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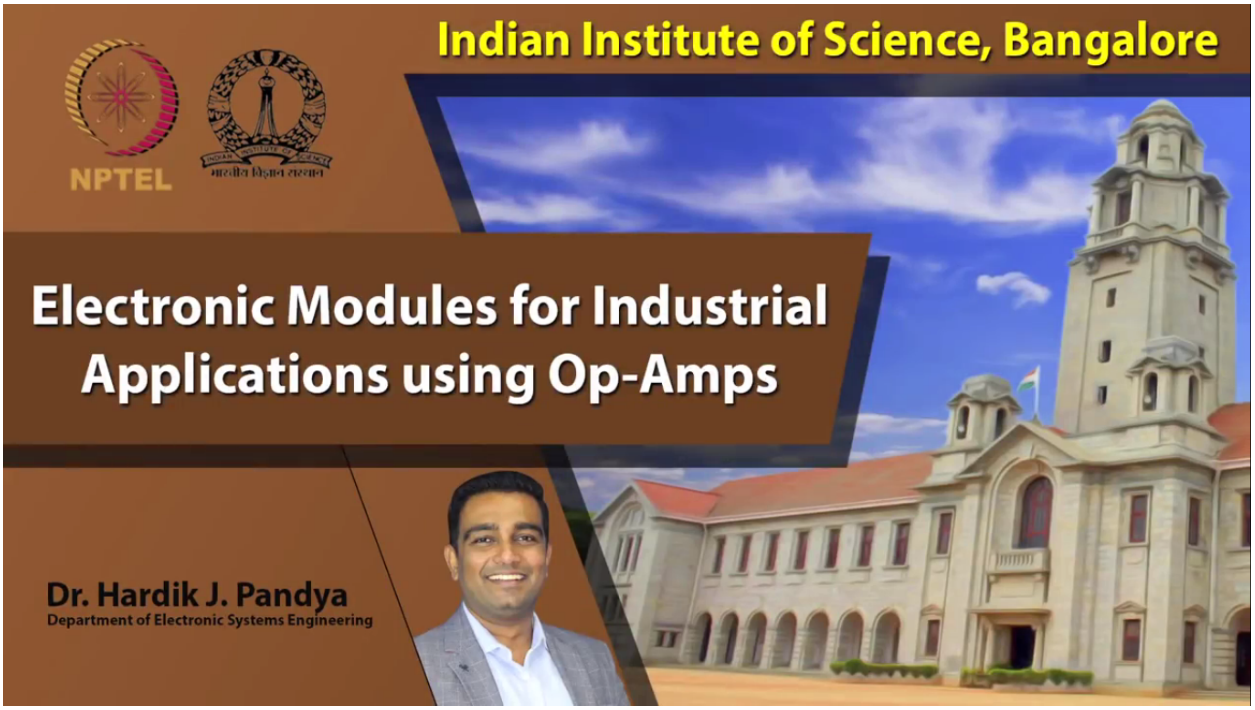
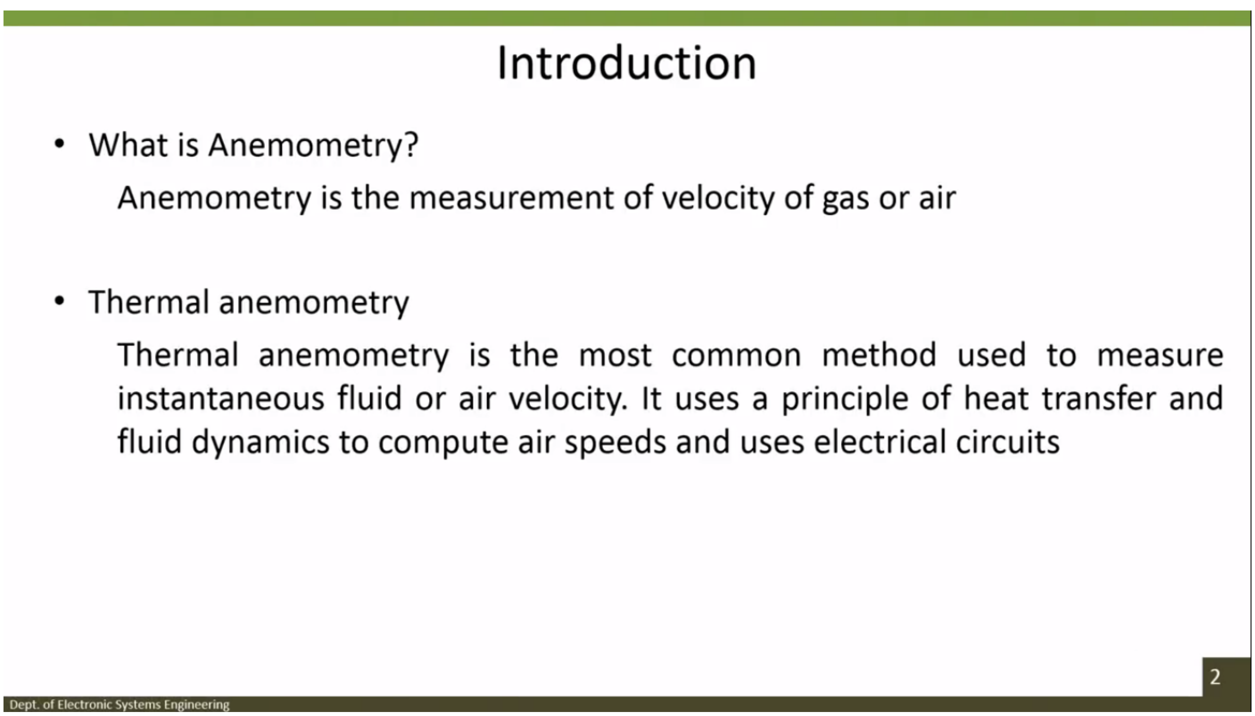


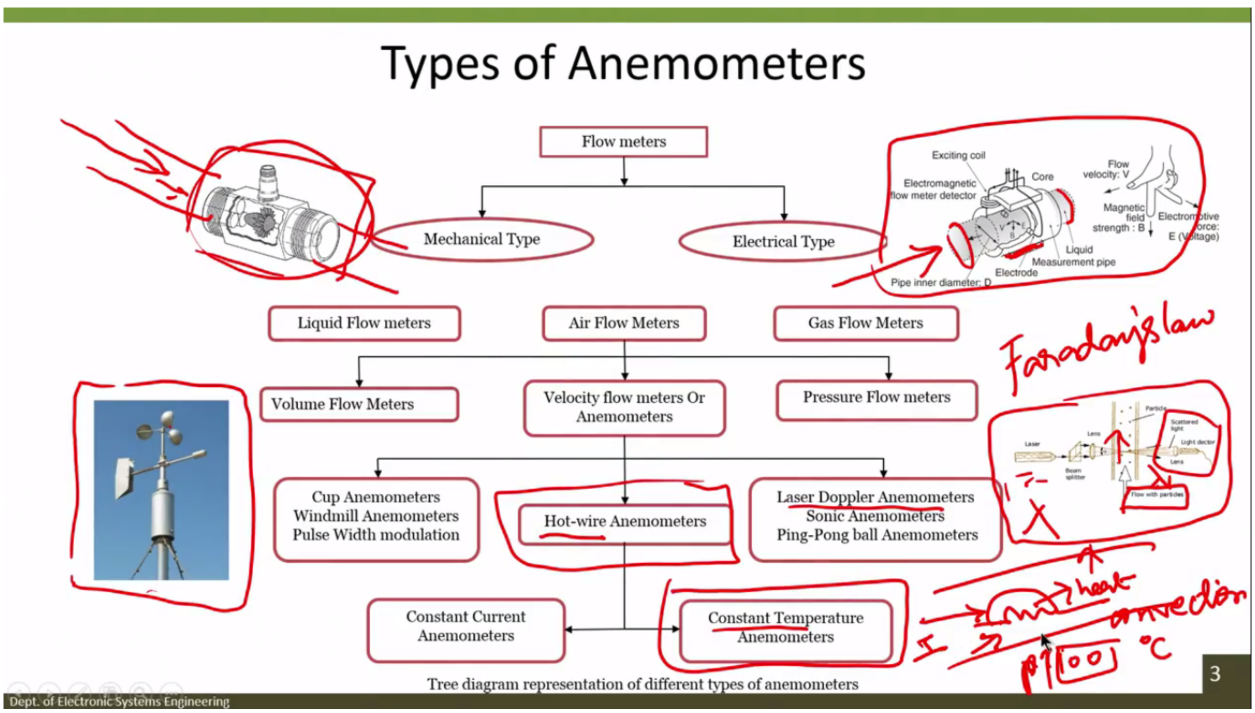
Hello everyone. Welcome to the next module on industrial applications using Op-Ams. Today, let's study what is an anemometer and what are its application and how do you integrate various electronic components in order to realize the velocity of the fluid. So let's get into the details of the anemometer.



Like I mentioned, let's begin with the definition. What is an Anemometer? So Anemometer is the measurement of the velocity of gas or air. When you talk about velocity the term here is a vector. So make sure it is both the magnitude and direction which has to be considered when velocity is being talked about. Otherwise, in general it is used to measure the speed of the fluid. The fluid here could be a liquid, gas, or air. To be specific today we will be studying more about how the flow of air in a medium can be understood. The velocity of air.

Now thermal Anemometer. So the various types of measurement techniques which are used to measure the velocity or the speed of the fluid. Thermal Anemometer is one such class which is a common method to measure the instantaneous flow of fluid or air.

Now how does this measure the velocity? So when the term thermal here indicates heat. So based on the heat transfer and the fluid dynamics you can compute the speed of the air. So when we are talking about the speed of the air it's just the magnitude. In case you want to study the velocity then you need to even consider the measurement parameters in order to understand the direction of the flow of the fluid and it uses electrical circuits. So let's study in detail about the thermal Anemometer.



This slide talks about the different types of Anemometer like I said they are classified based on the application. So here the first classification, the measure classification talks about two types one is the mechanical type and the electrical type. The symbol here if you can see the figure here, this is one such example of a mechanical type Anemometer. As you can see there is a turbine like structure. So when the fluid flows through this, it could be the liquid, air or any other type of fluid where you want to understand the rate at which the fluid is flowing through the chamber. Say this measuring instrument comes in between your two channels where the fluid flows in this direction. So how do you understand the rate at which the fluid flows through this pipe. So you have a fixture like this, a mechanical type Anemometer which is designed to understand the rate at which this fluid flows through the device.

And another type here states the electrical type Anemometer. The example what I have quoted here is an electromagnetic type Anemometer. As you can see this here states the electromagnetic flow meter detector.

Now where does this come into play? So I am sure you understood what is Faraday's law. When there is a conductive fluid that flows through this device here, what happens is like you can see the coils here, the exciting coil. So when these coils are excited, there is a magnetic field that is generated throughout the area of the device. So when there is a magnetic field and when there is a conductive fluid that flows through this device a voltage would be generated. And the electrode that is placed here is used to measure the voltage that is induced. So depending on the rate at which the conductive fluid flows through the device proportionally a voltage is induced and that is captured by the electrode here.

So now you know based on the flow of the conductive fluid through the magnetic field a voltage is being induced and that is sent by the electrodes here which is located on the walls of this tube. This becomes a type of electromagnetic Anemometer. Now I hope you have understood the different type of applications. So it could be for a normal mechanical type where there is just water or any other medium flowing through or if there is a conductive fluid and then you have this type of electromagnetic paste flow meter.

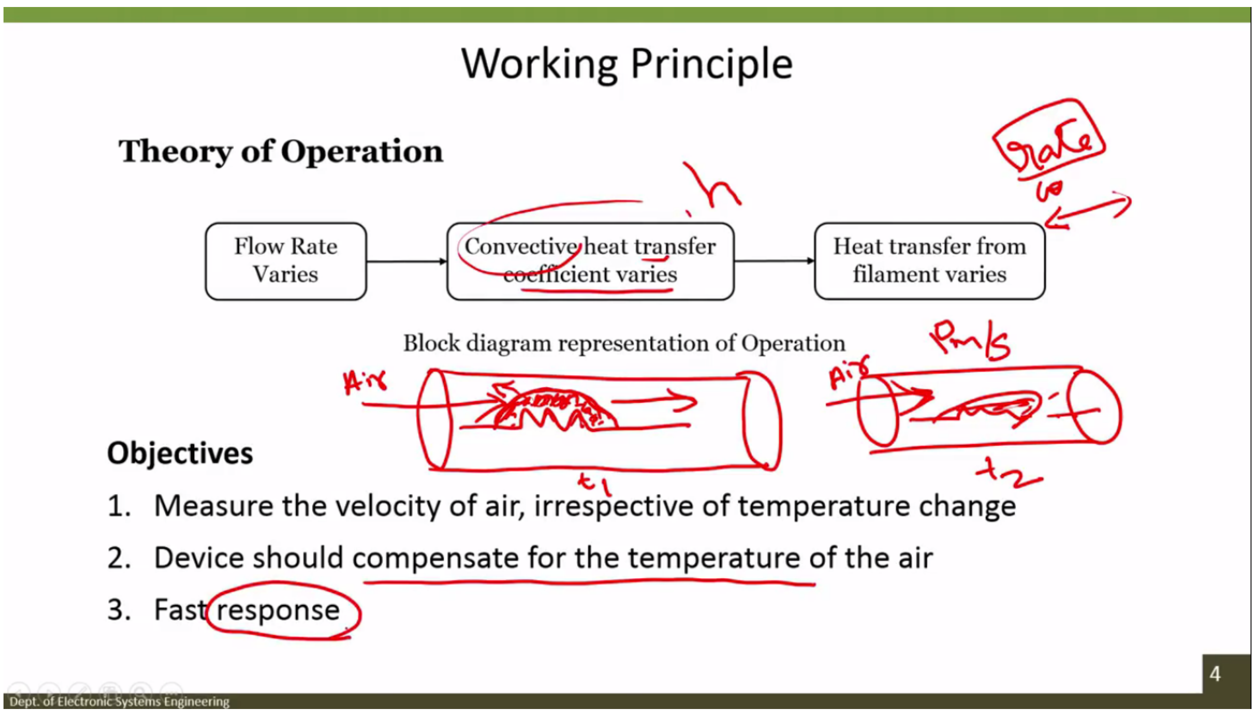
Further classification because we are interested in air flow meters, let's study how the air flow meters can be further classified. They are again classified , sub-classified based on what is the parameter that is being measured. So here this is the volume flow meter, velocity flow meter and then the pressure flow meter. But what is our major interest is to measure the velocity of the fluid flow. And again so when we are talking about the velocity of the fluid flow again the classification can be hot wire Anemometers or it could be the cup type Anemometers like you can see the symbol here. The figure here is one such type of a cup type Anemometer. If you have observed these have been installed where the wind mills are located.

So everytime the cup shape here rotates based on the speed at which the wind is blowing and that factor is being leveraged to understand the velocity of the air. So these are majorly used in the wind mills and hence the name wind mill type Anemometer. And the other classification is the Laser Doppler Sonic Anemometer, Ping-Pong ball Anemometer. You could study more about it. Let me just brief you about what is a Laser Doppler Anemometer. So this figure here talks about the Laser Doppler Anemometer.

As you can see there is a source that is the Laser light, a splitter and then the lens. So the Laser light here of a particular wavelength Lamda is focused onto a chamber where there is a flow of fluid with different particles. And what happens is each particle dimension basd on the rate at which the fluid is flowing the reflected light has Lamda one that is the reflected light is of a different wavelength which is being taken care by the light detector here. So this difference in wavelength of the incident and the reflected light is used in Laser Doppler Anemometer. This technique is non-intrusive. So depending on the type of application you could choose the type of Anemometer.

Now this was the details about the Laser Doppler velocity meter which works on the principle of Doppler effect. Now let's focus on what is a hot wire anemometer. Like the word here, hot wire it's nothing but a wire or a coil that would be heated. Let's get into the details and let's see how the flow of air in one direction can be leveraged to understand the rate at which the heat from this wire is being convected, convection. The heat here is being convected into the fluid medium here and the rate of convection is what is used to study the rate at which the fluid is flowing through the given medium. Again sub-classifiction of hot wire Anemometers are constant current Anemometers and constant temperature. Just like the term here when we say constant current there is a I, the current that flows through the register here remains constant and when we say constant temperature, the parameters, the resistor here is always maintained at a constant temperature. Say we are using a PT 100, when we say PT 100, 100 ohm platinum wire is being used. So 100 ohm at zero degree Celsius. So this is at zero degree Celsius, this is 100 ohm and then how do you constantly measure the temperature.

Let's get into the further details about constant temperature Anemometers for today. now the working principle is like I mentioned the flow rate varies.

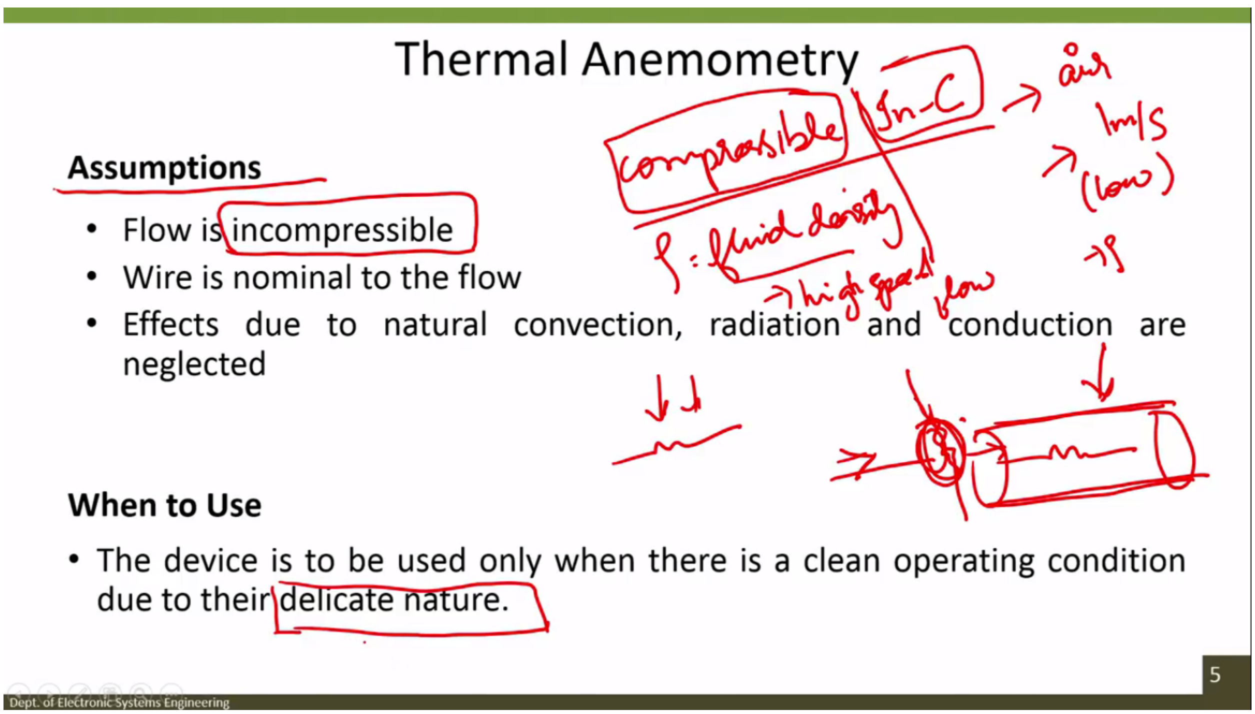


Let's assume this is your heater and this is the chamber through which the velocity of the fluid has to be measured. So let's say air is the medium and it flows through this. And now when I heat this at certain temperature the self heating of the heater radiates heat, there is an increase in temperature and this medium which surrounds the heater area gets heated. And what happens when air flows through this the amount of heat is being consumed. So this is nothing but convection. So the heat here is being taken away by the air and as it flows through the heater to the other direction it gets convected to the medium.

So what happens to the profile? After sometime so if this is the direction of air and if this is at T1 and at T2 the heat is shifted because of the fluid velocity and it is being convected into the medium. Now this is the theoretical – the theory behind the operation of an Anemometer. Flow rate varies. So this is – if there is an increase in speed say now it is at 1 meter per second. So there is some rate of convection. What happens when I increase it to 10 meter per second? At higher rate the amount of convection increases and the cooling effect of the heater becomes quicker. So the flow rate as the flow rate varies the rate of heat transfer also varies and hence the heat transfer coefficient h is what is a parameter which has to be considered here. And then the heat transfer from the filament varies. So this is the basic working principle when you are talking about a hot wire Anemometer.

Now what are the objectives? So we have to measure the velocity of air irrespective of temperature change because I said we will be talking about constant temperature Anemometer. And the device should compensate for the temperature of the air. Temperature compensation becomes very important. I will detail you about the method of compensating for the current temperature in the next slide.

And another objective is the response time. So how quickly is your measuring the heater instrument here and if there is a sensor what is the response time. So as you vary the rate at which the flow increases from one meter to 10 meter per second you know that there is a change in convection. So during what time is the rate of convection, the rate of convection rapidly increases. So is this rate being captured by your sensor or the detector if it is placed here. So the response time of the measuring instrument also becomes an important parameter and let's see how we can measure them.

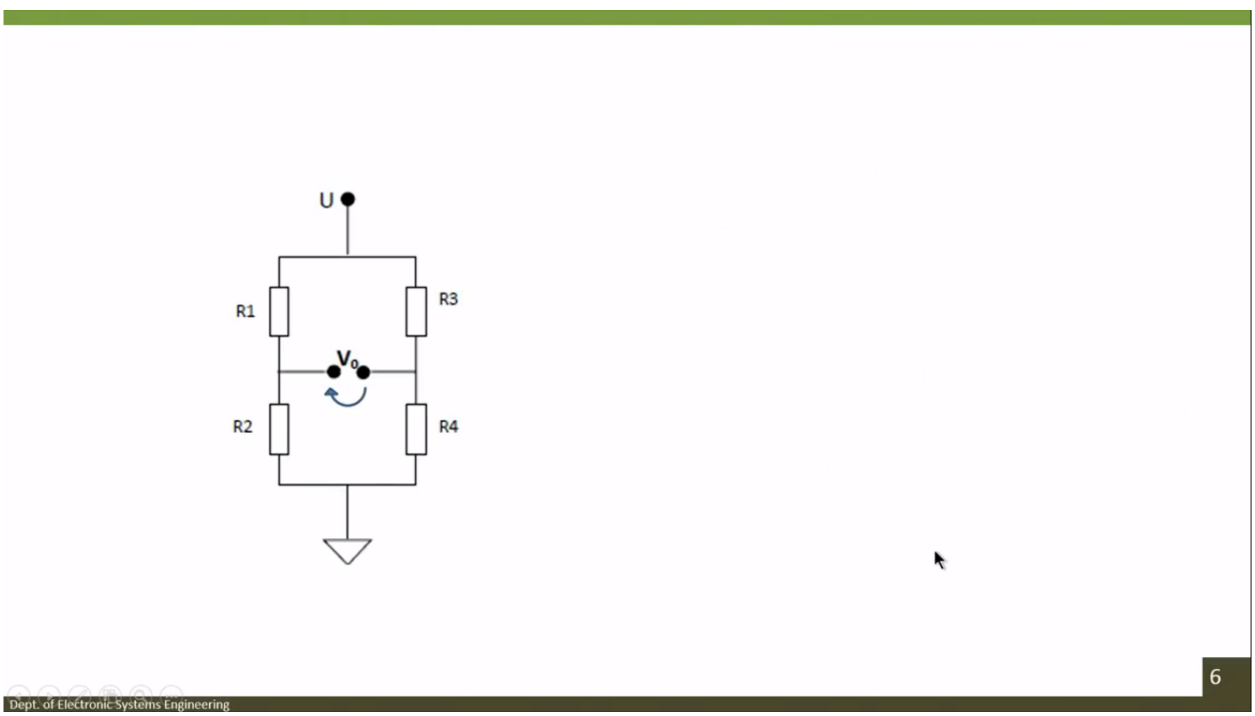


A few assumptions which has to be made while you are studying about a constant temperature type Anemometer is the flow is incompressible. So what do you mean by compressible and an incompressible fluid? So when we say compressible versus incompressible fluid here the density rho that is the fluid density varies with pressure. That if the fluid density varies with pressure during it's flow then it is called as a compressible fluid. However, if the density remains constant irrespective of the pressure then it is said to be incompressible fluid. In general compressible fluids come into picture when there is high speed measurement. When there is a high speed flow then you talk about compressible but we are talking about flow rates at one meter per second which is a relatively lower speed. And hence now that we are using air as the medium and the flow rate is relatively low and then assuming the density doesn't vary with pressure we are assuming it is incompressible. I hope you understood why the assumption is made.

Now that we have understood air is the medium and how it becomes incompressible. The next assumption that is made is the wire is nominal to the flow. So it is always say assume what happens just the basic principle is if there is a flow and you have the rate of convection becomes faster. The more surface area is exposed to the fluid medium, the more effective are your results and the measurement become easier. So the general convection is to have it normal to the direction of the flow.

Effects due to natural convection. Natural convection in case we don't like I mentioned before so I assume this is your platinum 100 and then this is the chamber through which air is flowing. So I have a medium here. The external agent, the external environment cannot affect the medium which is inside. However, if it is just exposed like this and it is prone to the external environment condition then you have to take care of the measurement errors. And the assumptions what we have made here is the effect due to natural convection radiation and conduction are neglected. With all these assumptions let's see the other point, the device is to be used only when there is a clean operating condition due to that delicate nature.

The word delicate here has been used. So I will tell you the details about why the term delicate has been used and why does it become an important parameter while we study the constant temperature type flow meter.



Now this is the basic circuit. Here like you all know this is the [00:18:11] switch. The supply here, the ground r1, r2, r3 and r4 let's understand where does your heater element go, where does your temperature compensating device go in this circuit and what is this, the difference between the voltage at this point and at this point. So let's study more about what are the different parameters that goes into this measuring unit. Before we get into details let me brief you about what is an RTD. R stands for resistance, T is the temperature, and D is the detector. Now why am I telling you about RTD is RTD like I mentioned it stands for the resistance, temperature, detector.

Now this is a type of temperature sensor where the resistance R directly depends on the temperature T. When the temperature changes it could be increased or it could be decreased the sensor resistance will increase or decrease accordingly.

So the choice of the type of a RTD sensor plays an important role while you are studying an experiment about the hot wire Anemometer. So by measuring the sensors resistance what can you achieve? So you would indirectly be measuring the temperature or vice versa. Now RTD sensors what is the type of material what goes into making of these RTD sensor so they are usually platinum, nickle alloys, copper, and various other types of metal oxides. We will be talking about a type of RTD sensor where we will be using platinum. And why platinum, PT100 becomes the heater or the thermal element in our device here. Why PT100 is what I will discuss.

Let's say the choice of this resistance becomes very important because we are directly – we want to measure a very precise rate at which the fluid is flowing. If we are trying to compromise on the type of sensor then the measurement errors would be higher. So we need a sensor which is highly sensitive to changes in temperature and this becomes an important parameter for us to use PT100. A few advantages of using platinum the PT100 here. Okay when I am saying PT100, 100 here stands for 100 ohm resistance at zero degree Celsius.

Now that we know why PT100 becomes an obvious choice for our experiment let's see the advantages of using PT100. The advantage is like I mentioned one, it is more sensitive to the change in temperatures and it has a reliable, repeatable, and linear temperature resistance relationship. So this linearity is an important factor. And another advantage is the sensitivity. Now you know the linear relationship between temperature resistance and its sensitivity becomes very important and hence platinum 100 is being used.

So this was all about RTD, the resistance, temperature detector. I am sure you have also heard about what is called as a thermocouple. How different is a thermocouple from an RTD? You also are – you should have heard about the word called thermocouple where the resistance again changes with temperature. So why not call platinum 100 as a type of thermocouple. There is a different between thermocouple and RTD sensors. So what is the difference between the two? Thermocouple are again temperature sensors. However, why are they not used in our circuit here is they are basically designed for high temperatures. So if you want to design an Anemometer measure the flow of fluid and it is running at relatively very high temperature and the choice would be a thermocouple and not an RTD sensor.

Another parameter is the thermocouple is highly robust in nature. So what I suggest is go ahead and look at the different available thermocouple in the market, their ratings, the sensitivity, and compare them with the commercially available RTD sensors. That can give you more clarity about how sensitive they are, based on your application, what is the choice you can make, can you use a thermocouple or an RTD sensor and another difference between the thermocouple and the RTD sensor is thermocouple are – they are not really accurate when you compare them with the RTD sensors and they are reasonably inexpensive when you compare them with RTD sensors. Another point, another different between the two is thermocouple requires cold junction compensation. However, that is not required when you are talking about an RTD sensor. In case there is any type of inhomogeneity in the temperature in the medium or the measurements circuit then there could be measurement results in case you are using a thermocouple and if you want a highly sensitive device which is not really working at very high temperatures and you do not want a robust however, accuracy becomes important, then you go with RTD sensors.

So now you know the difference between the commercially available thermocouple and an RTD go ahead and look at the differences, look at the data sheets, and then you will understand what is the right choice to be made based on your application and the circuit analysis in case you want to do any further studies.

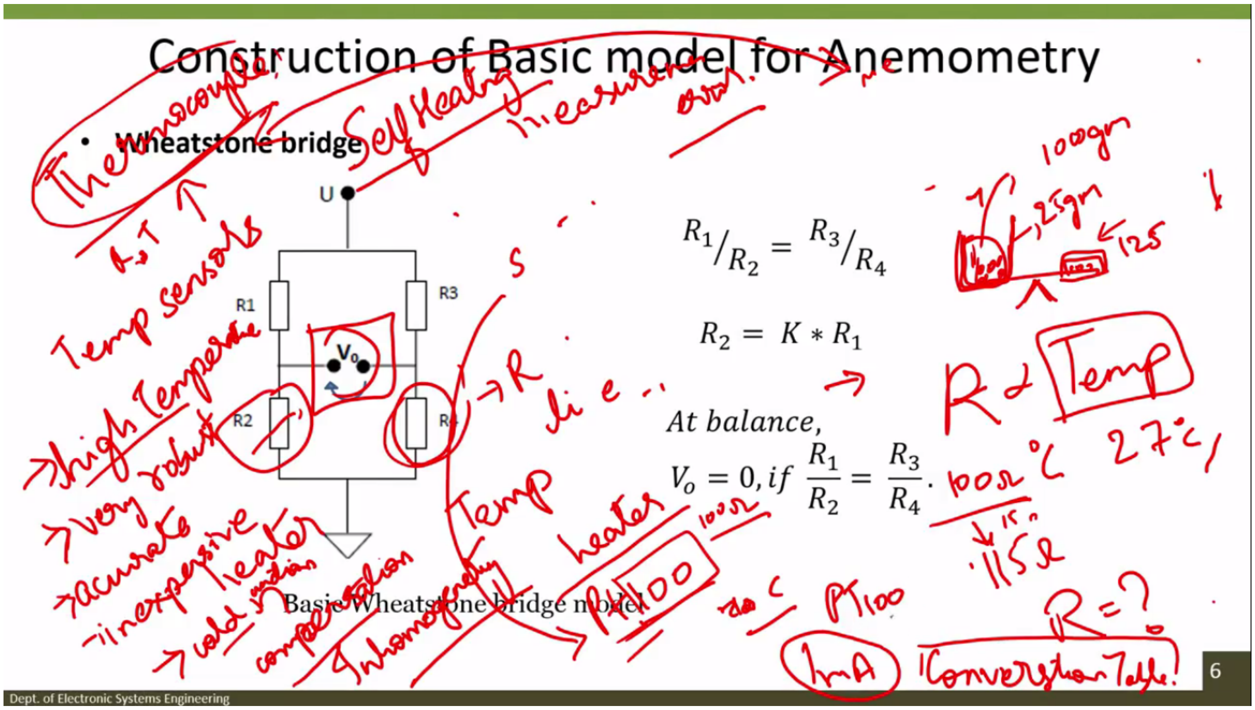
So RTD sensors are more accurate, linear, stable than the thermocouple and they do not require cold junction compensation. They are more fragile and they are expensive. So this was the factors that affect the change in resistance, and while they measure the change in with respect to their temperture, the change in resistance with respect to temperature. So if you are talking about an accuracy the choice becomes important between the different classification or the types of resistors. And another important factor which you have to understand when you are studying with resistors understanding the use of resistors and temperature compensation and other circuits is self heating.

So what is self heating? When current flows through RTD sensor so for now we are talking about an RTD sensor and when current flows through this sensor what happens is it causes the sensor to slightly warm up. And as it flows the warming up of the sensor creates heat around the medium. So this phenomena is called self heating. And say I use a very high current to flow through the resistor what happens if the very high current flows through a relatively longer time then you see that the warming up of the sensor becomes more rapid and there is lot of heat that is generated. Do not exceed the specification. Always make sure you look at the specification. If your sensor is designed for certain range of currents then do not exceed it to that level and what happens it gets heated and that is not what you want. There is no errors which you want while you are doing any sort of measurement. So this was an important parameter. Self heating will cause measurement errors and how do you avoid say you have platinum 100 in case you are using platinum 100 and the specification reads maximum tolerance of 1 milli ampere . Make sure you do not exceed that one milli ampere of current which is flowing through your PT100.

So this was all about understanding the tolerance specification and what is the choice of sensors which you have to use while you are making up the circuit.

Now let's get into the details of the circuit. So this was the basic model of the Anemometer. This was all about the wheatstone bridge circuit. Like you can see the four arms of the bridge and when they are balanced the voltage between the two arms is zero like I said R1 by R2 if it is equal to R3 by R4 then the voltage difference here remains zero and this is what you want always throughout your experiement. The V0 should be maintained to zero that is the bridge should be balanced and where does your temperature compensation come into play.

For instance, let's say you have a weight and you are weighing a crucible and you want 100 gram of substance. Say 100 grams of substance goes into this. And then you put a weight of which measures 100 gram. Would this give you an accurate result? Is this balanced? No. What about the weight of this crucible. Say the crucible weighs around 25 gram. Are you compensating for the weight of this crucible by just placing a 100 gram weight on this side? No, right. So you have to place 125 gram in order to compensate for the 25 gram of this crucible and only then you can accurately measure 100 grams of this substance. In the same way we have the temperature compensation. Because the major application here is you are understanding the change in resistance based on your temperature change. Ideally for instance platinum 100 it gives 100 ohm at zero resistance.



So 100 ohm resistance at zero degree Celsius. However, when you are using it at room temperatures the temperature is around 27 degree celsius how do you compensate? It is no more 100 degree. There is a variation. It could be 115 ohm. Who is going to compensate for this 15 ohm additional? So if you want a bridge to be balanced always make sure you use the compensating circuit and how do you understand what should be the resistance of the compensating circuit all of this can be understood when you use the conversion table.

What I suggest you here is go ahead and look at what is the temperature to resistance conversion table for a PT100 resistor. So if you check online you will get a table where for a given temperature starting from zero, starting from minus temperature to zero and then positive temperature how the R value of PT100 varies. So this is I am being specific to PT100 because that is what will be used but in general every RTD will have a conversion table which will brief about the relationship between temperature and resistance.

So what you have to do now is go and look for conversion table of PT100 and then based on that you can design your temperature compensation unit.

Now this was the basic construction model for an Anemometer.