Technology of Surface Coating
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Lecture-33
Measurement of Low Pressure and Gas Flow in Coating Deposition System

Measurement of low pressure and gas flow in coating deposition system, today we shall discuss this topic. Now we must find out the significance of pressure measurement during this coating deposition, point number 1 is that before conducting this deposition the chamber I mean that deposition chamber in most of the cases needs to be pre-evacuated down to 10 to the power – 4 to 5 Torr or even better to remove the traces of oxygen and other contaminating material to have effective deposition.

And during the deposition what is important to monitor and to measure the pressure and to have a proper control on this pressure because in the outcome of the quality of coating it is observed that this pressure has a very significant influence on the quality of coating, mostly it is the structure of the coating then the density of the coating, porosity and in certain cases also the growth rate, sometimes it is also seen that the composition of the coating is also altered by this pressure. So in summary what we can say that during this deposition the pressure has to be monitored and before start of the coating process in many cases it has to be evacuated to a very low value of pressure that means a very high vacuum.

Now here it is important to know how to have full assessment of this process that means measurement of the low-pressure that means evacuation of the system how effective the pumping system is and how quickly it can pump down to that low-pressure and for that we need some sensing element to measure that low-pressure. And also during the deposition when the pressure is relatively high that monitoring is also necessary and in many PVD system what we have one of roughing line and one is the backing line that means roughing evacuation to a very not to a very low value and followed by which is further refined that means evacuation is carried out down to a very low value of pressure. So in both the cases we need a sensing element for measurement and control of both this of the pressure.

Now here what we can see that measurement of the pressure it can be done by direct measurement or by indirect measurement. Direct measurement what we mean that in this case the deflection of any mechanical part component can be translated into the difference I mean the fall of the pressure or the change of the pressure. What we mean here because of the change of pressure in the system there will be some mechanical displacement or deformation of any mechanical element and that can show that fall of pressure or change of the pressure and this is what we mean direct measurement.

And there is some indirect measurement which we shall cover that means because of the change of the pressure some other characteristics of the gaseous elements which is present it changes its characteristics and which is a true reflection of this change of the pressure and thereby this indirect measurement can also be true representative of this change of the pressure. Now here we see that the very basic and very fundamental Bourdon vacuum gauge and schematically we can show this thing, this is nothing but a tube a circular tube which is originally circular but it is made something like an elliptical tube in this shape an elliptical tube and this tube changes its shape and dimensions when some change in pressure occurs within this tube, it can be fall of pressure or it can be rise of pressure.

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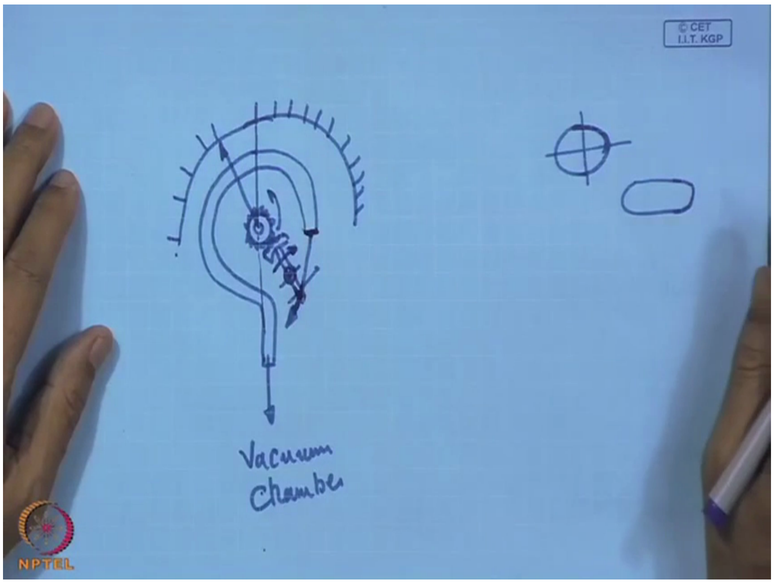

Now it is basically an elliptical tube and we shall see how does it work and when this elliptical tube is submitted to high-pressure then this dimensions changes and it becomes more circular in nature that means this major axis and minor axis that difference will be further narrowed, however when it is subjected to high vacuum then to will be flattened and this elliptical shape will change more or less of this shape and then also we have some change in the dimensions so this ellipse will either move towards more of a circular form or it will get the shape of a flattened shape, flattened shape what I mean and in that case also there will be some change in dimension.

And what exactly it means we can see quickly here schematically this is a tube and let us draw this tube like this and it is of almost 270 degree bent so this is the tube and at the end what we have? Centrally we have one needle and this needle is actually fixed with one pinion which is nothing but a tooth wheel and here we have the pointer and it can work over a scale work over a scale and this will be in meshed with one sector gear like this which is having also teeth and there will be have one extension of this lever and here we have pivot. So what happens, as it moves on this side, this sector which is pivoted at this point then this sector tooth sector will move this thing and then this pointer will move about this axis and here if we have the graduation it can show the pressure, so it is the graduation.

Now what happens, this is actually this is connected to the vacuum to the chamber to vacuum chamber. And this side which is actually soldered and here we have a rigid link so this is a rigid link, this side is closed so the tube is open only onto this vacuum chamber. Now what happens, as we evacuate the whole system which is on this side then this tube will get flattened from this elliptical shape it will get flattened and then it will bend more towards the centre, it will not open up.

When it is high-pressure then it will open up but now it will bent about towards this side and as a result of this will move, this will push this thing on this direction so this is actually moving in this direction and as a result of this sector gear which is pivoted at this point, this end will be pushed on this side because of this bending of this tube and then the sector will have a rotation and this rotation will be transmitted to this pinion which is actually rigidly holding that pointer and this pointer will move this way and that will show the fall of pressure. And when we increase the pressure then it will move this way and then this tube will try to open up with high-pressure and because of the high-pressure this link will be driven on this side and then this will move like this and as a result of that this will simply indicate high-pressure.

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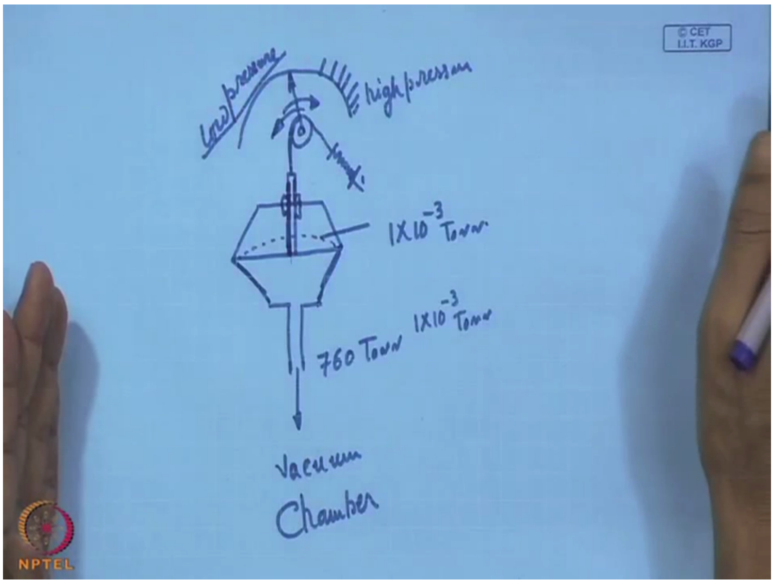

So this Bourdon vacuum gauge basically it is used for a comparison and quick assessment of the pressure and that can be sometimes quite convenient to work with. Now this principle of mechanical measurement of the pressure by direct coupling of this mechanical system with the vacuum chamber that can be further extended in the form of a vacuum diaphragm gauge, so it is actually a diaphragm gauge and in the diaphragm gauge what we have, we have actually a chamber like this so the chamber is actually divided into 2 compartments and this side is connected to the vacuum system that means which is the coating system so this side actually it is vacuum chamber. And the construction is such that this side is actually pre-evacuated, during the construction of the gauge this is actually evacuated to 10 to the power – 3 Torr.

And here what we have? We have here a shaft which is actually fixed to this diaphragm and here we have the Bellow so it is flexible and on this top of that what we have? We have a string, we have a string and then this string passes over a pulley and then this is actually the tension with the help of a spring. Now this pulley will move up and down depending upon the pressure what is prevailing in this vacuum chamber. Now if it is 10 to the power – 3 when it is high-pressure, suppose now the vacuum chamber is filled with air, in that case this will be 760 Torr which is higher than 1 – 10 to the power – 3 Torr so naturally that diaphragm will have a tendency to move in this way and this way the whole shaft this string and the pulley will move and that if we have a pointer then this pointer will move on this on a scale and this side movement on towards the right mean high-pressure.

However, when we evacuate the system I mean down to about 10 to the power – 3 Torr and this is actually a gauge which is actually used for measurement of low vacuum low vacuum that means low pressure I mean not too high vacuum of the order of 1 into 10 to the power 3 torr. In that case what is going to happen, when we evacuate the system, this diaphragm which is already bent that will try to restore to its original position so that means the whole thing will move in the downward direction so that the string will be pulled and it will be under tension so as a result of that this pulley will move because the string is passing over this pulley and that is why this gauge will move and the pointer will move in this direction which also in the case low pressure.

So these Bourdon tube which is a deformation of the ellipse Elliptical tube which becomes more and more flat that can be also used for measurement of the pressure or here it is the diaphragm gauge diaphragm gauge which can be also used for measurement of the pressure and however it can be noted that this pressure is only limited to 1 into 10 to the power – 3 Torr. Now this can be further extend, here what we measure? We measure the mechanical displacement of some of the mechanical element and in this case elements is a diaphragm, shaft, the string, the pulley and the pointer but this can be also a little bit modified and that can be converted into a capacitance gauge.

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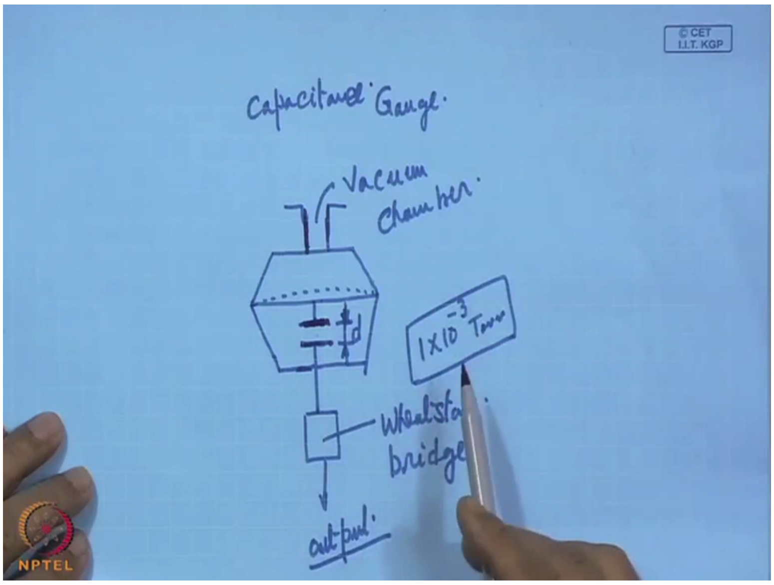

So it will be more or less similar to this one with little modification that means in this case what we have, here we have? Here we have one capacitor, one plate of the capacitor and this side what we have this is going to be actually this is another plate so this is another plate and which is fixed on this side so these are the 2, this is one plate and this is another plate of the capacitor and on this side we have the this Wheatstone bridge, Wheatstone bridge for the capacitor and this side actually it is connected to the vacuum chamber.

So what happens, during evacuation this diaphragm will change its shape or position when it is evacuated so depending upon the rise of pressure or a fall of pressure what is going to happen this diaphragm will change its position and since this plate of the capacitor the upper plate of the capacitor it is rigidly connected with this diaphragm so naturally this gas this space between the plates that will keep on changing and that will change the capacitance of this capacitor and on a Wheatstone which one of the earn if this becomes the capacitor then its capacitance will change and that will generate 1 error voltage and this Wheatstone bridge will give some output and this output will be will have a relationship with this pressure which will be prevailing in the vacuum chamber.

So this side is the vacuum chamber evacuation of the chamber or backfilling with the chamber so as a result the change in dimensions and position of this diaphragm and this diaphragm is rigidly holding this plate, so this plate will change its position but this is rigidly held. And as a result of this, this displacement of the capacitor capacitance plate that is actually converted into capacitance and it is an indirect measurement and this is not a direct measurement what we have described in this diaphragm gauge.

So this capacitance gauge is also used in the order of 10 to the power – 3 Torr and since it generates one electrical signal, this can be also used for feeding this error signal to the downstream side of a evacuation chamber or during the deposition to monitor the opening of the valve which is controlling the pressure that means what I mean that if I have a preset value and if there be any deviation of this value and that will be recorded here and that error signal will be fed, this output will be fed to the motor driving this throttle valve, it is actually setting the position of the throttle valve and that throttle valve have will have its particular position to restore the pressure.

So this kind of capacitive gauge will be essential for control of the pressure particular value or setting any value it is very convenient way of handling this kind of particular problem. So this is actually the type of gauge where we use mostly use the displacement or say that deformation of one of the mechanical element for measurement of the pressure and this is the pressure within the coating chamber. However we can have also, so diaphragm gauge capacitance gauge that we have mentioned here and now comes thermal conductivity gauge this is also used in the range of say 760 that means Torr, 760 Torr or 1000 Milibar 1000

Milibar so from these 2, 1 into 10 to the power – 3 Torr so that is the pressure range within which this thermal conductivity gauge can work.

Now the basic idea here is that this thermal conductivity of a gas does not affect is not affected by the pressure when it is obtained or it is also in the theory but when it is below this pressure then its thermal conductivity I means thermal conductivity is affected by the pressure that means the change in pressure can have a direct affect on this thermal conductivity of the gas and accordingly this heating or cooling effect will be affected and this is kind of indirect measurement. Actually the heat loss of a heating element when the heating element is hot and because of some conductivity of the medium some heat will be taken away and in this case the heating element is put inside the gauge and this when it is replaced we can illustrate here.

And this is centrally placed and when it is hot, these gas molecules can take away the heat just by conduction and when it heats the valve of the gauge then this heat is transferred on this valve. Now the number of molecules available within the gauge that also depends upon the pressure, lower the pressure less number of molecules available for this heat conduction, higher the pressure more number of molecules available so cooling that means heat conduction is more, and less the pressure heat conduction is less.

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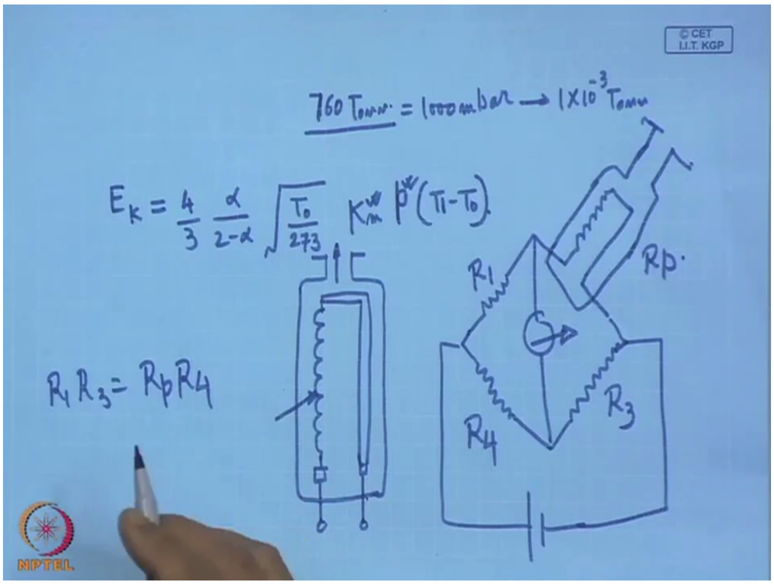

And so there is one equation and what can be written as E k that means the heat loss due to this conductivity it is given by alpha by 2 – alpha root over T 0 by 273 into so here we find that this is called accommodation coefficient, this is the molecular thermal conductivity, prevailing pressure, this is the temperature and this is the room temperature and here what we find that lower the thermal conductivity molecular thermal conductivity less will be the heat conducted by the gas. Now this guiding equation is will utilised in construction of a gauge which is based on this thermal conductivity principle and one of such is the Pirani gauge.

And in this Pirani gauge what we see that it is basically a heating coil and this is supported on a stand and this is 1-2 terminal and the whole thing is encased in a container and this side is the opening and so this side can be connected with one port of this vacuum chamber so this side will be connected to this vacuum chamber. So basically here we have one heating coil and this may be made of say for example tungsten and this side is a metal support so these are the 2 terminals.

Now what is what is added to this, and it is basically a Wheatstone bridge so this is one resistance and then what we have this one, this one should be placed like this so this constitutes one arm of this Wheatstone bridge and then we have another arm and that is the closing arm so here we have this is say resistance R 1 and this is going to be the resistance like this which is connected to this vacuum chamber. So this is vacuum chamber so this is R p say for example and this is R 3 and R 4. Now and here what we have additionally this is input to this bridge and that is going to be the output of the bridge and we are interested in this, what is the output of this which because of this change of pressure.

Now what what is going to happen, we can write further to this that in the null condition, R 1, R 3 = R p into R 4, now so long there is a balance, there will be no signal and now this R p is going to change and how it is going to change because of this conductivity fall of the conductivity because of the change in pressure what is going to happen the temperature will rise here and this rise of temperature will cause a rise in the resistance and this resistance will be the value will be disturbed and it will be different from the resistance what is actually prevailing during this null condition.

So as a result of that we can have output so that means basically the resistance of this arm is changing because for a constant heat for a constant heat the resistance of this one will keep on changing because of the lowering of the pressure and lowering of the thermal conductivity. And as a result what we get, we get one output that means this can be illustrated conveniently in a graph, so say this is actually this meter reading, this is the meter reading and with this meter reading that is the output and because of the change of pressure and this change of pressure, say this is the pressure and this is the meter reading.

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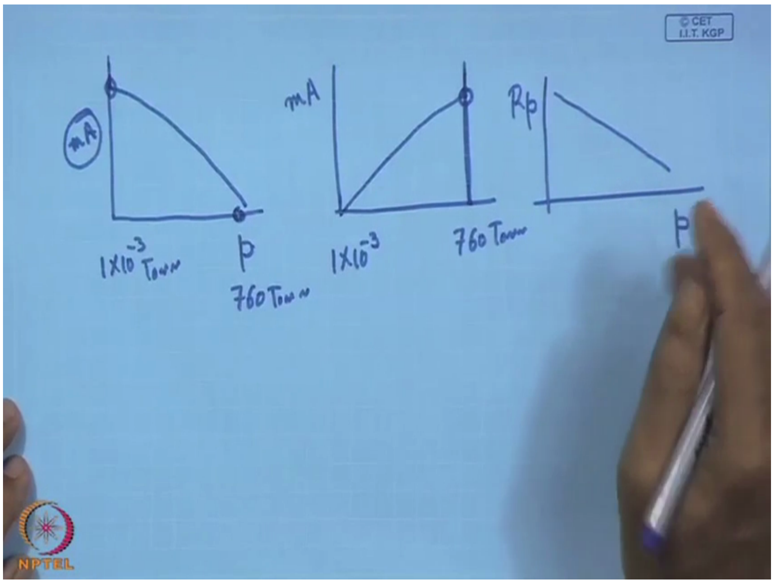

Say this is milliampere so what is what we see, because of the fall of pressure there is strange resistance so what we can have so this bridge may be balanced in the atmospheric pressure, this is 760 Torr so at the 760 Torr it is balanced so signal is 0 and when it is about 10 to the power – 3 Torr that is the limit and here we have a full-scale reading, so this is the full-scale reading so the graph may be like this and that is the milliampere output from this this one which we can see again so this is actually the output of the bridge so this is the milliampere and this milliampere is shown here with one with this or it can be other way we can do that is as a second option that this milliampere reading from this galvanometer.

So bridge can be balanced and 1 into 10 to the power – 3 Torr and it can have a full-scale reading here so at 760 also we can have such highest possible signal so this way also we can see. In fact the resistance R p of this gauge Pirani gauge that increases with pressure because of the simple reason that here cooling effect is less so resistance will be heated and as a result this resistance value is will keep on increasing and that helps in getting this error signal.

So this is one way of measuring indirect measurement of the pressure and that is conveniently used as a routine thing in any vacuum system for roughening roughing the vacuum that means after loading the chamber, the pressure inside the chamber is at 760 1 atmosphere and when we run this vane pump or roughing pump so it is actually from 760 to a pressure say 1 into 10 to the power – 2 and 1 into 10 to the power – 3 in between we can reasonably attain the pressure and there this pressure is actually resisted by this milliampere reading on the meter, so this way also we can have a thermocouple gauge, it is also the principle basic principle is same.

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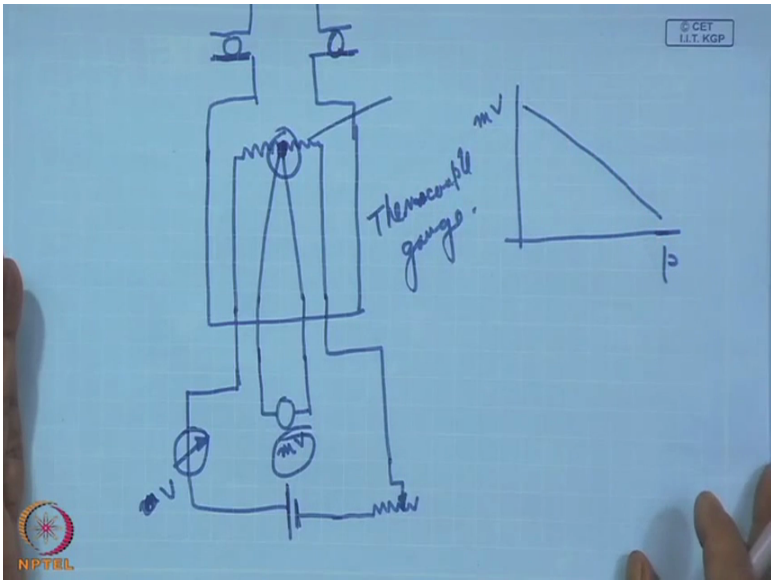

So here we have one thermocouple, one heating coil and this heating coil is actually there is a power supply and centrally what we have a thermocouple at the exactly at the midsection so this thermocouple has 2 terminals in fact, what we have here this is the casing and here this is the opening so this side it can be conveniently connected to this vacuum chamber with this flanges and here we have 4 terminals and this terminal will be the power supply terminal so here what we can do? We can change the power supply and here perhaps we have 1 meter and this is this is millivolts, so this is volt and here what we can see that will be the reading because of this thermocouple and that may be millivolts thermal EMF which can be generated.

So basically it is a heating coil which will be heated and it we give here a fixed power so this is actually thermocouple gauge and this is the thermocouple and here we have a millivolts to to record the thermal EMF now with a constant heating here with a constant heating. And because of the evacuation change in pressure, naturally the heating effect will be more because it will be more hot, if we have more of then the temperature will fall so depending upon the temperature the EMF will be recorded and this will be a true reflection of the pressure which will be on this side on this side so that is actually the vacuum chamber so this way also we can have such kind of calculation and this way we can see that this millivolts and this pressure.

So as the pressure is reduced as the pressure is reduced, we can see more of this millivolts because the loss of pressure I mean fall of pressure means higher the nature there will be this junction will record higher EMF and that will be record so it needs calibration so pressure and millivolts rating that can be conveniently used for indirect measurement of this kind of thing and this can be well used for measurement of pressure in the range of say from 760 Torr to 1 into 10 to the power – 3 Torr so this is thermocouple gauge what we have mentioned.

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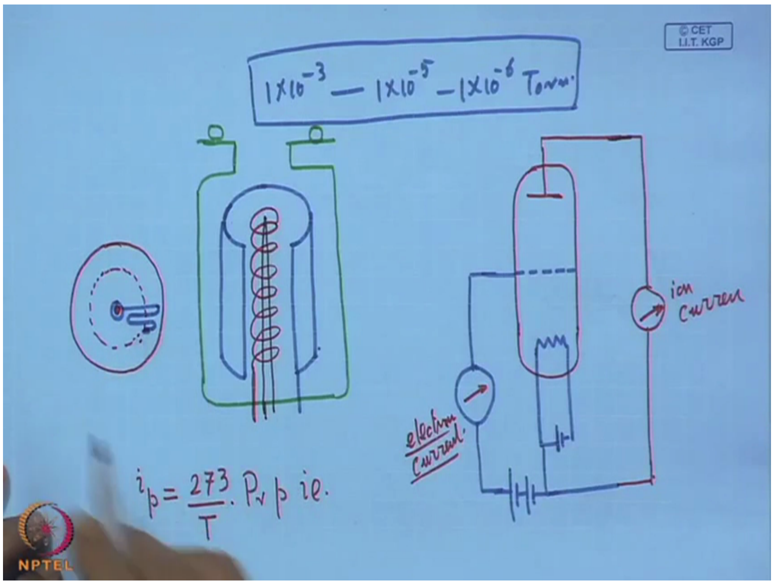

And now comes ionization gauge and this ionization gauge are used particularly for a pressure of say 1 to 10 to the power – 3 broadly to say 1 into 10 to the power – 5 or 1 into 10 to the power – 6 or where most of the I vacuum system or putting the position system for this mechanical application or wire resistance coating, thermal barrier coating though it is deposited and it is the zone where normally the preparation work and the conduction of the coating process is done. So this is the pressure and here what we find that to record the pressure that means evacuation of the system to this pressure we must need a very reliable system and for that what we have?

We have here this ionisation gauge where this ion current ion current versus the residual pressure that will be recorded and that will be reliably used as a measure of pressure. That means inside the gauge what we have in principle, we have one cathode and Anode and this will be used for ionisation of the residual gas and this ion current will be resisted and this ion current will be reflection of the residual pressure, let us have a quick look how does it work. So basically here what we have, let us have a cross-sectional view this... so this is just like an envelope and what we have here?

We have one we have one spiral so this has one terminal, this one 2 and what we have in additionally here one electron emitter, so this is the electron emitter so here we have 4 terminals and the whole thing is put inside a casing. So this is the casing and outside what we have so this is so this side goes to this, this is the flange and this side goes with this O-ring it goes to the chamber. Now what happens, we can also have another diagram for understanding and this is like this here this is the casing and then this is a plate what we call as an ion collector so this plate is the ion collector and so this plate is shown by this blue line and in the central position what we have this one, which we have drawn in the form of helix it is something like this in between and this is actually the electron collector.

So this helix spiral this shape that is the electron collector and this is the ion collector and this black one that is actually the electron emitter. So it is some sort of this thing and here what we have, here we have a meter. In fact this is also here we can see that this i p we can write it just like 273 by T into P r into p into i e that means this is one equation which correlates the ion current with electron current and that is the inside pressure that is the temperature and this one is ionisation probability and with this in this principle this instrument works. So what happens? This is electron emitter and with this residual gas so this is actually ion current and this is electron current, ion current and electron current and what we what we see here that as this electron emits, it will be moved towards this positively biased collector which is in the form of helix.

But if it does not, it is like a ring if it misses if it is not collected then it will towards this side which is negatively biased but it will be repelled so unless it is collected by this grid which is in the form of a helix, it will have oscillating motion in between and this oscillation we can also show this way so this is the and here we what we have electron collector and from here it is emitted and if it is not collected here, it will move like it will go to this side which is negatively which is negatively biased that means this is actually the ion collector so it will ripple and it will move like this and this way. So this way it will have an oscillation and finally it will be collected by this electron collector which is positive so this is electron emitter and that is ion collector and this is electron collector.

So if electron collector fails to collect, this electron will keep on singing and it is having an oscillation, the advantage here is that this oscillation will actually facilitate collusion more collusion with the neutrals and breaking up one positively charged ions and this positively charged ion release of this ion and collection of this ion that will be indicated by this meter and that is actually the measure of this ion current and this is connected with the pressure and as a result of this we can see that this pressure and this ion current they are correlated, however this is hot cathode ionisation gauge.

Though it is working and it can be used, one disadvantage of this one is that in the in the residual gas if we have something strong contaminant or some reactive gas that can also chemically damage or attack this filament and life of the filament will get shortened, so that is why this hot cathode ionisation gauge is replaced by 1 what is called Cold cathode ionisation gauge. So this cold cathode ionisation we do not have any heater but there is one cathode plate, we have in fact so this is actually hot cathode ionisation gauge but now we have cold cathode ionisation.

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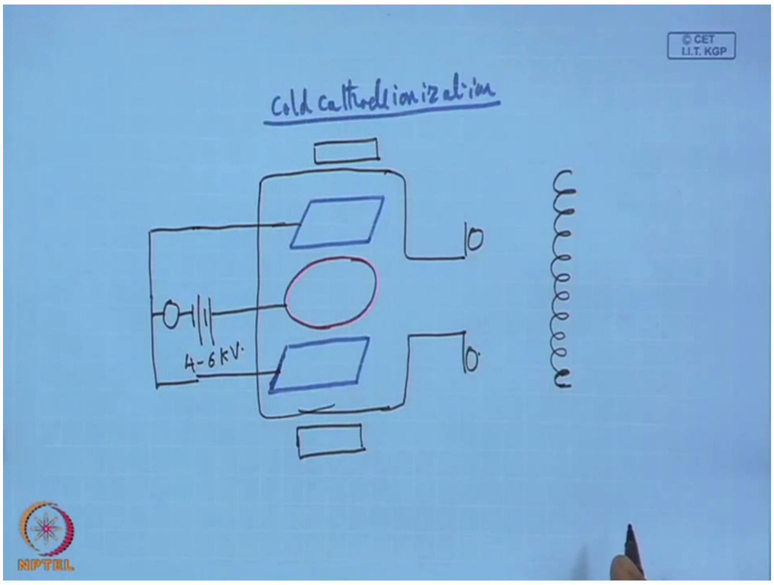

So with this cold cathode ionisation what we see, we have in fact 2 plates, these are the 2 plates, these are the twin cathode and centrally located one ring and what we have further to this, this is the opening of this gauge so we have a connection like this, so this should be positively connected and here the field is about 4 to 6 kilovolt very high voltage and with that we can have extraction of this electrons from this cathode surface and this will keep on singing in between and finally it will ionise unless it is trapped by this ring like a ring anode and it will keep on swinging and this oscillation may lead to facilitate that splitting having a collision with the neutral and to augment this process what we have here the magnets.

Two magnets are placed and there we have the lines of force and we have both electric field and the magnetic field and as a result of this the trajectory of the electron will be like a helical path and with this helix it will have an oscillation movement. So by this we are increasing the chance of probability or increasing the probability of collision of these electrons with this neutral and thereby making this gauge us more affective by this augmentation with the magnetic film. So this way this cold cathode ionisation is for is used and this is actually known as Penning gauge, this is used for measurement of the pressure in the order of 1 into 10 to the power – 5 to – 6 and by this ionisation current and this ionisation current is a reflection of the residual pressure.

However, it may so happened that if we activate the gauge when the pressure is spelling in that case activation of the gauge may be little difficult so in that case what we have one auxiliary emitter of electron which is activated to release additional electrons and one these electrons ar I mean in action then this auxiliary emitter is switched off and this is actually trigger ionisation gauge so that is the triggering of this emitter which supplies additional electrons at the moment when it is needed. And this may be useful when we like to switch on this case at the moment when the pressure is already very low.

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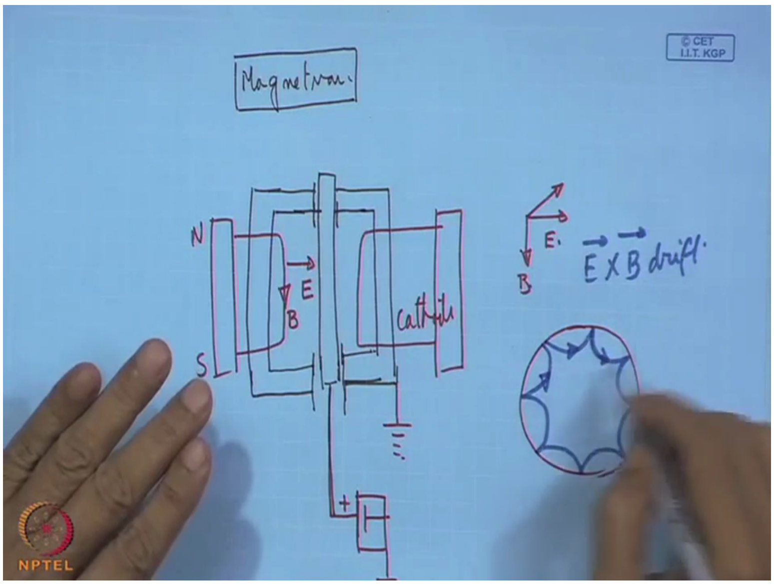

Now we have another called this is inverted magnetron gauge, magnetron so here we also use one magnetron to augment this process of ionisation and to make this change very very effective during the working. That means here we have one central anode and then we have one annular cathode and we have also one auxiliary cathode so these are the 2 cathodes so this is this is connected to positive and this is to this is this is actually grounded so this side is positive so it is a power supply and this side is grounded and this is this cathode is actually grounded.

So here what we see that this anode plate that is positively biased and this cathode which is an annular having an annular shape so this is grounded. And what we have in addition to this, we have the magnets and with these magnets what we have here we have the magnets so naturally this is North-South so with this magnate we have lines of force, so we have lines of force which is closing itself so this is the lines of force and here we have one electric field so this is magnetic lines of force, this is the electric field and with this E-B we have a drift motion like this so this is E-B drift and as a result result and if we see from the top so thereby what we can see if it is the cathode on this cathode surface what we can see.

We can have the trajectory of the electron which will move like this that means basically the whole idea of this using the magnetron is to augment this ionisation efficiency that means efficiency of this electron to make more ionisation willing full ionisation that made this electron becomes more and more efficient and when they are confined and localised and locked in a particular orbit and this is already a drift motion and this electron will have one orbiting motion and further to this because of this electron this E and B that means this electric field and the magnetic field because of this E-B drift we have a drift motion so it is clockwise so naturally they will go his way. So along with this circular motion it has a cycloid motion that means its path is longer and give electrons are more efficient, in that it has a longer path and in this longer part it has a fair chance of heating 1 neutral and ionising one neutral even with low pressure.

So with this magnetron this is called inverted magnetron because of the reason that here this is actually positively polarised and cathode is grounded and this inverted magnetron type gauge is also used for very low pressure measurement. Now comes so inverted magnetron gauge that we have mentioned, now comes this Flow measurement. In fact in coating deposition we have 2 process parameter, basically the pressure of the gas partial pressure of each gas and the total pressure both are important in monitoring or in monitoring the quality of the coating composition of the coating, structure of the coating, stoichiometric of the coating and also the amount of Guess which is flowing per unit time that is also useful in that that growth rate of the coating then that above the number of parts which can be deposited which can be coated that also decides what should be the flow rate and the flow ratio.

So the individual flow rate and the flow ratio all are important particularly in all PVD, CVD coating that individual flow ratio, individual flow rate and the relative flow ratio all are important and in this case this measurement of flow and setting the value of flow is becoming also equally important. So it is called a rotameter, rotameter actually flow measurement fluid flow measurement or gas flow measurement we have various meters say orifice meter, venturing meter, something like that, here what we see it is called a Variable area meter.

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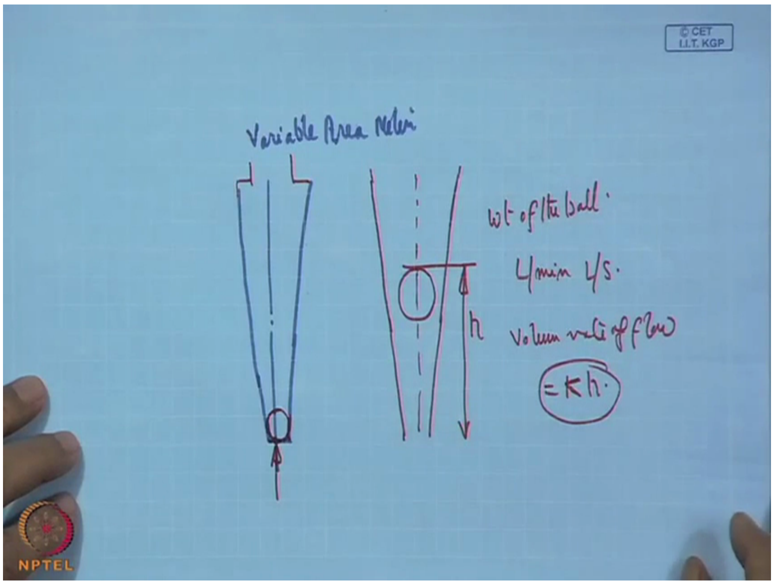

So it is a tube, it is a tube it is a tube and this is a tapered tube, this is a tapered tube and here this is the input, this is the inlet and that is the actually outlet so what happens we have a ball and the ball diameter it is a floating ball, ball diameter matches with the inlet diameter. Now what happens, during the flow because of the drag force and buoyant force this ball will be floating say here and we have a scale so this height can be measured so on one side we have weight of the ball and on the other side we have this buoyant force and the drag force because of this movement of this gas and both are balancing each other and this volume rate of flow which can be litre per minute or little per second and that should be proportional so this volume rate of flow rate of flow that is actually constant into height and that is the principle of measurement.

So this ball has a weight, this is calibrated and depending upon the height which is calibrated in litre per minute and under a particular pressure this ball position shows directly the reading. Now to increase the range of working we can have 3 balls for example, one made of Pyrex, the 2nd one made of stainless steel, we can still use one heavy ball made of tantalum, so having 3 balls here we can use one which goes to the other side of the scale but then the heavy ball may can may occupy an intermediate position so in that in that case this heavy ball or which is the stainless steel I mean the density wise it is in between the Pyrex and the tantalum those can be conveniently used to measure the flow rate.

And this is actually rotameter and since it is also keep on rotating because of the gas flow so this is that is why it is called the rotameter. So it is basically a float which will flow keep on floating under the action of the viscous low and the buoyant force and the weight and accordingly this annular passage will keep on increasing and the flow rate will keep on increasing. Now comes the mass flow controller, so this is actually the mass flow controller which controls the amount of mass which is admitted.

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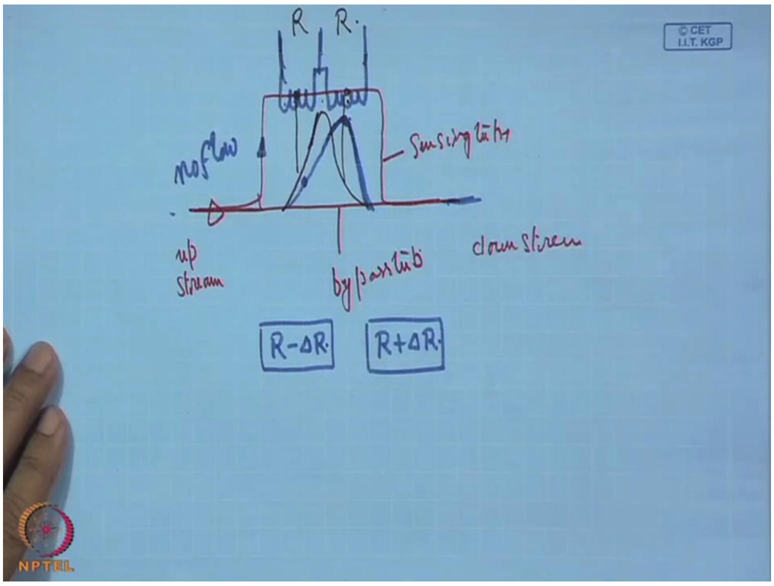

Basically here what we have, the construction is like this, this is a tube inlet upstream and this is downstream so this is actually called sensing tube, this is sensing tube and this is bypass tube, so what we have reasonably here 2 coils heating coils, it is actually like the resistance thermometer coil so these are constitutes two arms of a Wheatstone bridge. Now what happens, it is actually the heat capacity of the gas that is utilised to record and to measure the flow rate so the arrangement is such that the sensing the flow through the sensing line is proportional to the total flow the way it is designed, the bypass line and the sensing lines are designed in such a manner that the total flow rate is proportional to the flow which is channelized to this sensing tube.

Now what happens, when there is no flow when there is no flow these are all heated now when there is no flow okay when there is no flow what happens we have a temperature profile which is something of this sort so here mean value of the temperature in the zone and in this zone they are more or less same and these 2 being the 2 arm of the Wheatstone bridge they are resistance are R and R when there is no flow, however when the flow is on switched ON what is going to happen that because of this heat capacity that it will be transported that means in this case the heat will be taken by the flowing gas from this heating element and that will be delivered on this side. So that means in this case when the flow is on this temperature profile will change its location and it will go more will be shifted towards this downstream side.

And when they switch is shown by black that is no more in existence and it is more of a blue in that case what we find the mean temperature here is here is low and on this side wheat is high so naturally what is going to happen, here we have because of the change in temperature we have some change in resistance which will be which will be shifted little offset from this null condition so this change of resistance will be less so that means it is – Delta R and since heat is transported heat is taken away and added on this side, we have a resistance which will be increased by Delta R so this way what we can see that this – Delta R and + Delta R in the Wheatstone bridge arm there is a of misbalance.

So there is a misbalance and as a result of that what we see that this does not there is a signal and with this signal we can reasonably measure this particular flow during this process so it is actually change of resistance and by this we can have a signal and which can be utilised for this measurement of the flow and this way we can have a further understanding of both of pressure measurement device both for low pressure and high pressure, low vacuum and high vacuum and also the flow measurement.