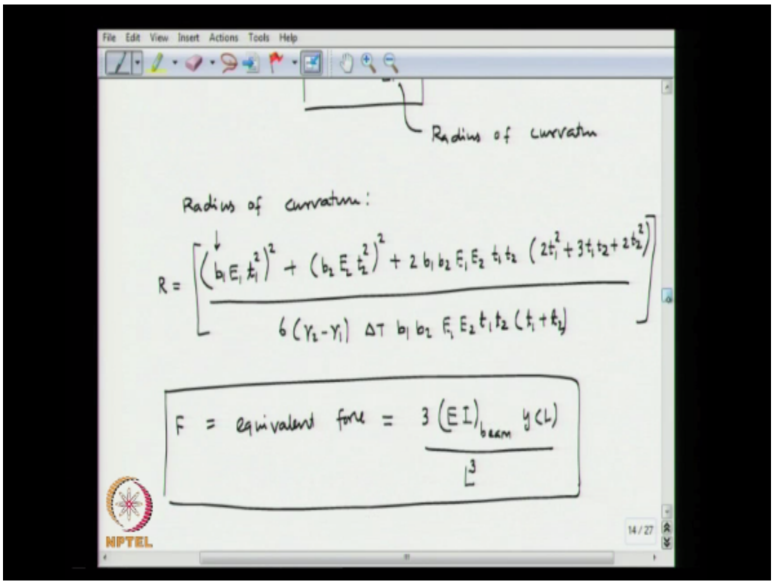

And the displacement of the tip yL is going to be L square over 2 R, where L is the length of the bimorph and R is the radius of curvature okay. So, the radius of the curvature is given by this expression, the radius of curvature R is given by b1 E1 t1 whole square. So, b1 is the width of the bimetal 1 E1 is the Young's modulus of bimetal 1, t1 is the thickness of bimetal 1 + b2 E2 t2 square, so these are corresponding parameter for bimetal 2 + 2 b1 b2 E1 E2 t1 t2*2 t1 square + 3 t1 t2 + 2 t2 square divided by 6*gamma 2-gamma 1.

So, this is the expansion coefficient difference between bimetal 2 and 1*delta T beta 1 b1 b2*E1 E2 t1 t2*t1 + t2 okay. So, that is the expression for the radius of curvature R. So, we can write the equivalent force F, because of the difference between the thermal expansion coefficients, the bimetal is going to deflect okay. And there is the deflection is going to be maximum at the tip. Now, there could be an equivalent force F, which can create the same amount of deflection at the tip, if the temperature were constant okay.

So, let us find that force, Force F is the equivalent force, which can buckle the bimetal like a cantilever so, that can be written as 3*EI of the beam, the composite beam*yL deflection at y = L divided by L cube okay. So, that would be the equivalent force which can create the same deflection at the tip okay.

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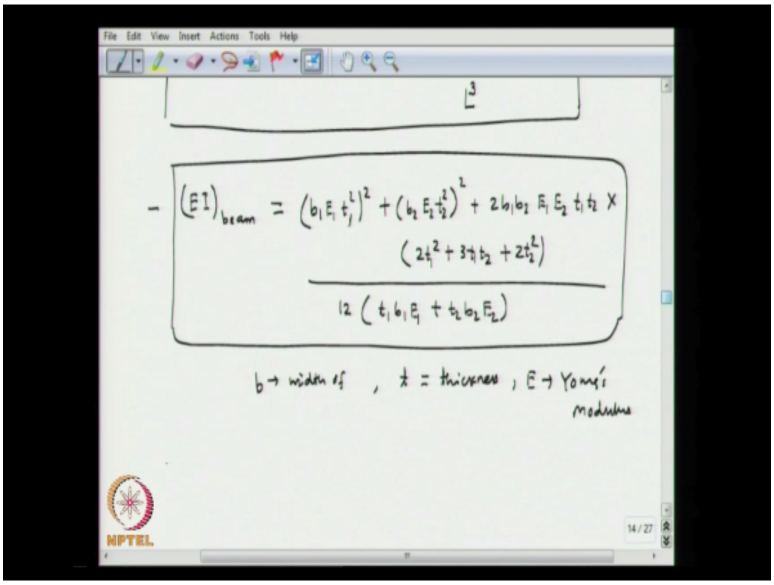

And the flexural rigidity EI of the beam, which is called the flexural rigidity of the beam can be found using this formula, which is b1 E1 t1 square whole square + b2 E2 t2 whole square + 2 b1 b2 E1 E2 t1 t2*2 t1 square + 3 t1 t2 + 2 t2 square divided by 12*t1 b1 E1 + t2 b2 E2 okay. So, that is how you can find the flexural rigidity of the composite beam. So, knowing that we can find what is going to be the equivalent force okay. So, here just to confirm the b width, t is thickness and E is the Young's modulus okay.

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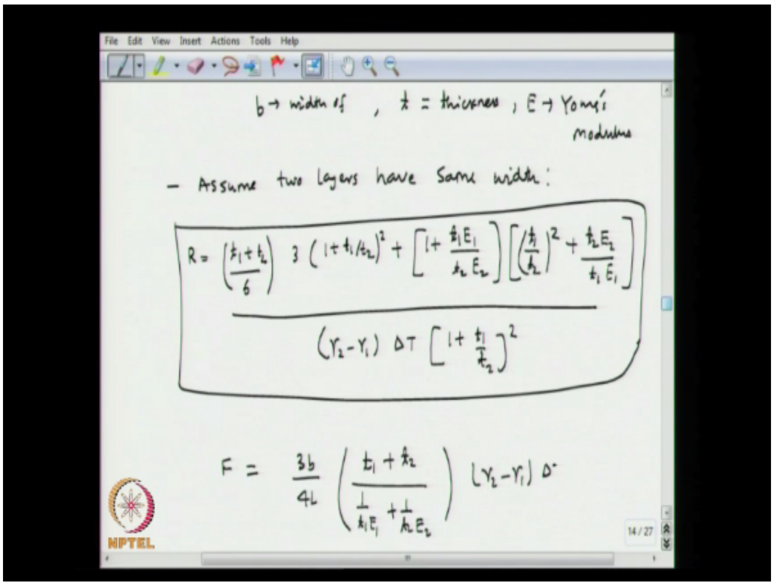

Now, if you assume that thE2 layers have same width, then the radius of curvature R can be t1 + t2 / 6*3*1+ t1 / t2 whole square + 1 + t1 E1 over t2 E2*t1 over t2 square + t2 E2 divided by t1 E1 divided by gamma 2 - gamma 1*delta T1 + t1 over t2 square okay. So, that is the expression for the radius of the curvature if thE2 straps have same width okay. So, in that case, we can find the force F will be 3 b over 4 L*t1 + t2 divided by 1 over t1 E1 + 1 over t2 E2*gamma 2 - gamma 1*delta T okay.

So, that is going to be the expression for the force okay. So, with that let us consider an example.

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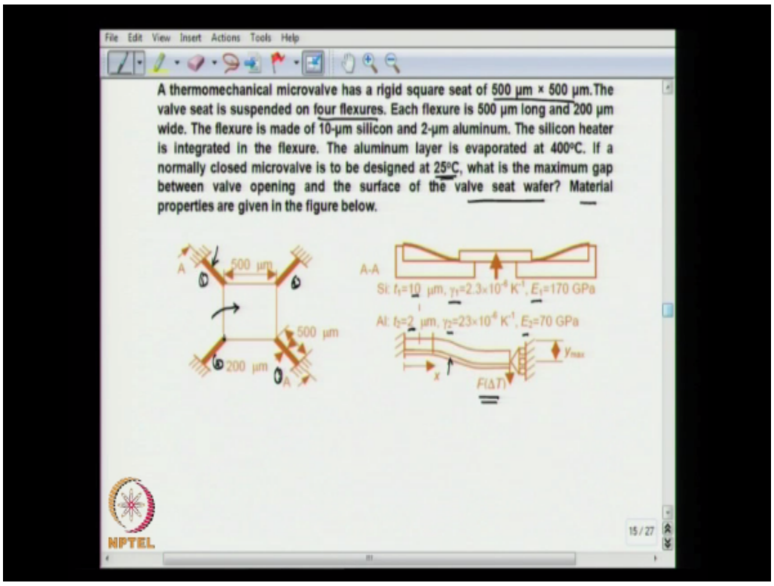

So, this is the example we have, we have a thermo mechanical microvalve, which has rigid square seat of 500 micron 500 micron okay. So, this is the rigids square seat, which has 500 micron 500 micron area and the valve seat is suspended on 4 flexures okay. So, these are 4 flexures 1, 2, 3 and 4 okay. Each flexure is 500 micron long so, each of these is 500 micron long and 200 micron wide okay and the flexure is made of 10 micron silicon and 2 micron aluminum.

So, it has 2 layers as you can see here, 1 layer is 2 micron, the bottom layer is 2 micron and the top layer is 10 micron okay. The silicon heater is integrated in the flexure so, this heater is integrated on to the flexure itself, the aluminum is evaporated at 400 degree centigrade okay. So the aluminum layer is at 400 degree centigrade. If a normally closed microvalve is to be designed at25 degree c, then what is the maximum gap between the valve opening and the surface of the valve seat wafer okay.

So, let us say initially it is evaporated of 400 degree c, now if, we were to design the microvalve to be closed at25 degree c so, it is getting the compressive stress okay because the temperature is going down. So, it is going to be compressed against the valve seat okay. So, we have to determine what is the maximum gap at which still the valve is going to be closed okay and the material properties are given.

So, these are the material properties the expansion coefficient gamma 1, gamma 2 okay and E1, E2 of the aluminum and silicon. So, first we try to find the force at the tip of each flexure, so we try to find the force at this locations, for each flexure.

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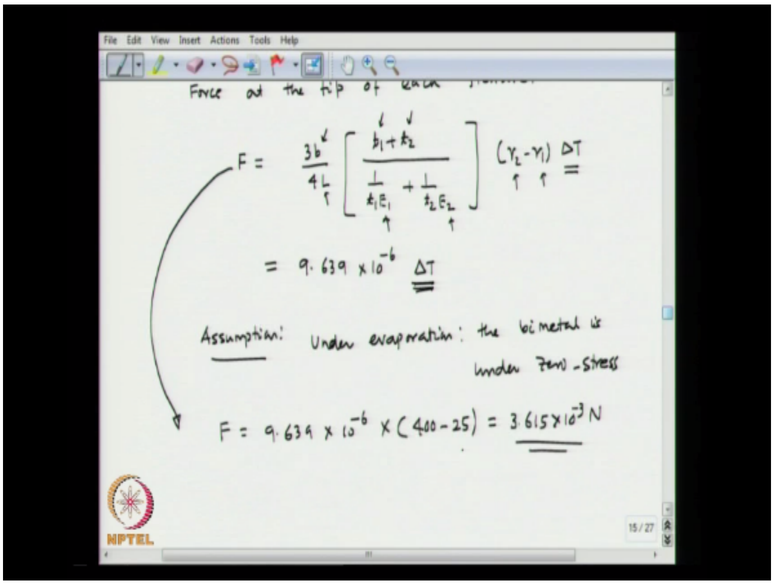

So, the force at the tip of each flexure so F is calculated using this formula 3b over 4L*t1 + t2 divided by 1 over t1 E1 + 1 over t2 E2*gamma 2 - gamma 1*delta T okay. So, if you plug in the values, we know the width of the flexure length, thickness of both layers we know 2 micron, 10 micron E1 and E2 we know. So, if we plug in and we also know gamma 2, gamma 1 and delta T, delta T is 400 degree.

So, we can find 9.639*10 to the power -6*delta T okay. So, delta T is 400-25 degree c. now, here we have to make an assumption that, under evaporation, so we assume that when we do the evaporation of the aluminum layer, thE2 bonded metal layers are stress free. So, initially there is 0 stress acting okay. So, under evaporation, the bimetal is under 0 stress. So, in that case, we can calculate F for a given delta T. So, F will be 9.639*10 to the power -6*400 - 25. So, that will be 3.615*10 to the power -3 Newton okay.

Now, let us try to find the flexural rigidity of the composite beam.

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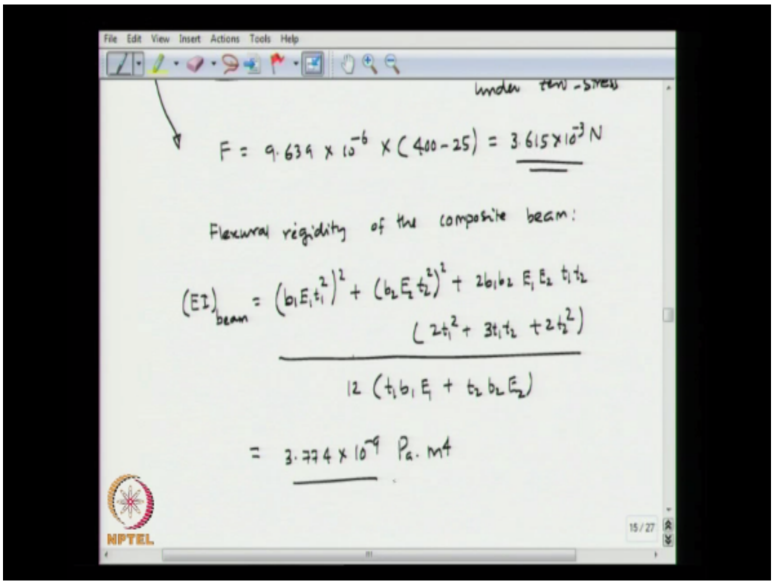

The flexural rigidity of the composite beam EI of the beam. So, we use the formula b1 E1 t1 square whole square + b2 E2 t2 square whole square + 2 b1 b2 E1 E2 t1 t2*2 t1 square + 3 t1 t2 + 2 t2 square divided by 12 t1 b E1 + t2 b2 E2. So, using this formula we can find the flexural rigidity to be 3.774 + 10 to the power -9 Pascal meter 4 okay. So, that is the flexural rigidity of the beam okay.

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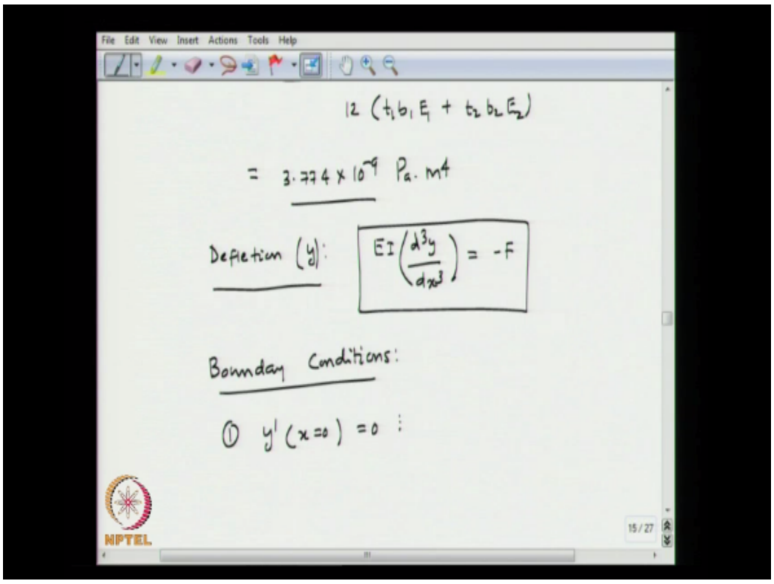

Now, if you want to find the deflection of the beam, so deflection y will be governed by this equation. So EI*d cube y over d x cube will be = -F okay. So, this is the equation will govern the deflection of the bimetal okay.

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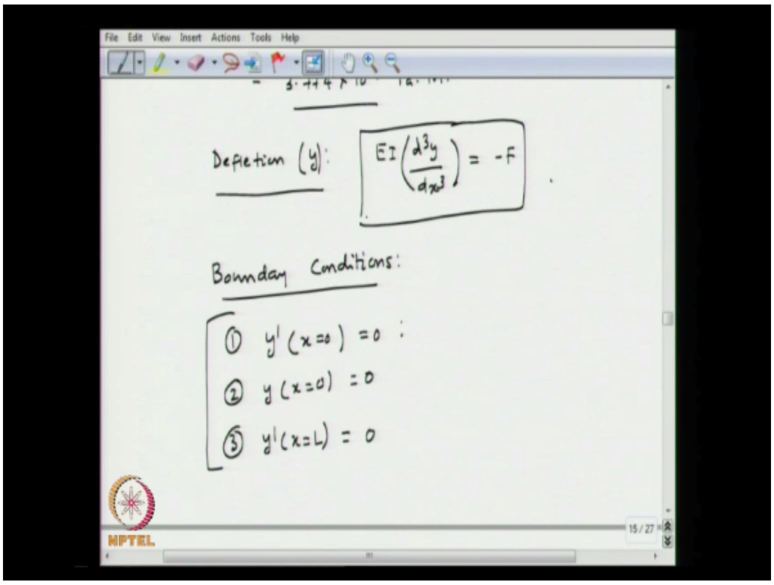

So, what are the boundary conditions to solve this equation? The boundary conditions will be the y dash, the slope at x = 0 is going to be 0 okay. So, if you look at here, this is x = 0 okay. That means at the base. This flexure is mount into a rigid base okay. So, the slope is going to vanish here and also since the membrane is rigid, the slope will also vanish here okay. And also since it is rigid, the deflection will vanish here as well.

So, y dash at x = 0 will be 0 and the y at x = 0 will be also 0 and the third condition is that, the slope at x = L at the membrane okay will be 0 right. So, if you use these 3 boundary conditions to solve this differential equation, then you get the solution.

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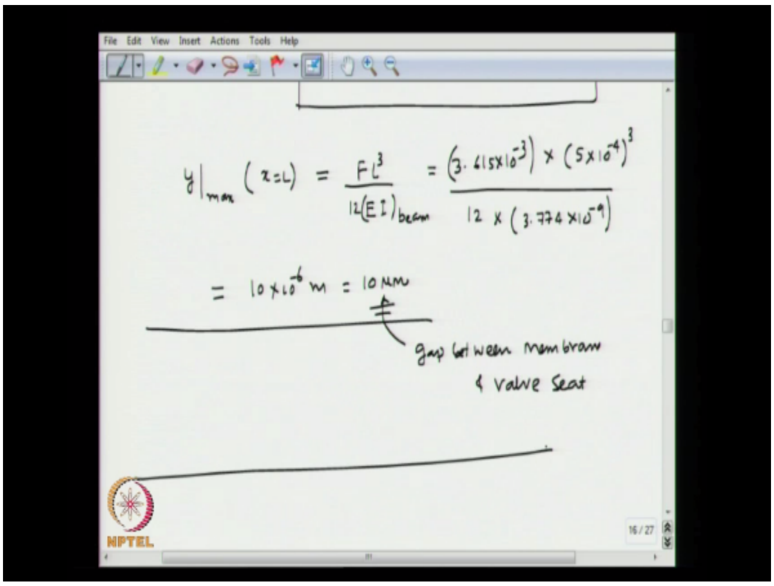

So, by solving we get y x is going to be F divided by 2 EI of the beam*-x cube / 3 + L x square / 2 okay. So, this is the solution for y okay. So, from there we can find what is going to be the maximum deflection. So, y maximum so that will occur at x = L so that we can find as FL cube over 12 EI of the beam, which will be so F we have found, F = 3.615*10 to the power -3. So, this is the force that we have found *L is 5*10 to the power -4 cube okay divided by 12*EI.

We have the EI for the composite beam 3.774*10 to the power -9. So, we can find the deflection to bE10*10 to the power -6 meter or 10 micron okay. So, we can allow a maximum gap of 10 micron so that when the temperature is the room temperature at25 degree c, the valve will still be closed okay. So, this would be a 10 micron gap, so gap between membrane and valve seat okay.

So, with that discussion let us move on and talk about the shape memory alloy based microvalve. The shape memory alloy is something, if you apply a load, it will go through deformation and it will remember its original configuration and if we heat the metal or the alloy, it is going to come back to its original shape that is known as shape memory alloy.

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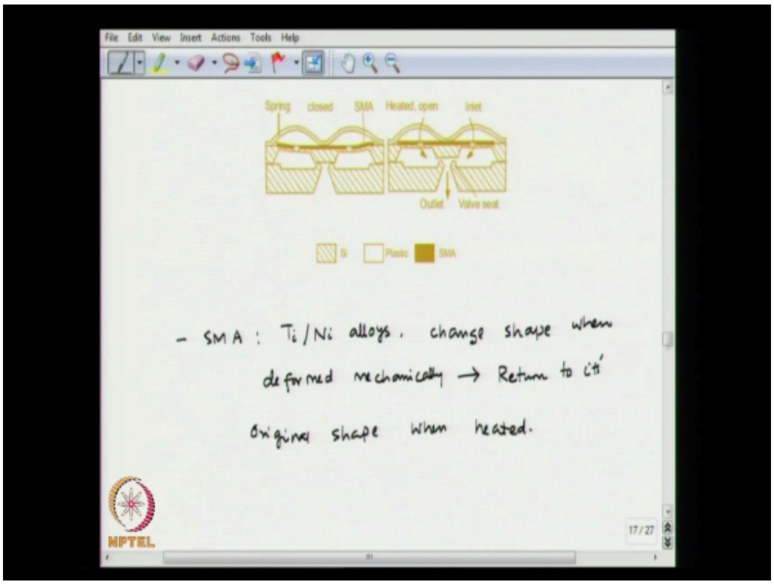

So, we look at shape memory alloy based microvalve. SMA stands for shape memory alloy. First try to understand what shape memory alloys are. So, they are typically titanium nickel alloys and they will change shape when deformed mechanically okay. But they will return to its original shape when heated okay. So, that is the property of the shape memory alloy.

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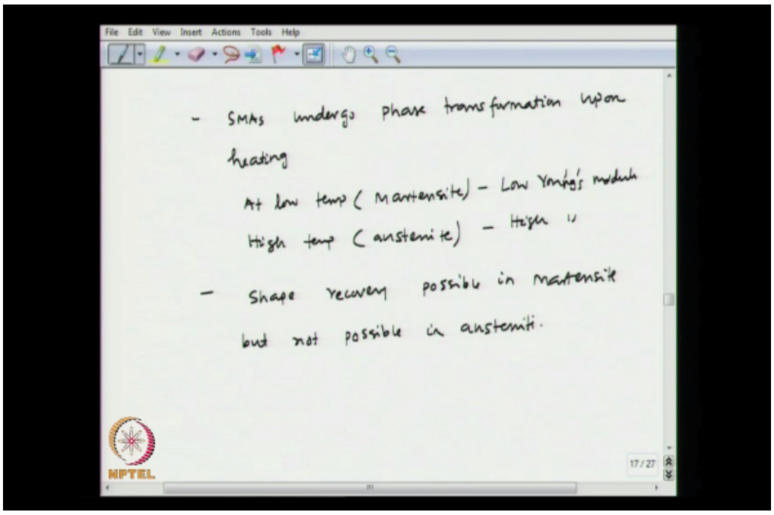

And the shape memory alloy will undergo a phase transformation upon heating. So, the SMAs will undergo phase transformation upon heating okay. So, normally at low temperature, they will be in Marten site and at high temperature, they will become austenite okay. And this will have low Young's modulus and this will have High Young's modulus okay. So, for that reason, the shape recovery is possible when it is in Marten site shape okay.

So, the shape recovery possible in Marten site but, not possible in austenite okay. So, this is one such microvalve, which is based on shape memory alloy. So, as you can see here, if there are, here initially the valve is closed okay because, that is the original state of the shape memory alloy and when the pressure of the inlet fluid will increase okay, when the inlet fluid here, the pressure of it will be increased, then this membrane holding the shape memory alloy is going to go up okay.

Now, when you want to again close the wall then we supply heat so, it is going to be heated. So, it will remember its original shape okay. So, its original shape will be remembered and so that the shape memory alloy when it tries to go to its original shape, the membrane is going to close down okay. So, this is what is going to happen. So here, we have shape memory SMA will be in original shape okay. So, valve closed. Now here, in this case, inlet pressure increases so, valve open.

Now, if we again want to close the valve, then we need heating of shape memory alloy to bring it back to original shape okay. So, that is how shape memory alloy based microvalves work. So, with that let us move on to piezo electric based microvalve.

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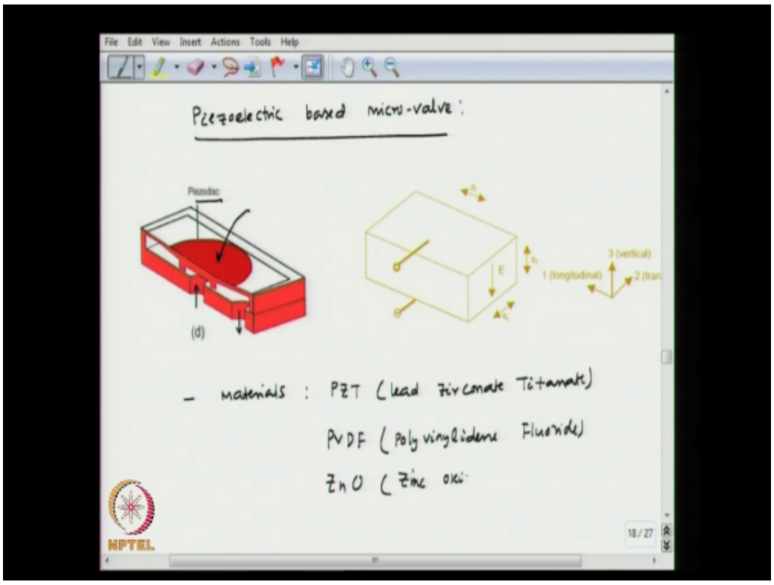

Piezo electric based microvalve. Here, you would have a piezo disc as you can see here and the piezo electric materials are materials which can undergo strain or it can be formed by applying in electric field okay. And they can be reversible so that, if we apply a strain, then it will produce charge okay. But, in this case, we are interested in deformation of the piezo electric crystal. So, we will apply an electric field to create a deformation or deflection.

So, when you apply an electric field, this piezo disc is going to deform and that is how the valve is going to be actuated okay. So, let us try to understand what piezo electric material is. So, typically they are PZE, which is lead zirconate titanate or they can be PVDF, these are some of the examples of piezo electric materials, which stands for poly vinylidene floride or they can be zinc oxide okay Z n O.

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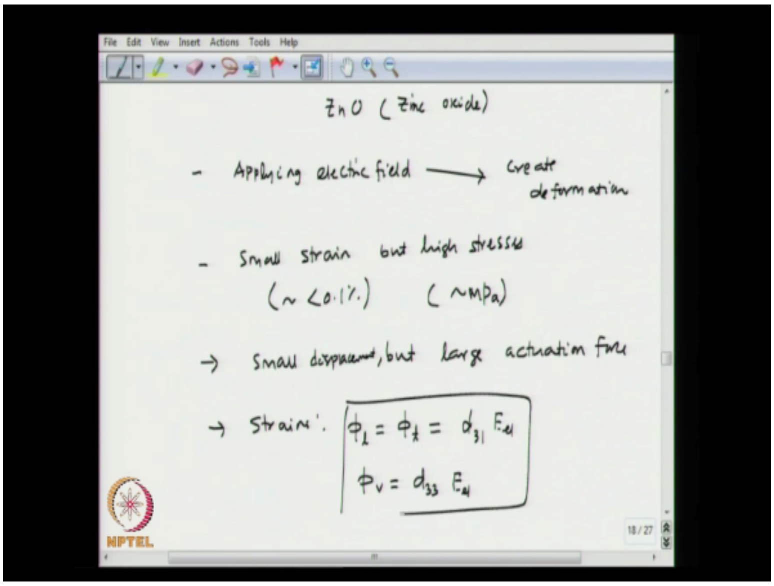

So, here we are interested in applying electric field and create deformation okay. And these piezo electric materials have characteristic to produce small strain but high stresses okay. So, the strain is of the order of < 01% and the stress is of the order of milli Pascal okay. So, we would be using piezo electric based micro actuation in microvalves, where we need small displacement but large actuation force is required okay.

So, the application would be where we need small displacement but large actuation force okay. So, we can find out the strains, this is the longitudinal strain transverse strain and so the longitudinal at transverse strains are going to be equal, which is d 31*electric field and the vertical strain is going to be d 33*electric field.

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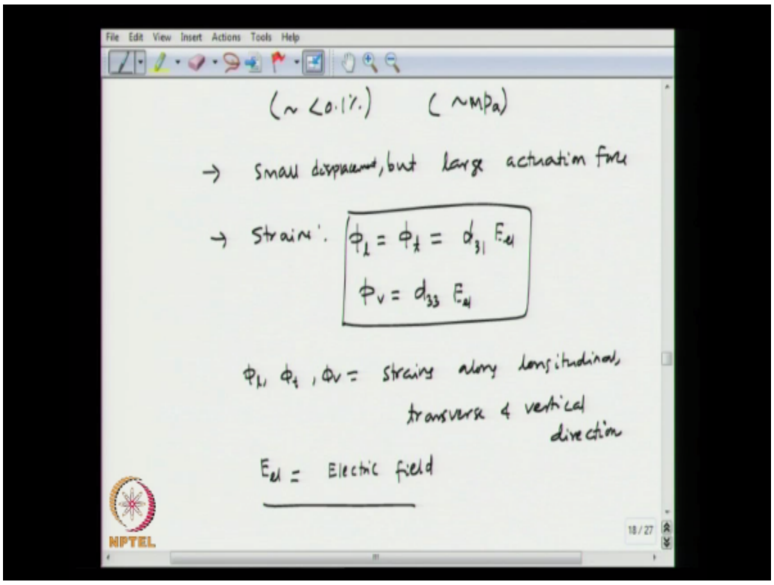

So, these are pi l pi t and pi v are strains along longitudinal transverse and vertical directions and this is the electric field okay. So, now let us take a small example.

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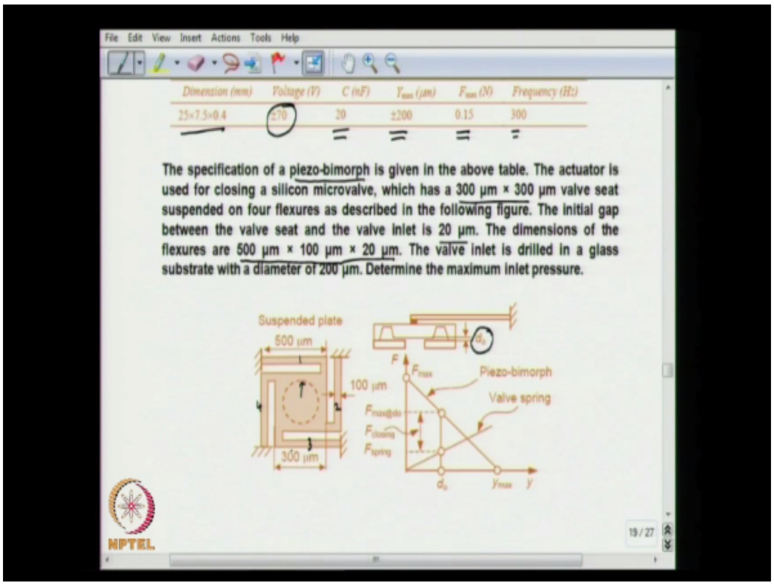

So, here we are specifying a piezo bimorph so, you have a piezo electric material made out of 2 different metals and the properties are given here, so the dimension is 25*7.5*0.4 milli meter. We are applying +- 70 volts, this is the capacitancE20 nano faraday and the maximum reflection is going to be +-200 micron and the force that we encounter is 0.5 Newton at a frequency of 300 Hodge okay. So, the actuator is used for closing a silicon microvalve, which has 300*300 micron valve seat okay.

And suspended on 4 flexes as described in the following figure. So, these valve seat is suspended by 4 flexes okay. The initial gap between the valve seat and the valve inlet is 20 micron, so this is the initial gap, that is shown here. The dimensions of the flexes are 500 micron, 100 micron and 20 micron. So each flexure has this dimension and the valve inlet is drilled in a glass substrate with a diameter of 200 micron okay. So, the valve inlet is sort of shown here, this has 200 micron diameter or 100 micron radius.

We want to determine the maximum inlet pressure okay. So, this is how it is going to the characteristics is going to look like at 0 deflection, the force is going to be maximum and as the deflection occur, the force is going to reduce okay. And this is the spring force of the valve and this is the force that is coming from the piezo bimorph okay.

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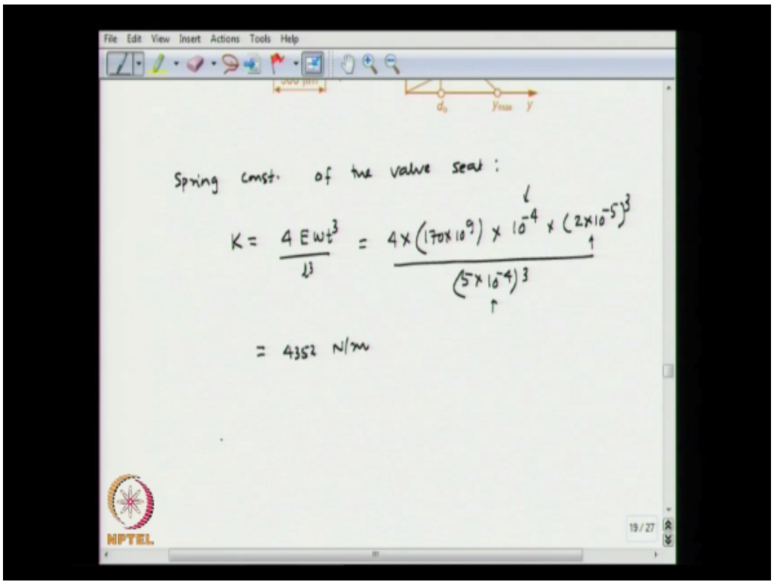

So, the spring constant for the valve seat, spring constant of the valve seat is modeled as 4 different beams, so we can find the spring constant as 4Ewt cube divided by l cube. So, 4*170*10 to the power 9 and the width 10 to the power -4* the thickness is 2*10 to the power -5 cube okay divided by 5*10 to the power -4 cube okay. So, this is 500 micron right l, this is 100 micron, this is 500 micron and this is 20 micron right, so 2*10 power -5.

So, we get K as 4352 Newton per meter. So, the characteristics are shown here as we described. So, force and displacement of the piezo bimorph are inversely related and the valve spring will increase with deflection.

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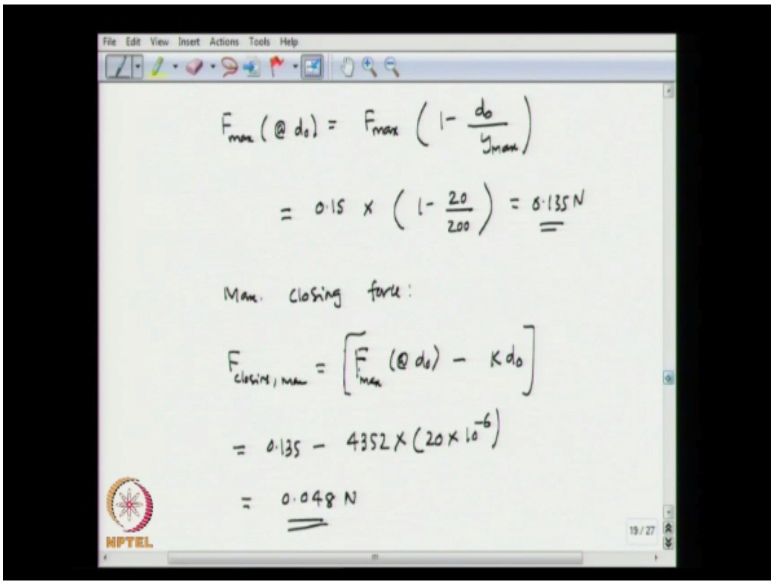

So, what we say, the maximum achievable force at the displacement d0 is going to be F max at d0 is going to be F max*1-d0 over y max okay. So, the d0 is the initial gap right. So, that is

.15*1-20/200 so, that is going to be .135 Newton. So, you can find the maximum closing force is F closing max is the F max at d0- the spring force. So, which will be = .135 Newton - k is 4352*do is 20*10 power -6 okay. So, this is going to be 0.048 Newton. So, that is going to be the maximum closing force okay. Whereas this is coming from the bimorph okay.

So, this is coming from the bimorph. So, we can find the maximum inlet pressure valve can withstand delta P max is going to be F closing, the closing force max divided by the area okay. So, this is going to be .048 divided by pi*10 to the power -4 square, that is the closing area. So, it is going to be 15.28*10 to the power 5 Pascal. So, which is about 15.28 bar. So, you need, the maximum pressure the valve can still be able to close is about 15.28 bar okay. So, with that let us stop here.