Chemical Process Instrumentation
Prof. Debasis Sarkar
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 05
General Principles and Representation of Instruments (Contd.)

This is lecture 5. So, this is the last lecture for week 1; after this lecture you will be given assignment problems. So, what you plan for today is.

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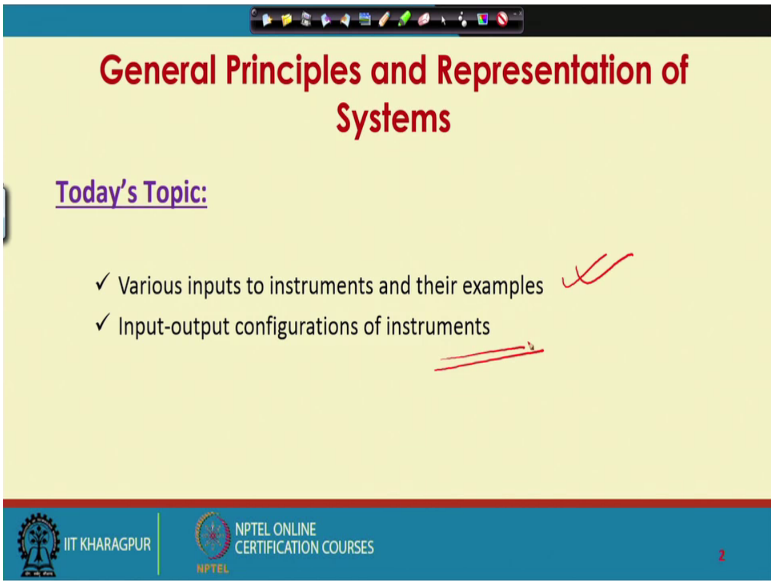

Various inputs to instruments and their examples; see we have various types of instruments like temperature measuring instrument, pressure measuring instruments, flow measuring instruments, level measuring instruments so on and so forth. So every instrument has been designed to be sensitive or to measure certain inputs. But unintentionally, it also become sensitive or receive signal for some other inputs which actually creates problem in measurements.

So, we will try to see what are the various inputs that go to an instrument? So, how we define them? How we classify them? And what steps can be taken to eliminate or reduce the effect of such inputs, then we will talk about various sorry we talk about input output configurations of instruments.

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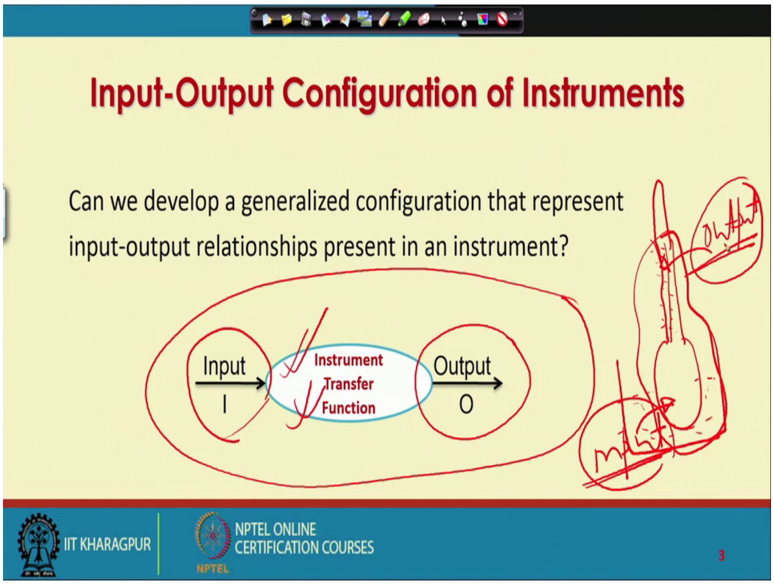

By input output configuration of instrument; what you mean is as follows, can we develop a generalized configuration that represent input output relationship present in an instrument. What is shown here? Is a very simple representation of an instrument in terms of block diagram, imagine the instrument; as a black box, so an input signal goes in and an output signal comes out. So, consider for example; then mercury in glass thermometer one of the most simple instrument, so we have this mercury layer and you have a graduated scale attached here you put this bulb of the thermometer into let say; some hot water.

So, what is input to the instrument is? This temperature or the thermal energy and output Is? The displacement of the mercury which can be read from it is position against the graduated scale. So, input is this temperature of thermal energy and the output is; the displacement of the mercury in the capillary. Now while the thermometer receives thermal energy it undergoes certain processes like; if this is the thermal energy there is unrestricted expansion, so as pressure is developed, so the mercury level goes up through the capillary so on and so forth, but here I just look at this input and an output. And let us say put a mathematical representation of all the processes that happens inside here then is it possible for me to relate between these input or thermal energy to this output or the deflection.

So, I repeat one more time; any instrument will receive some signal, let say for mercury in glass thermometer if this is temperature or thermal energy a signal, then it undergoes certain steps like; for mercury in glass thermometer, when it while it receives thermal energy the bulb in containing the mercury will undergo a restricted expansion, restricted expansion of the mercury in the capillary in the bulb. So, pressure will be developed, so that will force the mercury to go up through the capillary and there is a graduated scale attached to the capillary and wherever the mercury level rest that becomes an indication of the temperature.

Now, the question I ask is; it possible for me to represent in terms of some equations to describe the processes that goes within the mercury in glass thermometer, it may be a very simple equation, it may be very complex equation, it may be one equation it may be series of equations whatever. So, in that case, what I will do is? I will put all these equations in a black box and I will put the temperature as input signal all these equations will work on this temperature signal as input and will produce the output which will be the displacement of the mercury in the capillary. So, in principle all this input and output relationship of an instrument can be described in terms of some functions known as transfer functions.

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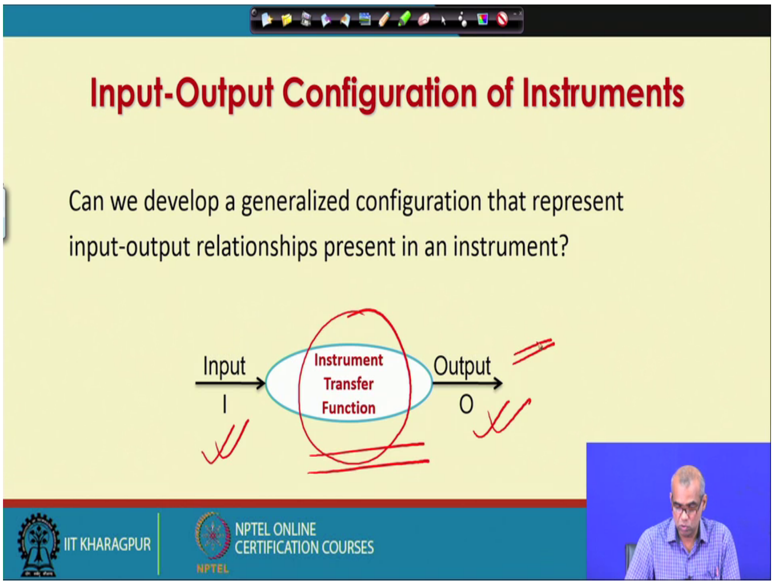

So, this is that instrument transfer function. So, we instrument transfer function is available for a known input I can find out the output, the transfer function will work on this input and give you the output as a result, you learn more about transfer functions when you study process control in some other course. So, we will make use of this concept little later in this lecture.

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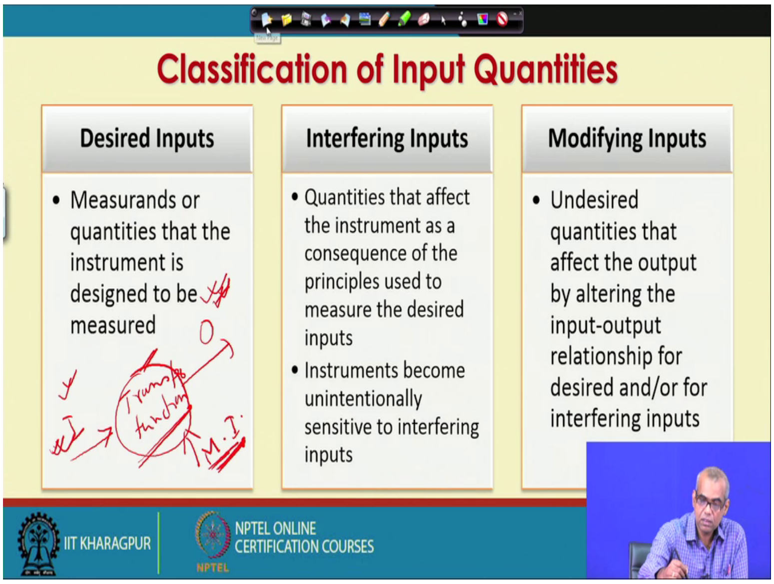

Now, let us classify various inputs that an instrument intentionally or unintentionally receives while it measures a medium a quantity of a medium, desired inputs are those inputs for which the instrument has been specifically design for. So, measured or quantities that the instrument is designed to be measured are desired input, so ideally the instrument should be sensitive only to desired input, because the instrument has been designed specifically for the desired input.

But there are interfering inputs, quantities that affect the instrument as a consequence of the principles used to measure the desired input. So, interfering inputs affect the instrument as a consequence of the principles used to measure the desired inputs, so while the instrument has been designed to be sensitive to desired inputs. The instrument become unintentionally sensitive to interfering input, this because the principles that has been used to design the instrument that make the instrument unintentionally sensitive to some other inputs other than the desired input.

Then there are modifying inputs; again modifying inputs are undesired inputs, so these are undesired quantities that affect the output by altering the input output relationship for a desired and or interfering input. Just now we learnt about the transfer function, so this is a transfer function of an instrument we have input signal here and we have output signal here. So, transfer function is basically a relationship that exists between input and output.

So any input; any undesired input, that affects these transfer function will also change this output, but that change is not because of desired input, that change may be because of modifying input. Why? Because this transfer function is basically an equation, there may be some parameters involved modifying input may change one or more of those parameters then the output will change, but in the absence of modifying input the desired input will give a different output, corresponding to the two transfer function of the instrument, but modifying inputs modifies the transfer function. So, this is an undesired input.

So, there are three different types of input all the inputs can be broadly classified in three different categories; desired input, interfering input, modifying input, desired input we desire instrument has been designed to measure this input only but; unintentionally the instrument also become sensitive to interfering input and also there will be undesired modifying input.

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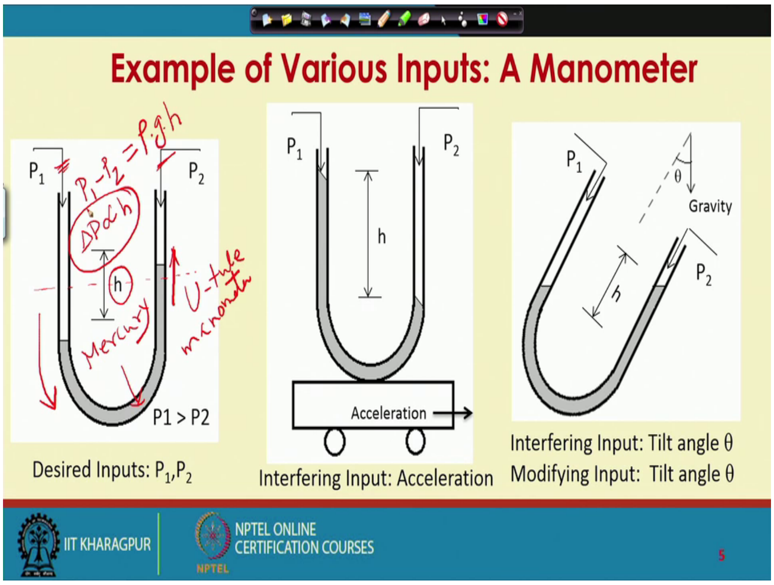

Let us now take an example of various inputs; desired input interfering input and modifying input then the concept of these various inputs will be clear to you. Let us consider a manometer specifically, let us consider a u tube manometer this is u tube manometer. You must have seen this in your school days text book or in laboratory, it is a tube open in both ends and bent in the form of English letter u, within this there is a manometer fluid often times it is mercury.

Now, when both this limbs are connected to the same pressure source, let say both the limbs have connected to atmos to both the limbs are open to atmosphere, it means that both the limbs are connected to the same pressure source which is equal to the atmospheric pressure, in that case the level of the mercury in both the tubes will be same say when P 1 equal to P 2 maybe the level of the mercury will be like this, it will be same in both the limbs.

Now, if P 1 is greater than P 2; that means, if I now connect the limbs of the manometer to 2 different process sources, then there will be difference of level of mercury in both the limbs a simple balance will tell you that, for this example; P 1 is greater than P 2, so this pushes the mercury level more and mercury level in this limb is higher so this goes like this, at equilibrium the force balance will be maintained and the difference of level in the mercury is a measure of the pressure difference between these 2 limbs.

So, P 1 minus P 2 is basically density of the mercury; then g and then h, so h is a measure of delta P 1 minus P 2. So, delta P is proportional to h, h is a measure of delta P. Now, in this case you have two limbs connected to two different pressure sources, so there a level difference. So, input or desired input to this manometer is; P 1 and P 2, because the manometer has been designed to measure pressure difference and the desired input is P 1 and P 2.

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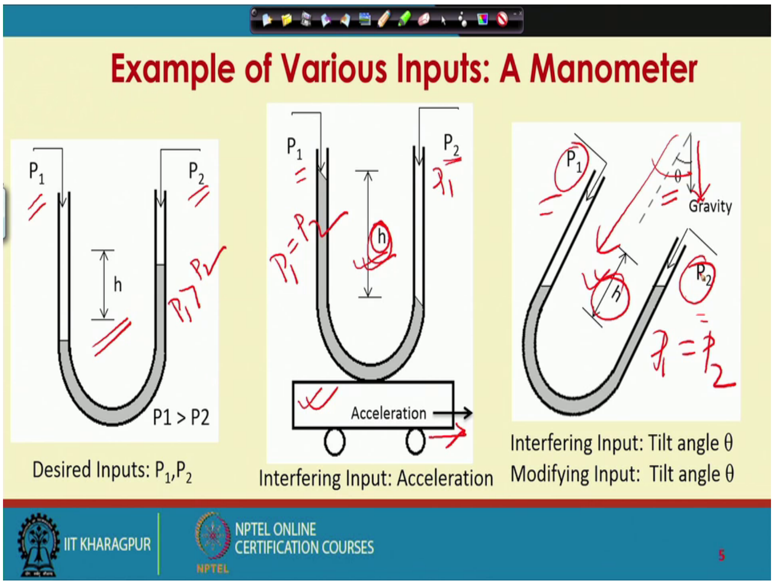

Now, let us put this manometer on a vehicle which is moving with acceleration and let us connect both the limbs to the same pressure source, so here P 1 equal to P 2. Note here; P 1 was greater than p 2, but here we are talking about a case where both the limbs are connected to the same pressure source, so you can consider this P 2 as P 1 or can write separately as P 1 equal to P 2. Then under stationary condition, it should be 0 in other words the level of the mercury in both the limb should be same. But, a simple analysis will tell you that if you place this manometer on a vehicle which is moving with an acceleration there will be a nonzero h even the pressure sources are same, this is because the acceleration works as an interfering input. So, this h is not because of difference in pressure, but this h is a result of acceleration so manometer becomes unintentionally sensitive to acceleration, so acceleration is an interesting input.

Similarly, if you tilt the manometer and even if these two pressure sources are same, there will again be a nonzero h. So, this tilt angle theta is an interfering input, again a simple analysis will tell you that the gravity works like this but here you have to look at this component this angle is theta, so because of this theta you have a nonzero h here and this nonzero h is not because of the pressure difference, because both the limbs are connected to same pressures P 1 and P 2, but this nonzero h is due to the tilt angle theta, so the interfering input is tilt angle theta.

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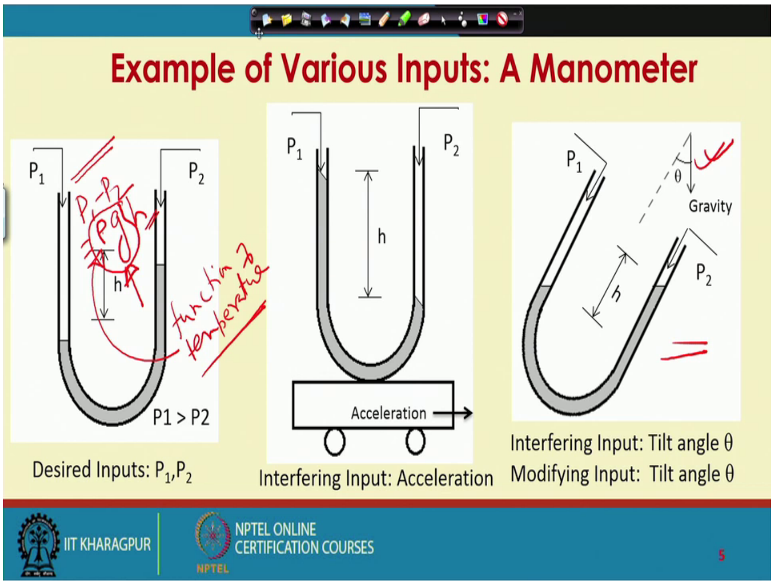

Well, we talked about P 1 minus P 2 equal to density of mercury acceleration due to gravity and h P 1 minus P 2 equal to rho g h, now the density of the mercury can be temperature dependent. Now, look at this here; this is something like the transfer function, because this P 1 minus P 2 is input h is output. So if you know rho g and if you know P 1 minus P 2 we can find out h; now if due to change in temperature the density changes the h value will also change. So, the temperature is a modifying input here, the g also is different here because of this tilt, so the tilt angle is modifying input here as well.

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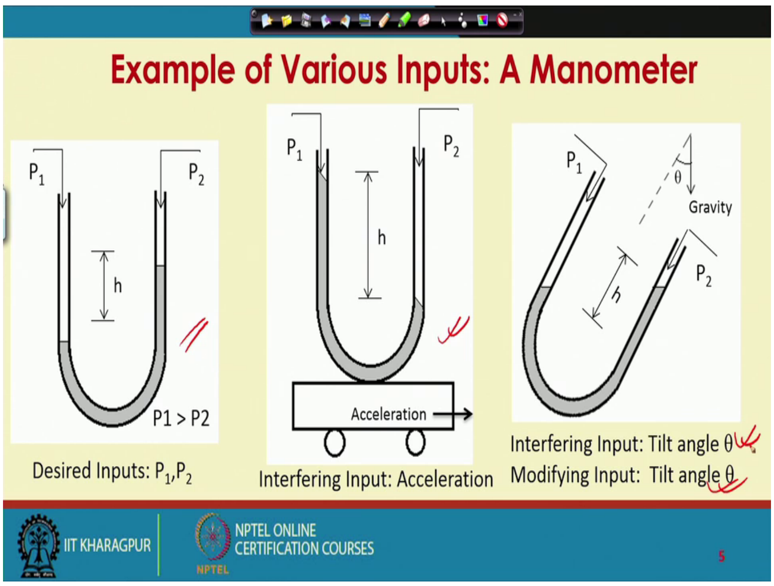

So, what you learn from here is? That for manometer P 1, P 2 the pressure sources in both the limbs get the desired inputs acceleration maybe an interfering input, tilt angle maybe an interfering input, tilt angle can also be an modifying input temperature can also be an modifying input.

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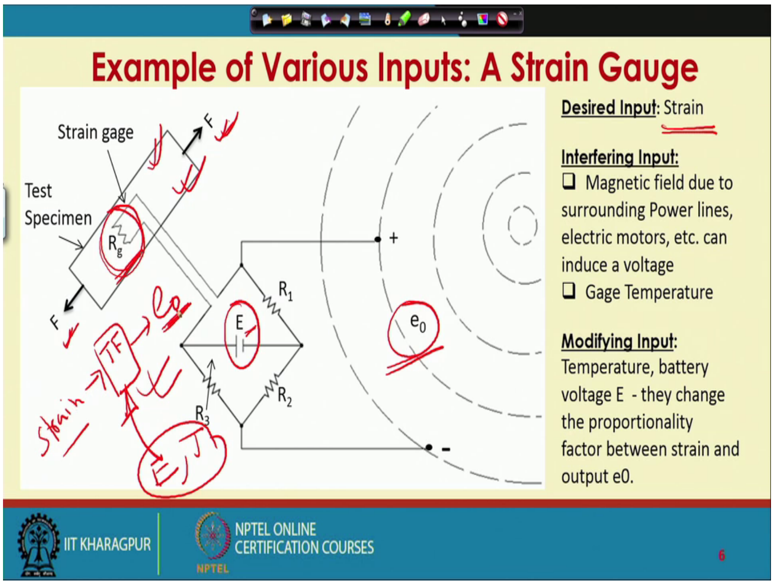

Let us take another example; now will take an example of strain gage, strain gage measures strain. So, it works as follows; you have a resistance wire, this is the test specimen this is under strain by these two forces that are being pulled. So, the specimens are under strain due to application of these two forces.

Now, I bound this resistance wire here. So, as the specimens undergo strain the resistance wire will also undergo strain, so there will be change in resistance and then that change in resistance can be measured using a Wheatstone bridge, this is the power source for the Wheatstone bridge and this is the output voltage from the Wheatstone bridge. So, initially we will maintain the null point and then the strain will be applied the resistance will be change that will create an imbalance there would not be any more null point, so the measure of imbalance the imbalance is becomes a measure of the strain or this output voltage that will be measure of the strain. So, desired input; is of course strain, because the instrument has been designed to be sensitive to strain.

Now, see if there are magnetic fields present around this strain gage it may be due to surrounding power lines or electric motors etcetera, they can induce a voltage even if there is no strain in the specimen. So, the magnetic field due to surrounding power line so electric motors can induce a voltage, even if the specimen is not undergoing any strain, so this becomes an interfering input. Similarly the gage temperature also becomes an interfering input, because the gage temperature can change the resistance, so it is not only the strain in the specimen that is changing the resistance, the change in temperature can also change the resistance of the gage, so the gage temperature also becomes an interfering input.

The proportionality factors that exist between the strain and the output, this strain is input and output is this output voltage e 0. So, if I say there is a transfer function for this instrument which relates strain and this output voltage these transfer function will involve the battery voltage E as well as temperature. So, this may be an equation which will involve the battery voltage E and the temperature T, so any change in battery voltage any change in temperature will also change e 0 the output of the strain gage. So, the temperature and battery voltage are the modifying inputs here.

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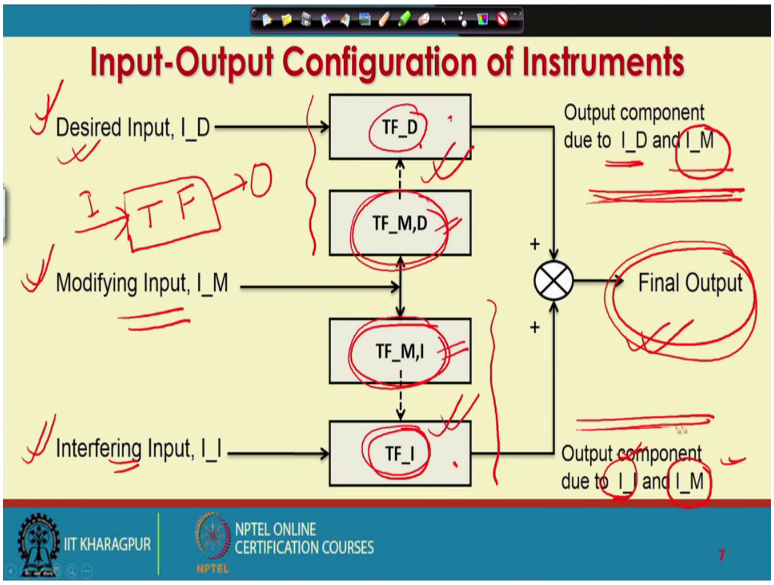

Now, let us see input output configuration of instruments. So, we have now learnt about desired input, modifying input and interfering input, we have also learnt about the transfer function of an instrument. There is a transfer function of an instrument and transfer function works on this input and gives you this output, so this is a mathematical representation for benefit of analysis.

Now, I can say that there are transfer function for the desired input, their transfer function for the interfering input and modifying input since modifying input changes the transfer function for desired input as well as interfering input, in other words modifying input can affect the output which comes only from desired input or the output which is only comes from interfering input.

So, modifying input affects both desired input as well as interfering input, so we can say that modifying input has a component of I mean component of transfer function for desired input as well as component for transfer function for interfering input. So this is the transfer function of modifying input for desired input and this is the transfer function for modifying input for interfering input. So, the desired input is processed or operated on by this transfer function and gives you a component output component for the desired input.

Interfering input is operated upon by this transfer function for in interfering input and gives you an output component for interfering input. Now modifying input will affect both interfering input and desired input, so it has a transfer function component for desired input and modifying input also has a transfer function component for interfering input, so it affects the desired input it also affects the interfering input. So, there is an output component along with desired input coming from modifying input and also there is an output component along with interfering input coming from modifying input.

So, the final output is a combination of these two as well as these two, in other words the final output from an instrument is a result of desired input, modifying input as well as interfering input. So, that for benefit of analysis we have introduce these transfer functions, so this is transfer function for desired input, this is transfer function for modifying input, sorry this is transfer function for desired input, this is transfer function for interfering input. Now modifying input affects both desired input as well as interfering input, so modifying input has a com transfer function of modifying input as a component for desired input and also transfer function for modifying input has a component for interfering input.

So, these two transfer function gives you a; output component for desired input and modifying input and these two transfer function gives you output component for interfering input as well as modifying input and the final output becomes an algebraic sum of all these four inputs.

Now, let us look at the same concept again. So, we have measured or measuring variable the instrument or sensor receives physical variable interfering input as well as modifying input and gives you the output, say in absence of modifying input I have these relationship between input and output, in presence of modifying input this relationship has changed.

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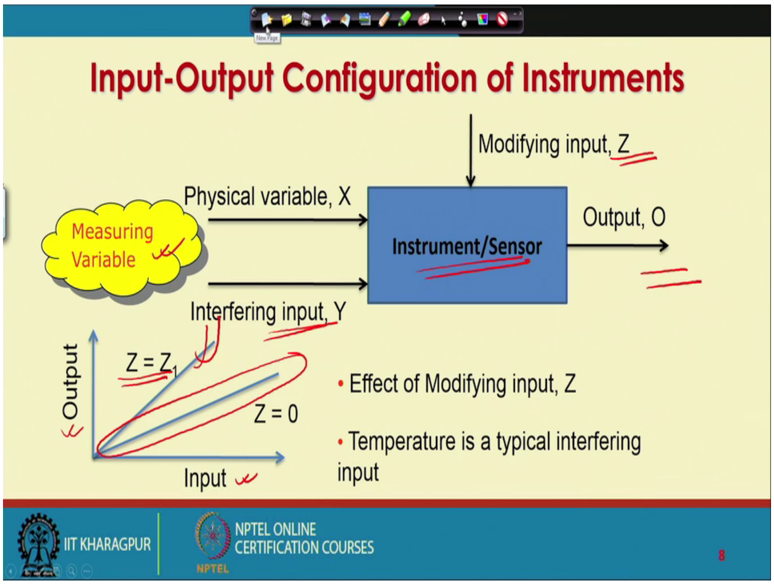

Now, the question you ask now is; how to eliminate or reduce the effect of interfering inputs and modifying inputs? There are two common schemes input filtering or output filtering and method of opposing input, the method of opposing inputs cancels the effect of an environmental input in an instrument by intentionally introducing an equal and opposite input to the instrument. So, as the name suggest; input will filtering or output filtering relies on filtering the undesired inputs at the entry level or at the exit level.

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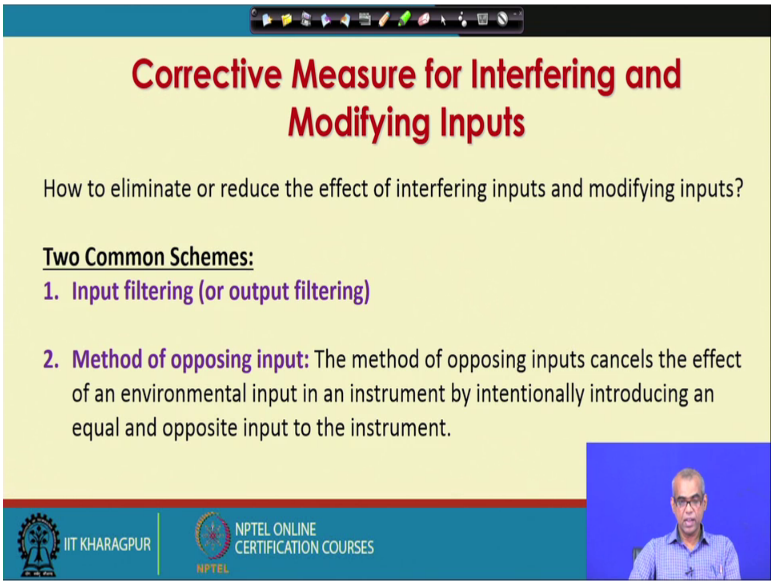

Method of oppose in case of method of opposing inputs we intentionally introduce an input, whose effect is equal and opposite to that of unintentionally sensitive interfering input. So, that it effect so that the introduced input cancels out the effect of interfering input.

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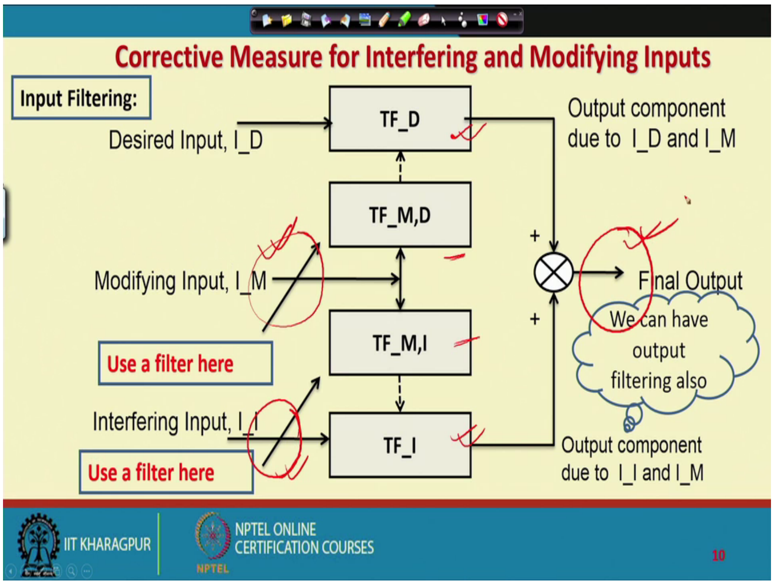

So, let us now take this look at this schematic. So, this is again the same block diagrams of the instruments working in terms of transfer function; you have desired input, you have interfering input, you have modifying input for desired input, you have modifying transfer function for modifying input for desired and interfering input. So, I can put a filter here to filter out the effect of modifying input or I can put a filter here to filter out the effect of interfering input it is also possible to put filter at output, so these are known as input filtering.

When you are putting filter here or we are putting filter here is known as input filtering and putting filter at output is known as output filtering. This is a schematic of method of opposing inputs this is the desired input transfer function, so this is the output component; for desired input, this is unavoidable interfering input and let us say this is it is transfer function and this is intentionally introduced interfering input. And let us say this is the transfer function for this.

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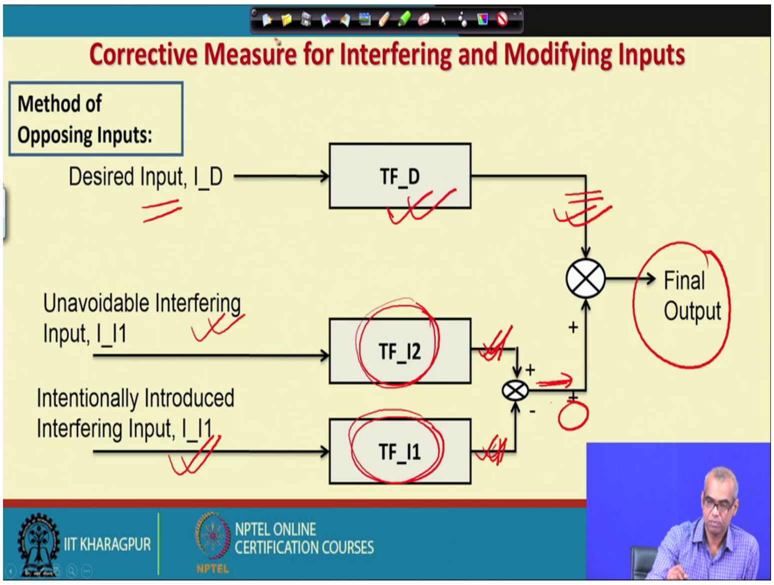

Now, this is the output component for unavoidable interfering input, this is the output component for the intentionally introduced interfering input, now if this and these are equal and opposite then here we have 0. The effect of unavoidable interfering input can be completely cancel out by the introduction of a suitable interfering input, so you have to find that suitable interfering input, then this found a final output becomes a result of desired input only, because this signal is now 0 this and these are equal and opposite and cancels each other out.

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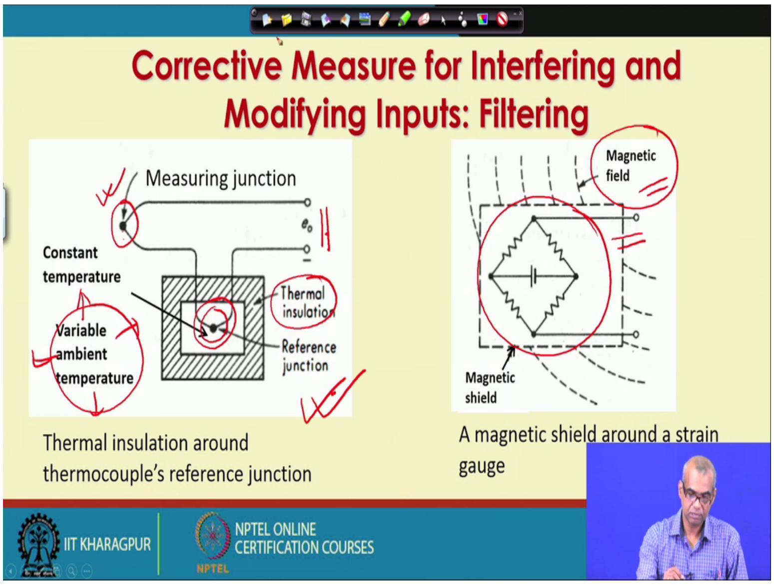

A quick example of filtering this is an example of thermocouple; has two junctions, this is known as measuring junction or out junction, this is known as reference junctions. So, thermocouple made of two dissimilar metals and two junctions are formed, if these two junctions are kept at two different temperatures then this e m f produced will depend on this temperature difference between these two junctions.

Now, this reference junction has to be kept at constant temperature, so that this e m f becomes function of this measuring junction's temperature only. Now there are there will be effect of variable ambient temperature, so to filter out the effect of variable ambient temperature the reference junction can be put in thermal insulation, so this is that thermal insulation. So, this is to filter out the effect of variable ambient temperature, similarly in case of strain gage the effect of surrounding magnetic field can be filtered by putting the strain gage within a magnetic field, maybe made of metallic box to filter out the effect of magnetic field. So, this is example of filtering.

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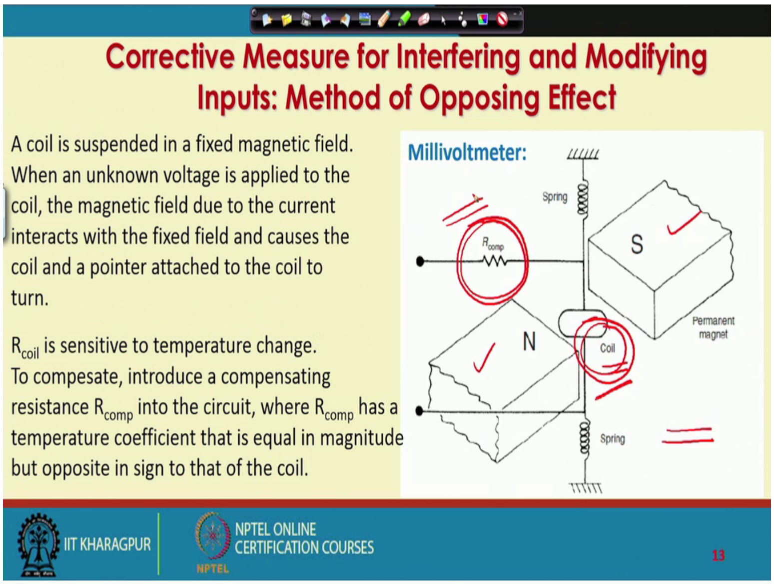

Finally, will take a brief example of method of opposing effect for correcting measure of interfering and modifying inputs; this is an example of millivolt meter, so coil is suspended in a fixed magnetic field, when an unknown voltage is applied to the coil the magnetic field due to the current interacts with the fixed field and causes the coil and pointer attach to the coil to turn.

Now, the resistance of this coil is sensitive to temperature. So, if the temperature changes; the resistance of the coil will change, to compensate for this effect of temperature change we introduce a compensating resistance here and the temperature coefficient of this compensating resistance is equal in magnitude, but opposite to the temperature coefficient of this coil resistance. So, when the temperature changes; coils temperature increases, but compensating resistors resistance decreases and this is equal in magnitude. So, one increase another decrease by the same amount so the effect is cancels out. So, this is an example of method of opposing effects.

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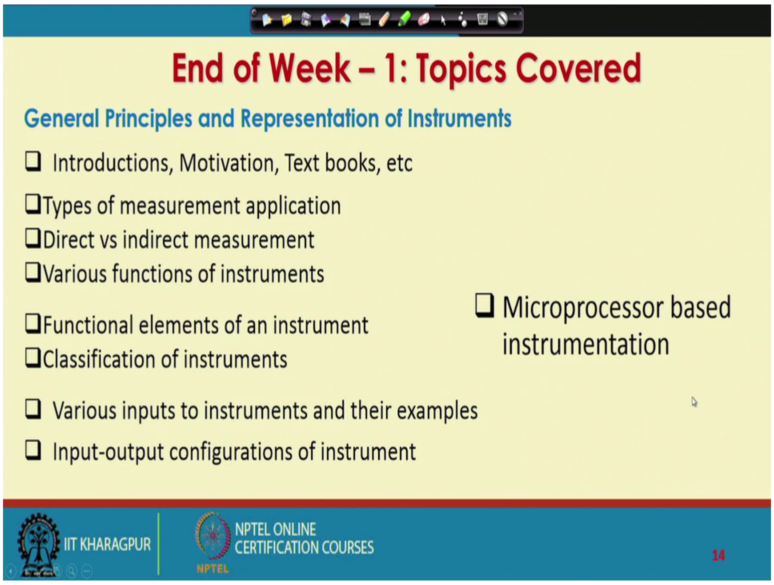

So, this is end of week, so what you have covered are as follows the broad topic that has been covered is general principles and representation of instruments under these heading, we have given introductions, motivations we have talked about text books etcetera, we have talked about types of measurement applications. What are direct measurements? What are indirect measurements? Various functions of instruments, we have introduced concepts of functional elements of an instrument classification of instruments, we have briefly touched upon microprocessor based instrumentations. We have seen various inputs to the instruments and their examples, we have also seen the input output configurations of instruments and how to reduce or eliminate the effect of various undesired inputs.

So, this is the end of week one. Now, you will be solving assignments questions for this week one topics covered.

Thank you for listening.