Experimental Methods in Fluid Mechanics
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Lecture 14
The McLeod gauge, The Pirani gauge, The Ionization gauge Contd.

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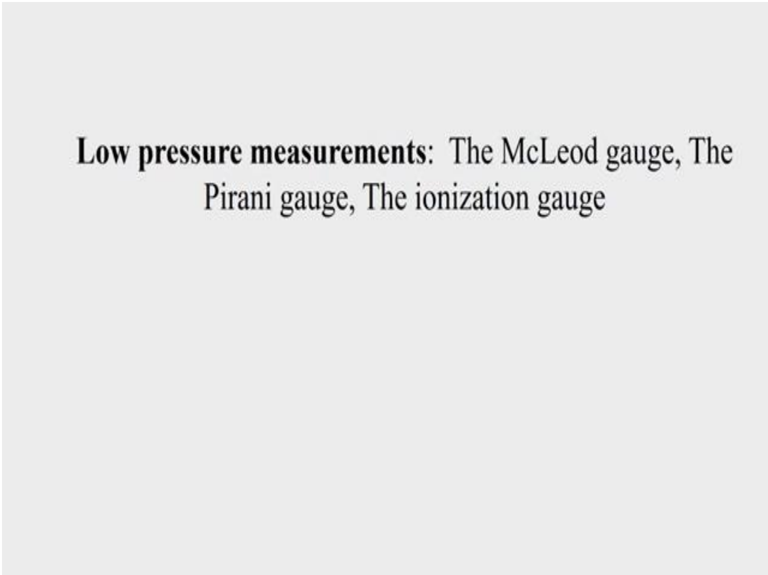

Good afternoon, I welcome to this session of experimental methods in fluid mechanics. And today we will continue our discussion on the techniques of measuring low pressure. In fact, in my last two lectures we have discussed about the low pressure measurement techniques and we have discussed about the operational principle of the McLeod gauge and in the Pirani gauge. And today we will briefly discuss about the working principle of the ionization gauge and then we will solve one numerical problem related to the flow measurement that what we have discussed in one of my last lectures.

So today, we will discuss about the operational principle of the ionization gauge, which is used to measure a very low pressure, which is in the range of 10 power minus 6 to 10 power minus 2 Pascal, and we will see today, how we can measure such a low pressure using this gauge.

So, again today to have a better understanding, you know about the operational principle of this gauge we will discuss this instrument with a schematic depiction and this ionization gauge is similar to an ordinary triad vacuum tube where tube is open to vacuum pressure. And we will see by how of course relying on the empirical relation we can measure such a low pressure. So, we will discuss about the ionization gauge.

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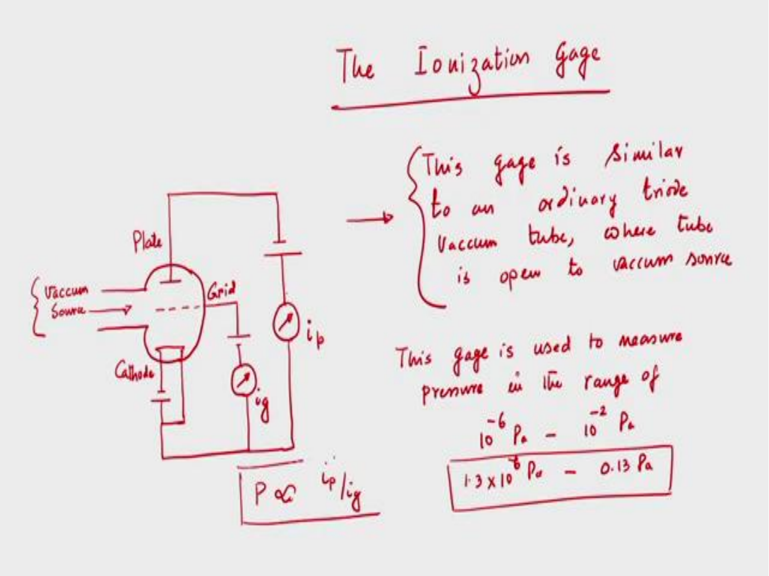

So, the ionization gauge as I said that it is similar to an ordinary triad vacuum tube or tube is open to vacuum pressure rather vacuum source, so we will draw the schematic depiction. So, this gauge is similar to an ordinary triad vacuum tube where tube is open to vacuum source. So, this is the, you know, the gauge details. Now, if I try to draw the schematic because that is very much important to know, rather it will help us to know the operational principle of this gauge. So, now I will try to draw a schematic of this gauge.

So this is a schematic of the ionization gauge and we will discuss the steps by how rather the steps are very much important to measure a very low pressure while using this ionization gauge in to in any experiments to measure the flow meter that is the low pressure. Now, if we look at the schematic, you can see that it is having a tube and the tube is open to vacuum source that is clearly you know same from the schematic and it is having note the cathode and the plate and also it is having one grid.

And now, if I discuss the steps rather I will write the steps, then we can understand clearly that by how we can measure such a low pressure. Of course, again I am telling that we need to rely on the empirical relationship that is what we have explained even in the last lecture that for the you know, Pirani gauge based on that empirical relationship we can measure such a low pressure.

And again I am telling, this gauge is used to measure pressure in the range of 10 power minus 6 Pascal to 10 power minus 2 Pascal, so that is the typical range of pressure which we can measure. In particular we can say 1.3 into 10 power minus 6 Pascal to 0.13 Pascal, so this is the range of pressure. And if you would like to measure any pressure within this range, we can use this ionization gauge that and we can expect that will get the correct results and of course, we have to rely on the empirical relationship. Now, if we look at the schematic we have, we can see that there are two different currents; one is the plate current, another is grid currents, I p and I g.

And the measured pressure, which we would like to get or obtain from this gauge is that the pressure measured can be shown to be professional of the ratio of the plate current to the grid current. And now, we will see how we can express that the pressure measured by this gauge can be retained as the ratio of plate current to the grid current. Now, the as I said that the pressure which will be measured that is proportional to the you know plate current by the grid current.

Now, this proportionality constant that is very much important, if you do not know this proportionality constant will come up with the wrong results but this proportionally constant is obtained from the empirical relationship. Now we will see now the steps, then we will try to establish the relationship between the pressure which we would like to measure and the ratio current that is the plate current grid current.

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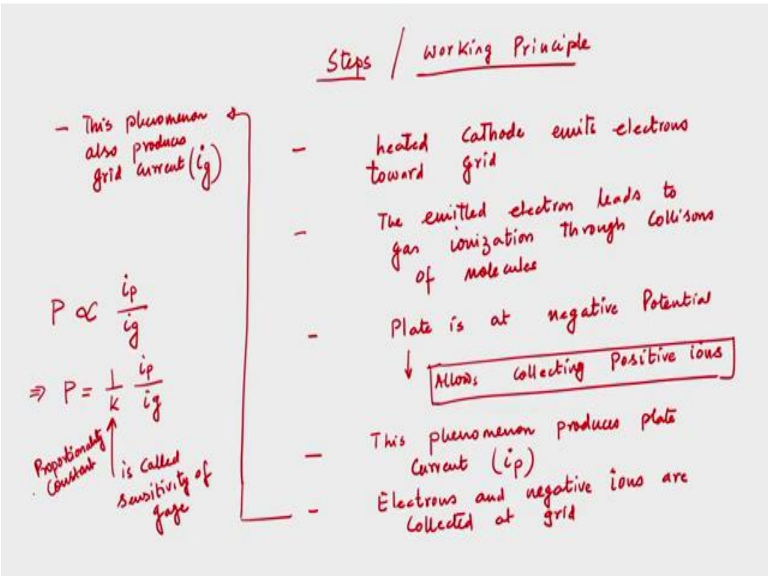

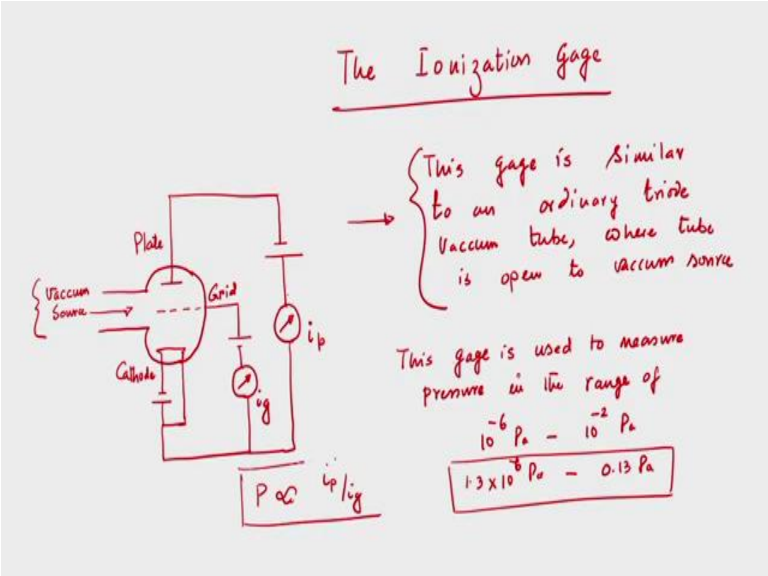

So now, the steps rather the working principle. So, I will write the steps one by one, then we will explain by how we can measure. So number one is very important that if we will go back to my previous slide that is cathode. Now, the cathode will be heated, of course we would like to have you know current, otherwise it will not be heated. So, if we allow current to flow then the heated cathode emits electrons toward grid. So, that means the cathode which is heated, if you allow current to flow now, it will limit electron and that electrons would be emitted towards the grid.

No, if the electrons are emitted by the cathode and whether you know heated cathode, you know emitting electrons towards the grid then what will happen? So, the electrons that are emitted electron, the emitted electron leads to gas ionization that is why the name is the ionization gauge through collision of molecules, gas molecules. So now, again I am coming back to the previous slide where it saying that the tube is open to vacuum source.

So, if the you know, space is filled up with gas, of course, low pressure gas, now the electrons which are getting emitted by the cathode they will move towards the electrode, towards the grid and, the emitted electron leads to gas ionization through collision of the molecules. Since, the plate is at negative potential, so that means plate is at the negative potential, so this is negative potential. Now, what will happen? This plate will allow this collection of positive ions.

So, that means, this plate allow which is there and is at negative potential, this allows collecting positive ions. So, the plate is at negative potential so that the plate will collect the positive ions. Now, this phenomenon of electron emission, movement towards the grid and then since plate is at negative potential they will try to collect the positive ions. Now, this phenomenon produces plate current IP.

And if we again go back to the previous slide that is cleared that the cathode and plate and that is connected to circuit, so we will get plate current IP, rather this phenomenon will produce the plate current IP. Now, electrons and negative ions are collected at the grid so the electrons are emitted by the cathode, they will move towards the grid and the movement of the electron towards the grid will leads to gas ionization.

So, gas will be ionized, the positive ion will move towards the plate because the plate is at negative potential and this phenomenon will leads to develop a producer current IP that is clearly seen in the schematic. Now, while the electrons are electrons and negative ions are moving towards that grid. So, electrons and negative ions are collected at the grids, moving towards the grid and it also this phenomenon also leads to another current or produce another current that is known as grid current.

So, I am writing that the electrons which are emitted, electrons and negative ions are collected at grid and this phenomenon also produces you know grid current I g. So that means so next step I am writing at the left hand of this slide and the electrons which are getting emitted by the cathode will be collected at grid together with the negative ions, because of the gas ionization, gas will be ionized, so basically negative and positive ions.

Positive ions will move towards the plate and that will lead to a development of the positive you know plate current IP and while the negative ions as well as the electrons will move, rather will be collected at the grid and this phenomenon also leads to development of the grid current I g. Now, so, we have understood that the heating of the cathode will trigger this entire phenomenon of having development of the plate current as well as the grid current.

Now, gas pressure that is very important and that is what we would like to measure, the low pressure the tube is connected to the vacuum source. And as I said a few minutes back that the pressure that we would like to measure is proportional to the ratio of plate current to the grid current. Now, the gas pressure is proportional to the ratio plate current to the grid current. Now, this P gas pressure, which is proportional to the plate current by the grid current, right.

And if I remove this proportionality then I can write P is equal to 1 upon S or 1 upon K, I p by I z. So, if I remove the proportionality then I can have one promotional constant rather proportionality constant K and that is P is equal to 1 upon K I p by I g, and this K is called which is proportionality constant, the K is called the sensitivity of the gauge, sensitivity of the gauge. So, proportionality constant, this K is the proportionality constant and which is called the sensitivity of the gauge.

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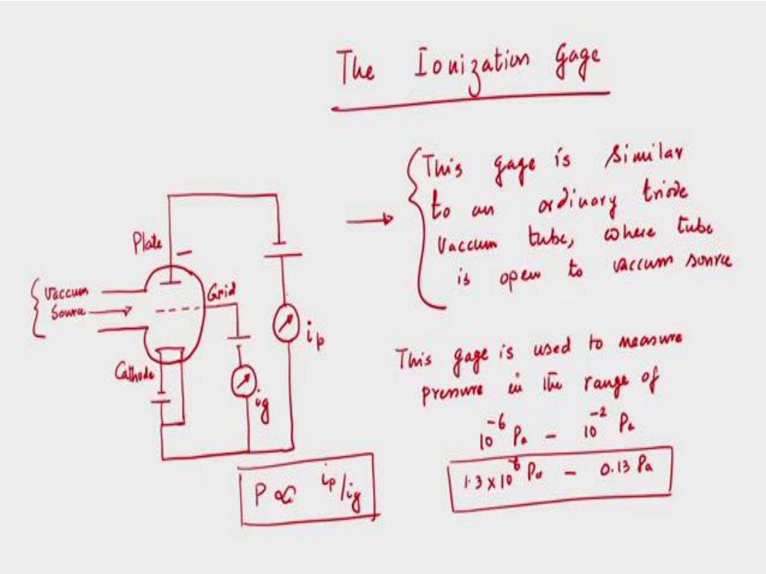

Now, see. so the working principle is very easy that means, if I go back to my previous slide where it is clearly seen that construction wise this gauge is similar to an ordinary type vacuum tube where the tube is open to the vacuum source. Now, if we look at the schematic then we can see that the heated cathode will emit electrons.

Now, depending upon the gas pressure, gas pressure that is inside the chamber, now this emitted electron will try to ionize the gas as they are moving towards the grid. Now, because of ionization, we will have positive and negative ions, positive ions will be collected at the plate that will be positive ions will move towards the plate and this phenomenon will induce one current that is plate current that is IP.

Now, depending upon the gas molecules, gas pressure that is the strength of the current which we are getting, strength of the plate current as well as the strength of the grid current. Now, see, the ionization will also depend upon the number of electrons being emitted by the cathode. So, if we can correlate that that if this is the gas pressure I mean because of this you know heated cathode that cathode will be heated and cathode will try to emit electrons.

And if this much number of electrons are being emitted by the cathode, it will try to ionize the gas and because of this ionization and that in a way depends upon the number of electrons being emitted by the cathode. And this number of how many number of positive ions will be accepted by the plant based on that we will get the plate current. So, and also the electron as well as the negative ones will be attracted or collected at the grid and that also will leads to development of the grid current.

So, the ratio of these two currents in a way will lead us or gives us an information about the pressure inside the chamber that gas pressure, small number of gas molecules they are you know, that is what I have written that collision of the molecules, so that will essentially give us the pressure that is the thermodynamic pressure that we would like to measure.

So, basically pressure can be retained as the function of the ratio of the plate current to a grid current and this proportionality constant that is very important, that proportionality constant is obtained through empirical relationship and that is known as the sensitivity of the gauge. So, this proportionality constant is sensitivity of the gauge and that is obtained through empirical relationship.

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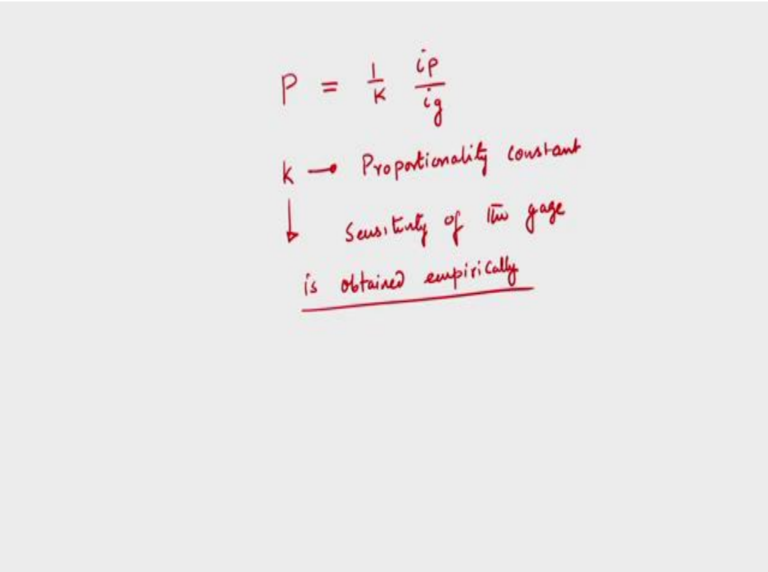

So, P equal to 1 upon K I p by I g, and this K is the proportionality constant and this is known as sensitivity of the gauge. And not only that, this K is obtained empirically, so this is obtained empirically. So, this is what is the, you know, all about the working principle of the ionization gauge. And again I am telling, this gauge is used to measure a very low pressure that is 10 power minus 6 to 10 power minus 2 Pascal.

So, with this, I stop my discussion about the measurement technique of a low pressure using different instruments and we have discussed about the working principle and their constructional features of 3 different gauges; one is the McLeod gauge and then is last class we have discussed about the Pirani gauge and today we have discussed about the Ionization gauge.

Now, I would like to solve one numerical problem and that is we have discussed, the theory part we have discussed in one of my last lectures that is the pneumatic displacement gauge, because if we can recall that pneumatic displacement gauge is used to measure a very small displacement that is very important in the context of this course. So, today we will work out one example and see how we can measure very small displacement using this pneumatic displacement gauge.

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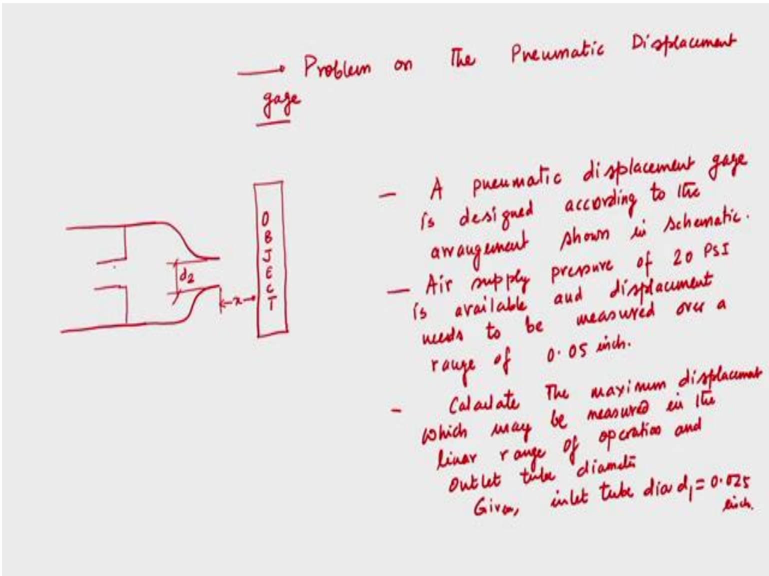

So, now we will solve one problem on that and I am writing that is problem on the pneumatic displacement gauge. Again, a schematic depiction of the pneumatic displacement gauge will help us to solve the problem quickly rather, because we need to recall what are the different parts of the pneumatic gauge? So, again we have to draw the schematic depiction but before that I would like to write the problem statement.

So problem is, a pneumatic displacement gauge is designed according to the arrangement shown in schematic, it is given that the air supply pressure of 20 psi pounds per square inch is available and displacement had to be measured over a range of and displacement needs to be measured over a range of 0.05 inch. Calculate, so there are 3 parts I am writing; calculate the maximum displacement which may be measured in the linear range of operation and the outlet tube diameter.

Given, inlet tube diameter d 1 is equal to 0.025 inch. So, this is the problem statement that problem is related to pneumatic displacement gauge. We have seen the schematic depiction of this kind of pneumatic displacement gauge, but again we need to redraw it to essentially to have a better understanding of the problem and then it is given that the air supply pressure of 20 psi is available and the displacement needs to be measured over a range of 0.05 inch.

We have to calculate two things; first one is the maximum displacement which may be measured in the linear range of operation and second is the outlet diameter of the gauge, and also it is given that the inlet diameter of the, inlet tube diameter of the gauge is 0.025 inch. Now, again we have to you know redraw the schematic. So, if we can recall, this is object work space, this is object and this is the outer diameter and we have orifice, that is diameter d 1 and this is the upstream flow.

Now, we have to calculate that x the maximum displacement which may be measured and of course, and also the value of d 2. Now, it is given that we have to measure the, you know, maximum displacement in the region of linear range of operation. Now, if we try to recall, we have studied maybe a few days back that this gauge is used to measure a very low, very small displacement that you cannot using other you know, typical gauges and other devices.

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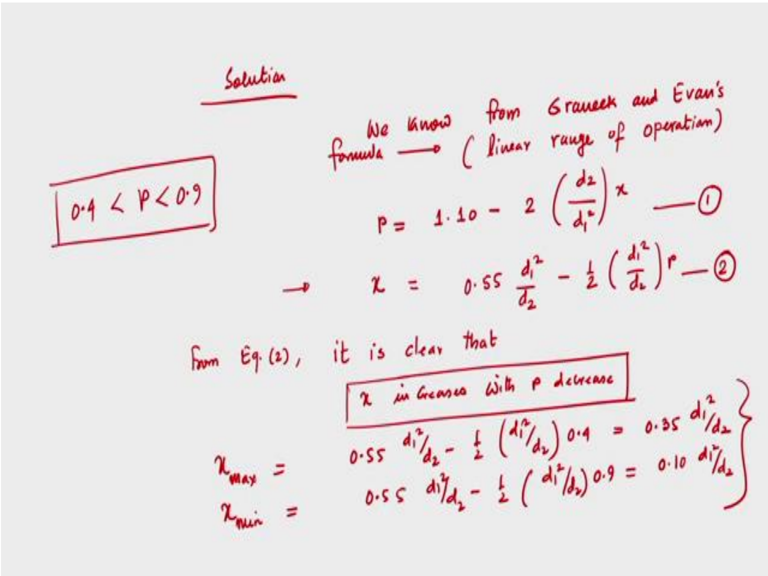

So, if we try to solve this, now the solution is that we have derived that in the linear range of operation, there is one formula and that was established by Graneek and Evan's. So, we have established that relationship while we have you know derived the rather we have discussed about the operational principle of this gauge. So, according to rather we can write, we know from Graneek and Evan's formula that R is equal to 1.10 minus 2 into d 2 by d 1 square into x, this is in the linear range of operation, so this is equation one.

Now, here this is very important that we know this formula, we have to measure x. And this we have used this formula provided by Graneek and Evan's and we know the typical range of R, that we know the minimum and maximum value of R. So, if we try to write the x that is what we would like to measure for this problem is, so this is another form of equation 1, I mean just you have written what is the value of x in terms of R d 1 square by d 2 and R.

Now, from this equation, if I write this equation is 2 from this equation it is clear that so from equation 2, it is clear that if R because the value of R which varies from 0.9 to 0.4 that is we have discussed while discuss about the operational principle of this gauge. Now, if we look at the equation 2 we can see for x will be maximum, if R is minimum and vice versa. So, x increases with R decreases, so if R decreases, x will increase and vice versa.

So, we can write x max that is 0.55 d 1 square by d 2 minus half, d 1 square by d 2 into 0.4 because we will get the maximum value of x when R is minimum. So, it will give us 0.35 d 1 square by d 2, and x minimum is equal to 0.55 d 1 square by d 2 minus half d 1 square by d 2 into 0.9, that will give us 0.10 d 1 square by d 2. So, these 2 values, I means these two values of x that is x max and x min we have obtained because the typical value of R which ranges from 0.4 to 0.9. So, considering the minimum and maximum value of R we can calculate the maximum and minimum value of the x.

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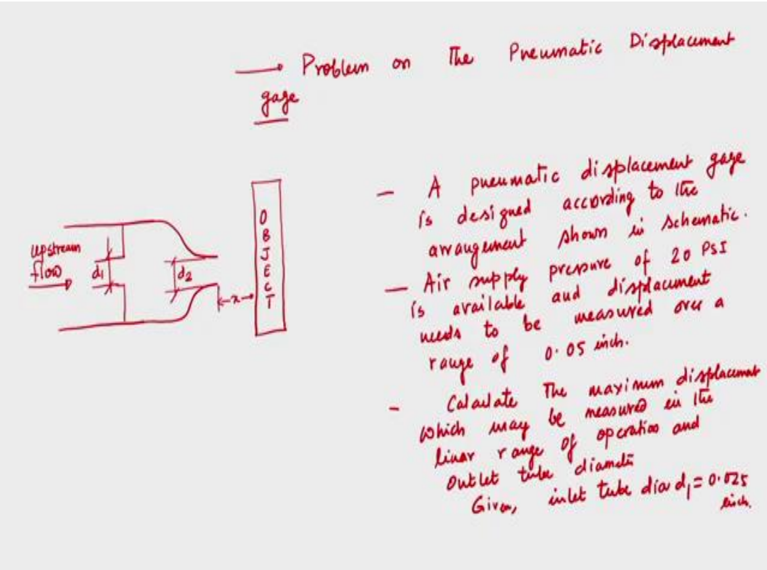

Now, if we go back to the problem statement, then we have to calculate the maximum displacement which will be measured in the linear range of operation, linear range of operation that is the formula given by Graneek and Evan's and we have to rely on the value of R that is reported that the value of R typically varies from 0.4 to 0.9 with its maximum value of 0.9 and minimum value 0.4.

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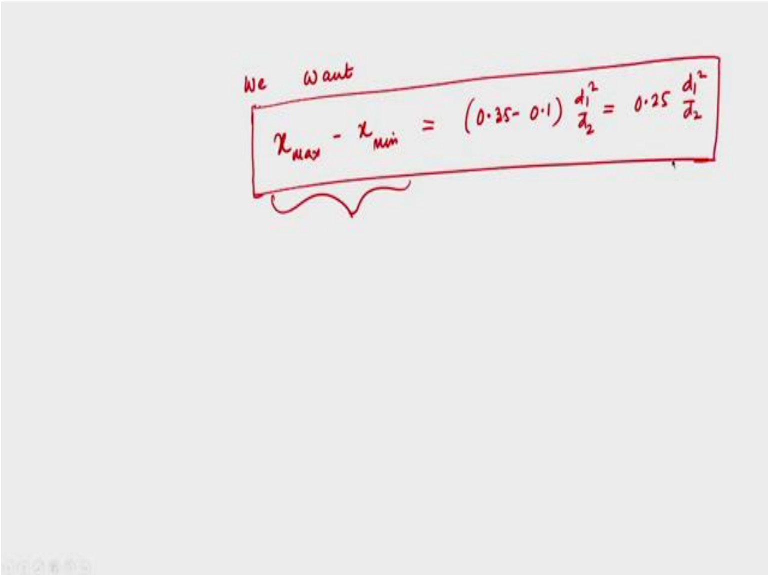

Now, that x max minus x min that is we want, so we want x max minus x min, right, that is nothing but you know 0.35 minus 0.1, d 1 square by d 2 that 0.25 d 1 square by d 2, so this is what we have obtained. Now, this x max minus x min.

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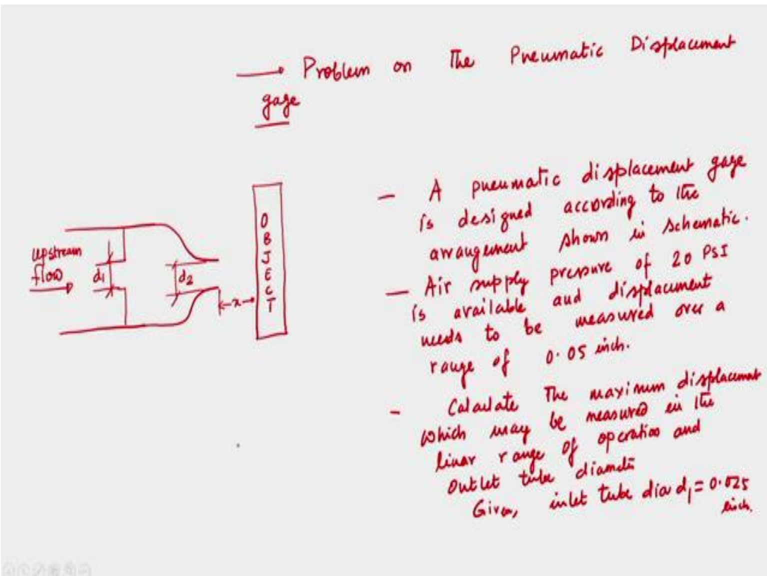

If we go back that available and displacement needs to be measurable range of 0.05 inch. So, that we have the range is 0.05 is that is what is given that air supply pressure of 20 psi is available and displacement needs to be measured over a range of this.

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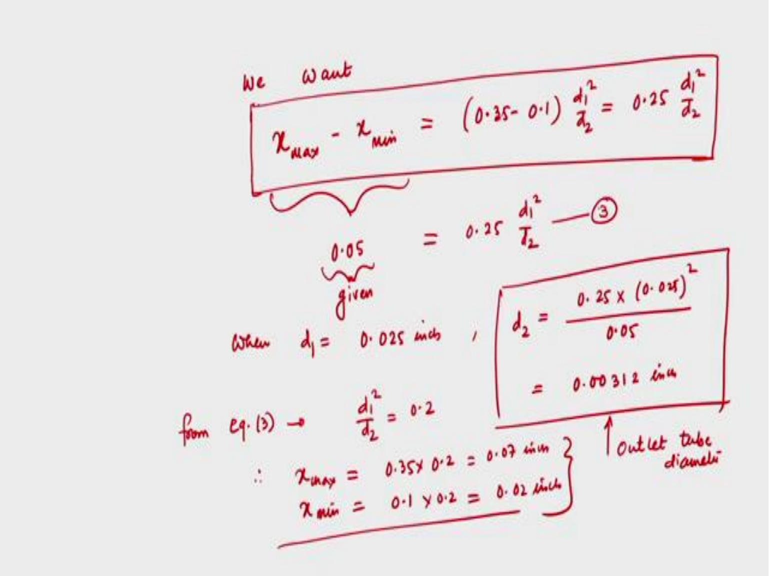

So, this x max minus x min that is 0.05 it is given and that is 0.25 d 1 square by d 2. Now, when d 1 is given that is 0.025 inch, then d 2 will be 0.25 into 0.025 square divided by 0.05 that is 0.00312 inch. So, this is the out that is what our objective was that the outlet tube diameter, so this is outlet tube diameter. And if I use either x max or x minimum that is rather if I say this equation is 3, so from equation 3, we can write d 1 square by d 2 is equal to 0.2 and therefore, x max will be, so we can get d 1 square by d 2 from this that is 0.2.

Now, what will be x max? X max will be 0.35 into 0.2 and x min will be 0.1 into 0.2 that is 0.07 inch and this is 0.02 inch. So, that is the maximum displacement which may be measured is the 0.07 inch and minimum is the 0.02. So, within this range that is 0.05 inch can be measured, I mean the displacement needs to be measured within the range of 0.05 inch.

So, we have seen that this displacement is, this gauge is used to measure a very small displacement and of course, in the linear reason and we have used the formula proposed by Graneek and Evan's that is what we have discussed in details while we have elaborated the operational principle of this device.

Now, to summarize, today we have discussed about the operational principle of another kind of the pressure measurement gauge is the that is the Ionization gauge and we have seen that the ionization gauge is used to measure a low pressure and that essentially depends upon the number of molecules present in the chamber and their molecular collision.

So, and we have seen that the measured pressure can be expressed in terms of the ratio of two current that is the plate current and grid current, and we have seen how the plate current and grid current is induced in the circuit and the induction of those currents are essentially depend on the number of gas molecules rather the pressure which is there in the chamber.

And, of course, using empirical relation that is very important to know the proportionality constant that is called as the sensitivity of the gauge, we have seen how we can measure and this is used to measure very low pressure. And finally, we have solved one example to see that how we can you know the maximum distance which can be measured using the pneumatic displacement gauge, the theory part of that gauge we have discussed in one of my previous lectures.

So with this discussion, I stop here today, and we will continue our discussion in the next class and we will discuss about the, we will discuss about another technique of measuring pressure using probe. Not only pressure, we will see that if we use probe, we can measure different several flow parameters. And we will see the operational principle and the constructional figure and that we will discuss in the next class. Thank you very much.