Principles and Practices of Process Equipment and Plant Design
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Module - 04
Lecture - 59
Process Instrumentation and Control

Hello wishing you all a very good day. Today we continue our module 4 and we will be talking about basics of Process Instrumentation and Control which is required to be known by the process designer.

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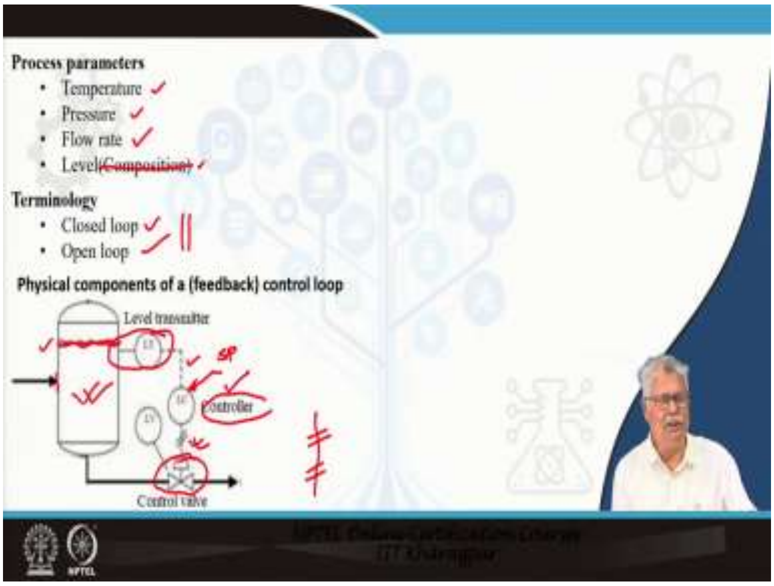

To start with, if we look at the process parameters it is very interesting that there are only four basic parameters which are involved in process control. The first is temperature, second is pressure, the third is a flow rate and fourth is a level and also composition. So, composition comes I have struck it off, but it comes at times in terms of other measurements, but it is not a very common one.

We get familiarized with two terminologies often we say its a closed loop and when we see that say that it is a closed loop what we mean is it is a closed feedback loop; that means, it is a feedback control system and it has got a controller in it. And at times you will be listening if you go to the industry people say there are 49 closed loops and about 72 open loops, the open loops do not have any controller in fact you should not control.

Say that it is a loop it is just an indication of the process parameter which is expectedly temperature pressured flow or level in most of the cases and in some cases it could be composition as well. So, you know the difference between the closed loop and the open loop now.

Now, let us look at the physical components of a feedback control loop. Here what we have we have a drum the drum has got a liquid level above that I have the vapor or air whatever it could be and here I have the liquid. So, we have the level of the interface level at this particular location or elevation.

In order to control this level it has to be measured. So, what we have is a sensing arrangement for the level I am just showing this as a sensing level arrangement, but there could be various types of the same thing, but I am not going to details of that. Now, the sensed level has to be transmitted as a signal.

So, this shows the signal which is getting transmitted from the level transmitter who receive the signal it is received by the controller, since this controller is meant for level control it is marked as LC or level controller. Now, what is a action the level controller takes the level controller will definitely be taking an action depends on what is the desired level required which is often called the set point.

So, that is an information which is also there with the controller and it finds that in order to maintain the set point or come to the set point value there should be some change that is required on the process here in this particular case; that means, the outlet flow has to be regulated.

So, it sends a signal where it sends a signal to the control valve. So, this is also a signal and the symbol which is used here a line with some sort of marking like this shows a pneumatic signal. So, it sends the signal to the control valve and the control valve here since it receives a pneumatic signal the control valve is also a pneumatic control valve the symbol shows that and it opens up or closes according to the requirement of changing the level up or down.

So, what are the physical components of a system you have the controller, you have the sensor with the transmitter, you have the final control element and these are the three physical components which will be there in every loop apart from the process itself.

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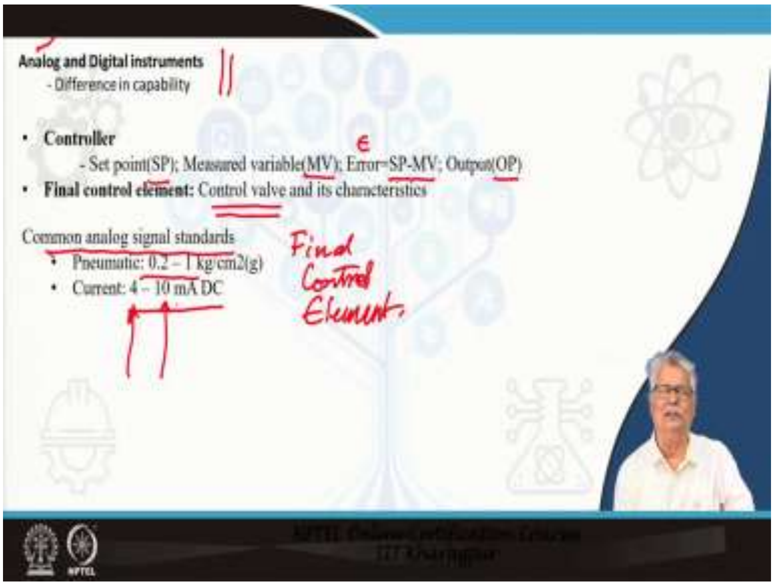

So, we move forward, these instruments particularly the controller and the sensor transmitter could be analog type. What is an analog signal? An analog signal will be taking a it can take a continuous value from its minimum to maximum. Typically, if I talk about a 4 to 20 milliamps analog signal of DC current in that case the current value could be anything between 4 to 20 in case of digital it is not so.

In case of analog signal or analog 4 to 20 milliamps current signal one thing is true; that means, you will be requiring 2 wires which will be running and carrying the current. In case of digital signal the digital instruments will have connectors with it and it will be in terms of certain digital values which will which is also basically pulsed electrical signal which is communicating the information through the wires usually more than 2 or at times 2 even with different type of digital connectors between different instruments.

Now, if I look at the differential capability of the analog and the digital instruments the analog instruments are rather limited, they do not have much of computational capability. They have filters they can filter out noise and similar things can be done, but it cannot do the mathematical manipulations like, making a some sort of a transform taking an inverse of a particular quantity dividing one quantity by the other such things are not possible using the analog directly.

It can be done indirectly using more than one analog instrument of course, but in case of digital instruments naturally you have a much more higher capability of mathematical manipulation of the signals. So, digital instruments in general are more expensive definitely, but they are much more versatile as well. And in fact if you are talking about a digital controller just by changing some settings it you can have it as a P controller as a PI controller or whatever you wish.

Now, when we talked about a controller I mentioned about the set point the controller receive the value from the transmitter which is a measured variable. And by definition set point minus measured variable is the error epsilon. Now, the controller generates based on the error an output. So, this output is the output signal which goes to the control valve.

Now, we have seen the control valve does what in the last example it changes the outflow of liquid from the particular vessel. So, this control valve is a final control element its a final control element. Now, there are different characteristics of the final control of the control valve and interestingly in process control or in processes control valve is the final control element in almost all cases almost all cases.

Here I have an I have listed for you the typical common analog signal standards and this standardization is necessary so that the instruments can be connected entirely; that means, one instrument can talk to the other instrument using the standard analog signals through such physical connections for the pneumatic tubing or through current through a pair of connectors.

And the pneumatic signal standard today is 0.2 to 1 kg per cm square gauge and the current standard is 4 to 10 milliampere DC. We will simply mean here that this corresponds to one extreme value of your variable this corresponds to the other extreme value; that means, if one is minimum the other is the maximum.

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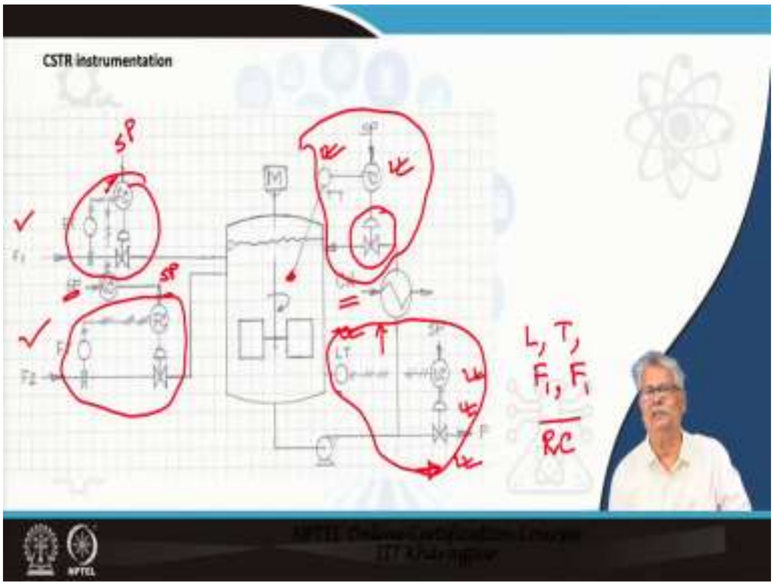

I just look at a typical instrumentation in case of a continuous star tank reactor. The reactor has got 2 feed F1 and F2. The 2 streams enter and you have the starter here and it goes out continuously. In order that you send a particular flow rate to the reactor you have a flow control loop here which is a feedback loop let us look at it.

Here you have an orifice meter with connected with a flow transmitter sending the signal to your flow controller. The flow controller here it is the controller again sends out a signal to the control valve and regulates the opening of the control valve so that this flow is maintained, exactly the same loop arrangement is there in this case also.

You have here one more additional para one more additional feature, here you have a ratio controller. In this ratio controller what happens it no knows or it gets the flow which is occurring here computes the other flow and sets the set point of this. So, this is the set point for F1 and this is a set point of F2 with a set by the setting of the ratio controller whose set point is this SP.

Now, there is something else beyond this you will find here that the liquid which is coming out part of it is taken out here and part of it is recycled after cooling; that means, possibly, and in fact it is so that it is an exothermic reaction. So, part of it is recycled back to the reactor through a cooler where cooling water flows and cools this particular stream.

Now, this temperature if it is to be controlled the amount of heat removal from this has to be controlled; that means, this particular flow rate has to be controlled. So, what is done is you have a final control element which is the control valve here whose opening good if it is more or increased more amount of flow will be there and naturally your cooling here will be more.

And if it is reduced if I reduce the opening the flow would come down the removal would come down. And this is controlled by what this is controlled by the temperature controller which knows what the current temperature measurement is from this temperature transmitter and there is a set point for this particular thing. So, this is also another temperature control loop.

Now, you want that the level of this CSTR should remain at its fixed value at its desired valued I will prefer to say that. On that 2 inlet flows we do not have any control they are as per the process requirement. So, what we need to have is we need to control the outflow from here in order to maintain the level of this. So, in order to maintain the level of this we need to measure the level. So, we require a level sensor with a level transmitter a level controller and the control valve on this line

So, what we have here is one more loop here. So, what I can say here is this is a typical CSTR instrumentation which controls the level, which controls its temperature, which controls the flow rate of the two reactants F1 and F2. So, how many control loops are there? You have 4 control loops and beyond that you have the ratio controller. So, there are 1 2 3 4 5 control loops in the small system itself.

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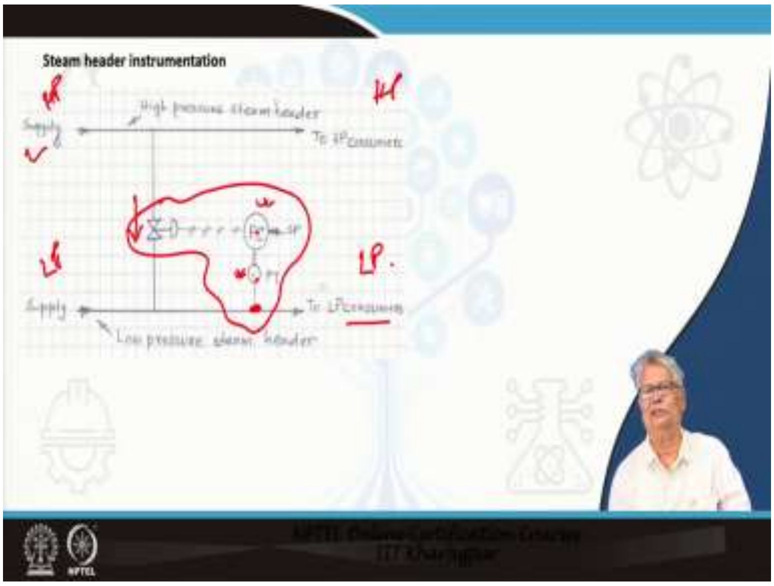

Here it is basically the same thing what you have here is a steam header instrumentation where, I have a high pressure supply this is a high pressure supply of steam this is a low pressure and you are supply you are supplying the header with your high pressure supply high pressure steam supply and a low pressure steam supply.

And in case it has got a provision that if your low pressure consumers consume more the pressure in the header would fall and that would be made up by opening this valve and allowing some high pressure steam to enter this. And how will it how it has to act in that case you would need to maintain this header pressure.

So, it has to be measured it has it has to be transferred transmitted to the controller and the controller will be sending a signal to this final control element and this would be the control loop. That means, this is a pressure control system for a header it could be steam or it could be some other gas it could be fuel gas or anything else also.

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The distillation column instrumentation I will not go through right now because this is something I ask you to refer to the distillation course where we had completed and included this instrumentation in fair details. If required we can revisit it in during our interaction sessions.

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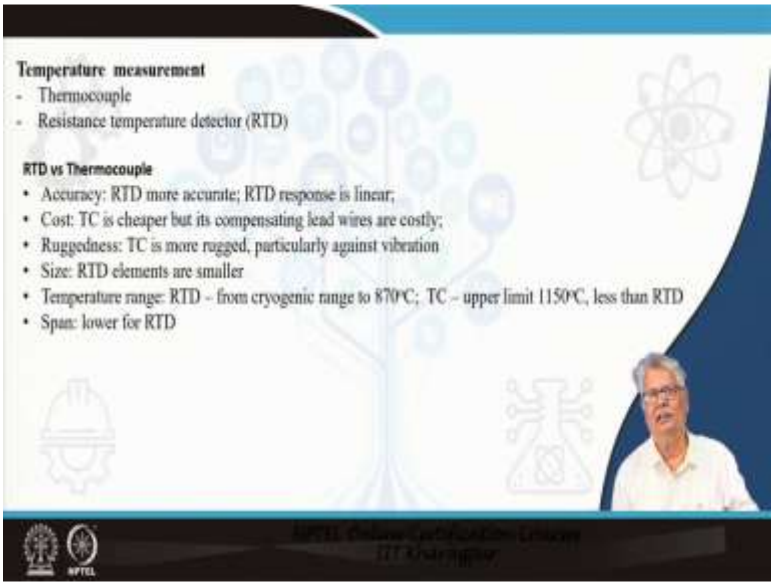

Now, regarding temperature measurements, the most popular temperature sensors in industry are the thermocouple and the resistance temperature detector or RTD, very often you refer to these as the TC and the RTD itself. Now the question is what to select? I could measure this sense, I could measure the same temperature using RTD or using thermocouple.

Remember, we have talked about thermo wells and this thermo wells are for housing the RTD or thermocouple inserts in that; that means, whether RTD or thermocouple will be within a tube and that tube will be inserted in the thermo well itself. Usually the thermo well is also filled up with a thermal fluid which has got high thermal conductivity and low vapour pressure so that it does not vaporize off.

RTD normally is more accurate a typical RTD is PT 100, if I say its PT 100 RTD what I normally mean is it is a platinum resistance and the resistance at the standard temperature is 100 ohms. Another thing is there in case of RTD the RTD response to the change in temperature is linear in case of thermocouple it is not. Over a very short span yes it is fairly linear, but if you are talking about a fairly large range of change in temperature there is nonlinearity that needs to be corrected.

Thermocouples are cheap, but it will require compensating lead wires which are expensive. Well you require compensating lead wires when you are sure that you would like to have a fairly accurate measurement of the temperature while there could be reasonable amount of variation in your environmental temperature, because thermocoupled is based on the difference in temperature between the two junctions.

Now, regarding ruggedness thermocouples are more rugged particularly against vibration, regarding size yes it depends on what exactly is your measurement point RTD elements are typically smaller. If we talk about the temperature range the RTD can be used from cryogenic range to about 870 degree centigrade, cryogenic temperature is starts from 100 degree kelvin remember that.

In case of thermocouple the upper limit is more it is about 1150 and the lower range is slightly less than the RTD; that means, it does not go up to it does not function very well in the very low temperature range. Now, I have to talk about the span. The span is lower for RTD, span basically means the maximum temperature that it can record minus the minimum temperature it can record the difference between the two is referred to as span. This is about the temperature measurement brief.

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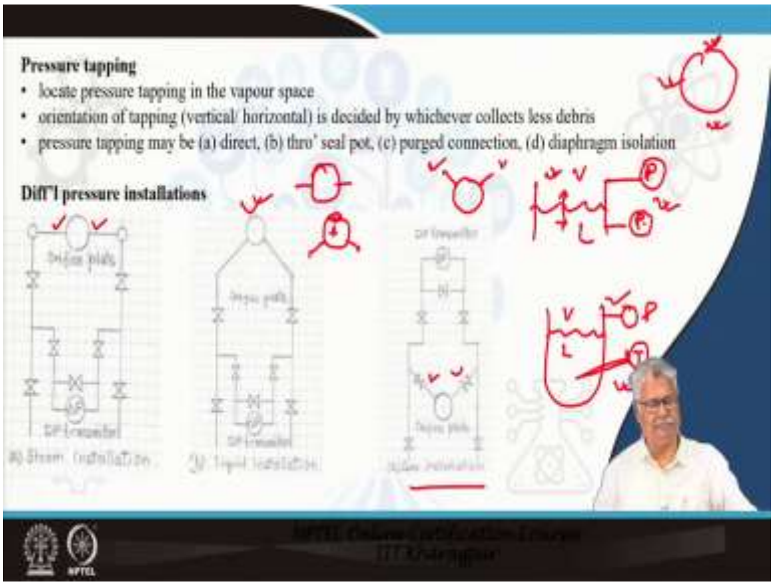

When, we talk about the pressure tappings. The pressure tappings are most of the time have to be located in the vapour space the logic is simple. If I have both vapour and liquid and I have an interface here and if I measurement my if I have my pressure measurement here, what happens is if my level varies my pressure would change.

In for example, in case if I locate it here in the vapour space my pressure would be basically the pressure on the surface. So, quite naturally if I would like to say that I have to have a measurement of the column bottom pressure the column bottom pressure should be the sensor for this the pressure sensor for these are the pressure tapping should be there in the at an elevation which is above the highest liquid level in my column.

That means above if I have my column bottom here the maximum level can this I must have a measurement here. This is not true in case of temperature, in case of temperature normally what you do is you insert your thermo well here in the liquid phase only this is a liquid this is a vapour.

So, you notice this difference because what happens is if you have a large temperature if you have a large amount of liquid its temperature changes and the fluctuations are less. So, what you get is an automatically averaged out temperature in your temperature sensor in this case this type of installation.

Now, the question is about the orientation of the tapping. The pressure tapping the could be in this location, it could be in this location or it could be in this location if it is a pipe say. You can see exactly the same thing in this case also, the differential pressure tapping in case of steam normally is from the side of the orifice plate. That means, if I have a header the tapping will be here the tapping will be here.

If it is a liquid installation normally as it is shown here it will here and here. These tappings are definitely for differential pressure measurement, but in general is true for pressure measurement also. Now, there is a question that why you would like to have your liquid pressure measured from this this particular point. The reason is very simple it is possible that some amount of vapour will be accumulating here that I do not want to come in my tappings.

In case of gases normally you will find you are having your tapping at the top exactly opposite of this which is here and here. So, the pressure tapping could be a direct tapping a direct tapping is here it could be through a sealed pot seal pot means you do not want your pressure measuring sensor to come in contact with the process liquid. So, you what you have is another vessel in between which contains may be glycerine which is a typical seal pot liquid.

And it transmits the pressure to the glycerine pot and the glycerine pressure is measured by your pressure sensing element. It could be a purged connection and it could be a diaphragm isolation also; that means, you have a diaphragm which isolates the processed fluid from the pressure measuring instrument.

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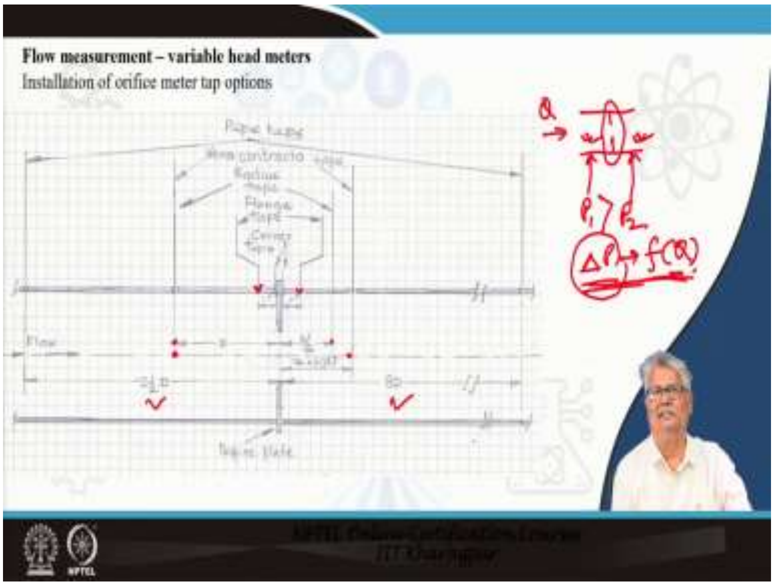

In case of flow measurements it is very interesting the most common type of flow meter is the orifice meter it is the cheapest it is fairly reliable and perhaps is the most used type of flow meter in large scale process industries. Now, it is a differential head meter; that means, if I have a; if I have a pipe through which there is a flow and I will have an orifice here whose upstream pressure is P 1 the downstream pressure is P 2. The delta P is a function of what flows through it this is my flow rate.

Now, there are different for it is possible to locate these tappings with respect to the orifice plate in different ways. One such option is you place it at the vena contractor you place it at the vena contractor you can have flange taps flange taps will normally mean roughly about 1 inch upstream 1 inch downstream, you can have radius taps all these are you can have D D by 2 and D taps also.

So, all these are different taps depending on the variation of Q with the delta P or delta H whatever you may call and they are chosen depending on how sensitive you want your flow, which is ultimately measured by this in terms of the pressure difference and the proper tap is chosen. For example, you will go for this two and a half D to 8 D when your flows are very large and it is a fairly stable flow. The most common are the flange taps; that means, here as well as here.

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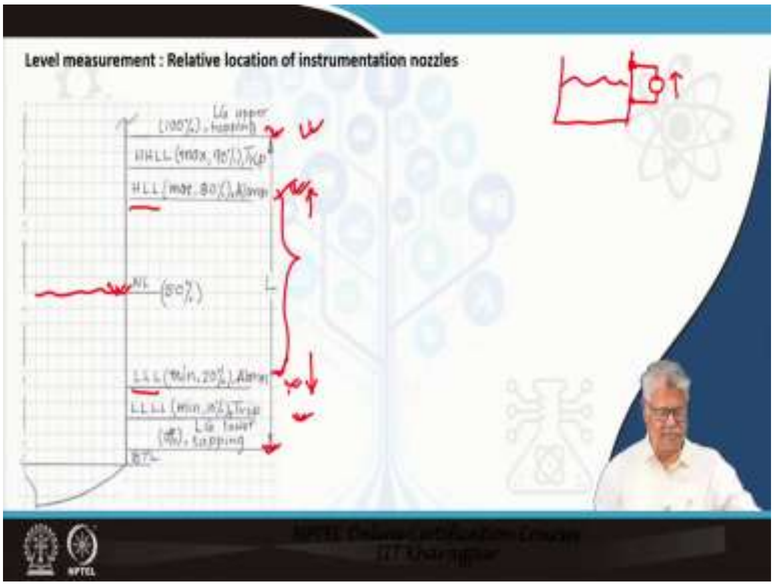

Now, this is something which we have seen earlier the level measurements. The relative location of the instrument nozzle that we have discussed already when we have talked about the hydraulics and the different we location so that we place our nozzles at different elevations and things like that.

Here we would like to add only one thing most of the level measurements in process industry are by a differential pressure measurement through a differential measurement of the static pressure. That means in order to measure the level in a vessel in order to measure the level in a vessel you will be requiring some sort of sensor here with two tappings. If the level rises up the delta P or delta H recorded by this also will go up and that will be indicating that your level is going up.

Normally; that means, you have here a bottom tapping level and a top tapping level. If the entire distance is about 100 percent normally the mid percent is taken as the normal level. And here I have talked about high level of liquid and a low level of liquid typically these are marked at the 80 percent and the 20 percent. There are usually alarms associated with a high level as well as a low level.

Quite naturally it is expected that you would not like to fill up your column bottom this is a typical column bottom and you want that your level should remain in this zone itself. So, what happens is if it exceeds this there is a alarm that will get actuated because possibly in that case it is going to fill up your column further and you have to take some action so that this does not happen.

The other situation is if your level falls below this particular thing if it continues to fall further your column will get emptied and you will be vapour locking your column bottom pump. So, definitely you would like to avoid both so you associate a low level alarm and a high level alarm. These are usually audible alarm with feasible indications in the control loop.

Now, there could be more severe situations also. If the level falls below this particular level possibly I cannot afford to run my system anymore, in that case I will be tripping my column bottom pump; that means, I will be stopping my column bottom pump so that it does not get it does not cavitate or it does not get damaged. Exactly in the same way I will also associate a trip with a high level here because if it touches the column bottom tray the tray may get dislodged.

So, this trips will be associated with the high levels and the low levels of not only, not to I mean high levels at the low levels to protect the equipment. Similar, trips and alarms are also associated with the pressure and temperature as well.

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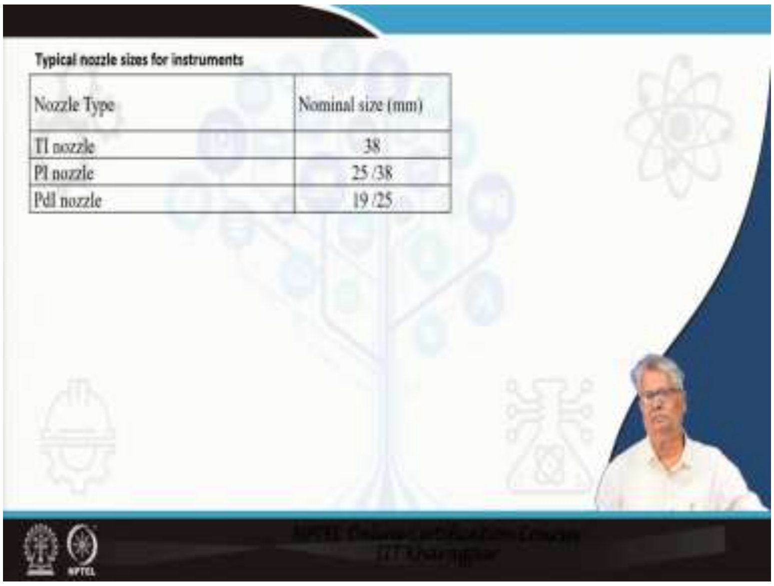

Typical instrument nozzle that also we know and we have talked about this when we talked about process vessels are 1 and a half in 38 millimeters, your pressure indication log nozzles could be either 1 inch or 1 and a half inch 25 38 differential pressure similarly could be 19 millimeters or 25 millimeters. So, these are the standards which is you typically used in industry.

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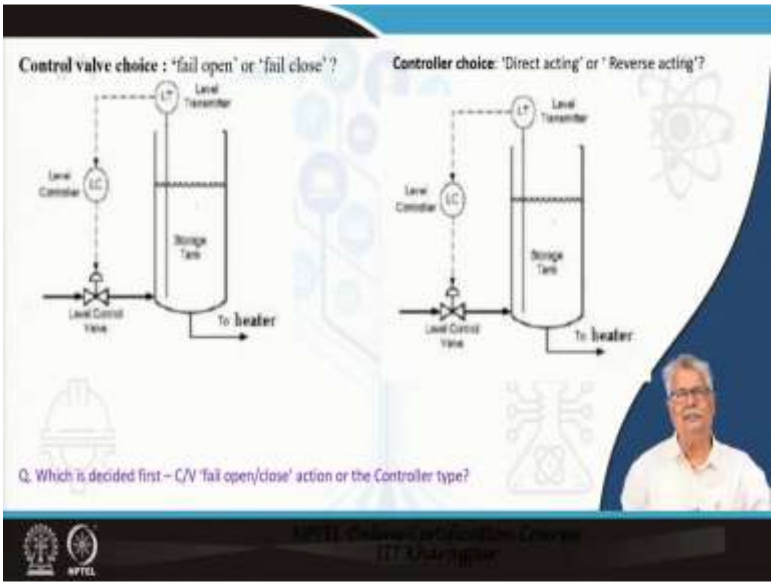

Now, you have a very interesting point here that is how to choose your control valve. We have seen that the control valve is an essential component and that is a final control element because it changes the flow and it somehow change in the flow is going to affect your pressure affect your system and here in this particular case what you find is a level control. What I do is I just look at two situations in the next slide in this slide here.

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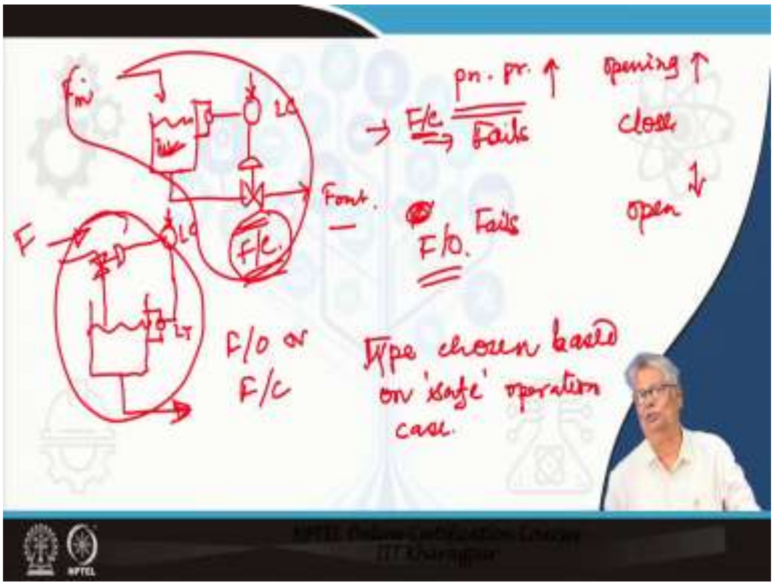

I have a vessel with a liquid which has to be maintained and there is an inflow and the inflow is while; that means, I have no control over it and it has to be served. Quite naturally I will have a level transmitter a level controller with its set point controlling this outflow from here, this is basically f in and f out this is my level controller here.

Now, if this be the case I have an option so this is a pneumatic control valve, there could be I could have a valve in which my pneumatic pressure if it increases the opening also increases; that means, if I have a failure in my pneumatic pressure this would sorry this would, if it fails this would close.

So, I call this type of valve fail close type, it could also happen that the opening would come down in that case it becomes a if it fails it is a fail open valve or it is a sorry it is a fail open valve. So, what you have here with you is you can have a control valve either fail type fail open type or fail close type.

Now, in this case let us say how do we decide which type of valve to choose from suppose it has it is chosen based on the process safety angle fail open or fail close type chosen based on safe operation case. That means what I would like to say is suppose in case of the instrument air failure if I say that it should immediately stop and I should retain some liquid inside in that case my valve on in that case I should choose a failed close valve.

That means, if I have a fail close valve here if I have a fail close valve here the moment there is an instrumentation failure instrument air failure in this particular case this liquid will be held up it will not drain by itself. If I had a fail open valve it would have drained by itself under such a situation. So, it is a safe condition of operation in case of instrument air failure which decides whether to choose a failed close or a fail open valve.

I will now perhaps you have a question that I have chosen a fail close valve here. I could let us look at the other case of the similar situation I have here the slow control is by manipulating the opening of the inflow. And, what I have here is again my level transmitter I have my level controller with its set point and it is controlling it this way and I have an outflow here.

Now, what happens is I do not want my vessel to overflow. So, what will I choose in such case, in case of instrument air failure it should I should choose a failed close in that case, but if I want the other way I could have chosen it and my choice of fail close is basically based on what is this fail safe condition of my process.

So, it is basically the fails if condition of your process which will help you to decide and it is the designers responsibility to since he knows his process best which he is designing to suggest that it should be a fail close valve or a fail open control valve.

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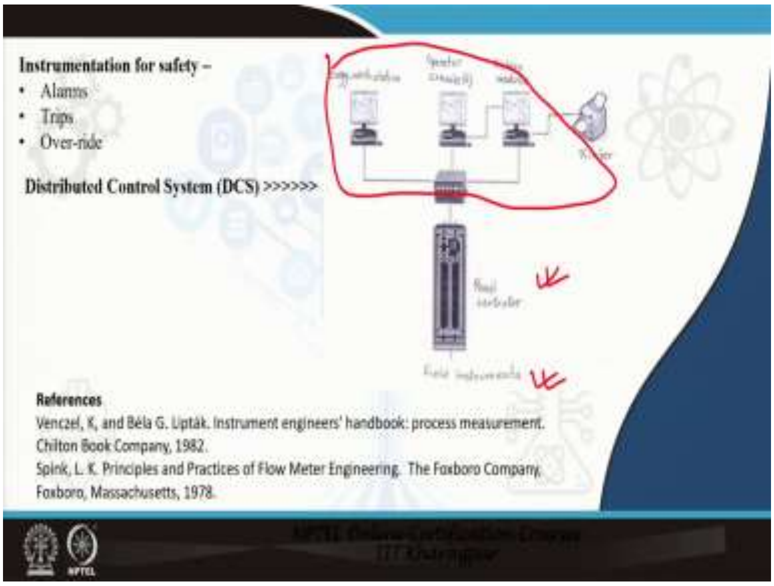

Today's system of instrumentation is much more advanced and I will just say that these are based on mostly electronic instrumentation which involves a distributed control system in large systems which are operated mostly by consoles and the configuration is something like this.

You have the field instruments, the field instruments are connected to the control panel instruments there and the settings of this control panel instruments comes from the hierarch above which is basically the supervisor control supervisory control. I think with this I will stop here.