Experimental Methods in Fluid Mechanics

Professor. Dr. Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati
Guwahati - 781039

Lecture 20

Thermal Anemometer (hot wire/hot film)

Hot wire anemometer Contd.

Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics. And, we will continue our discussion on flow measurements. And we have discussed this aspect in my last lecture that, we can measure flow velocity using another important instrument that is thermal anemometry. And if you try to recall that flow measurements, it may be the measurement of flow rate, volumetric flow rate, mass flow rate or it may be the will measurement of you know, point velocity or it is determination of the flow stream lines.

Now, we have discussed that thermal anemometry which is used to measure the point velocity measurement.

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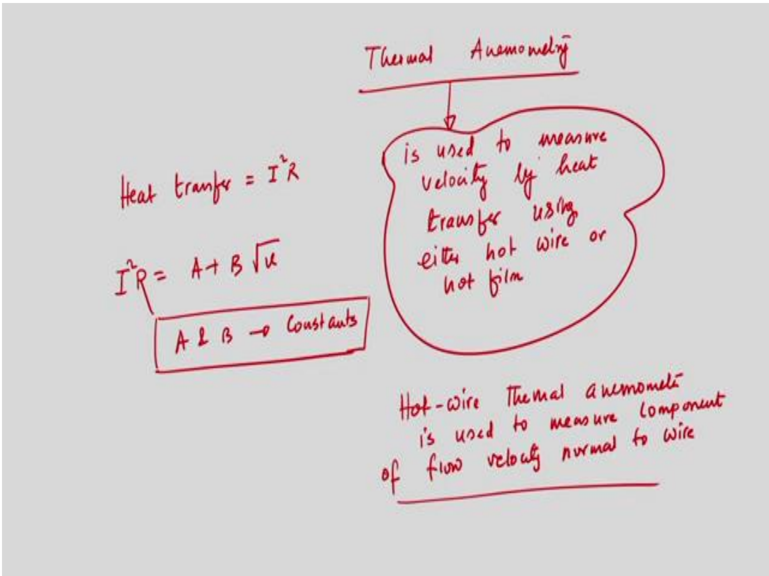

So, we have discussed about that thermal anemometry, this thermometer anemometry basically is the, you know, thermal anemometer that which is used to measure, you know velocity using heat transfer. And of course, I can say is measure velocity by heat transfer using either hot wire or hot film. So, this thermal anemometry is used to measure velocity of hot, velocity by heat transfer using hot wire or hot film. And we have discussed that hot film or hot wire is basically, you know a metal wire of diameter is one tenth diameter of the human hair.

And hot film is again, metal film, very thin film which is, I mean metal film on a glass. And this wire or film when you talk about, these are basically electrically heated, I mean element which are electrically heated and placed in a flow field. And by measuring the heat transfer we can measure the flow velocity and in fact, we have seen that the, you know heat transfer that is essentially you know, heat transfer that is I square R and this I square R, which is I have told that, you know that is experimentally and analysis and experimental evidence indicate that this is A plus B under root U where A and B are the constant.

And these constants are determined using experimental data. And so, knowing the value, I square R, that is heat transfer we can calculate the velocity. And we have discussed you know, the hot wire, you know thermal anemometer and we have seen that hot wire thermal anemometer is used to measure flow velocity, I mean I can say component of flow velocity normal to wire. So, we have schematically described that the in fact, the different dimensions of hot wire thermal anemometer and we have seen that these hot wire thermal anemometer is used to measure component of low velocity which is normal to the wire.

But, it is not the case that always you can, always the measurement will be the correct one because the heat transfer, so the component of flow velocity which is parallel to the hot wire is also responsible to take, I mean the heat transfer that we have measured that also includes the you know, component of flow velocity that is parallel to the hot wire. That means, what I can say that the heat transport that is also affected, the heat transfer that is also affected by the component of flow velocity that is parallel to the wire.

But that we, you know, to if you would like to include that, but we have discussed that, that effect is not very high and that can be intuited. But, the question is if really the component of flow velocity which is parallel to the wire is very high, I mean, that may be the case for the travel and flow, where the flow velocity is highly chaotic in nature, then the hot wire anemometer, that we have discussed in the last class may not work.

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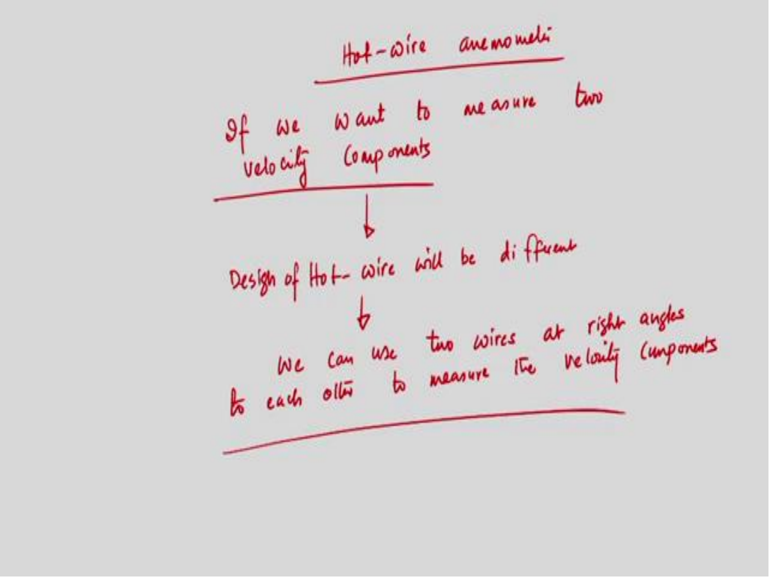

So, that means, the hot wire anemometers that we have discussed in the last class that the normal component of flow velocity which is, I mean the component of flow velocity, the heat transport is, you know that would will be affected by the component which is parallel to the wire. But that, that component is not significant, when we talk about very you know, where the flow is not turbulent and the measure value flow velocity may not be the, I mean, you know, wrong.

So, I can say the, if the flow field is highly chaotic, highly turbulent, then the component of flow velocity will be there and the existence of the component of flow velocity, which is parallel to the wire will also affect the heat transfer and for that the simple, you know (())(7:39) that we have depict, that we have discussed critically those hot wires may not work. Now, question is, that means, if we want to measure 2 velocity components, that means, if we want to measure 2 velocity components. So, it is not always the case that we will have only 1 component of velocity.

So, if you would like to measure the, measure 2 velocity components, then hot wire, I can say, I mean the design of hot wire will be different and I can say, we can use 2 wires at right angles to each other to measure the velocity components. So, the schematic depiction we have seen in the last lecture, where we had only 1 hot wire and that using that hot wire anemometer, we can definitely measure the velocity component which is normal to the wire but by measuring the heat transfer. But you also need to know that, the existence of velocity component which is parallel to the wire will disturb, will affect the heat transfer.

And if you would like to really measure the velocity components, I mean 2 components then we need to modify the design of hot wire and one such modification is that we can use 2 wires at right angles to each other, to measure this components. So, now we will try to see the schematic depiction of the hot wire, 2 wires are used and 2 wires are, you know, placed right angles which are there at what to measure the components.

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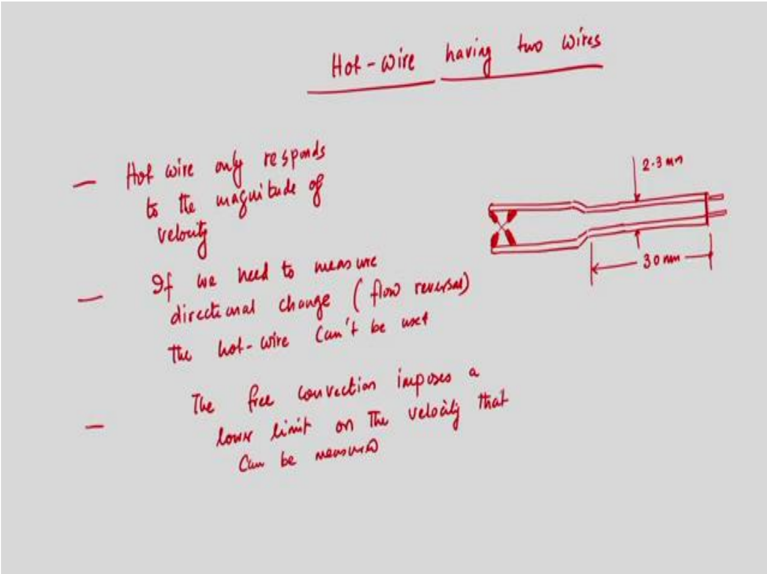

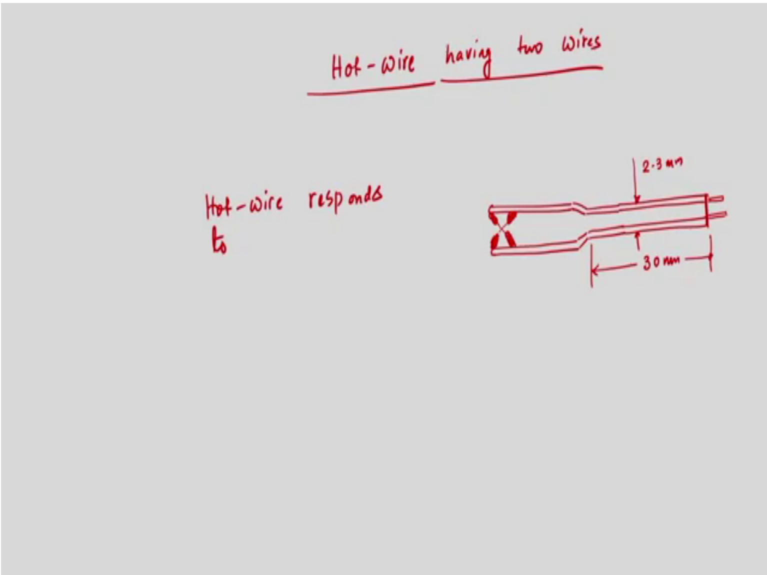

So, now we will try to use that hot wire having 2 wires. So, we will now see the schematic depiction of the hot wire, so now I will try to draw that, this length is 30 mm just I am showing the, I am showing different dimensions and this is 2.3 mm diameter. And, now we have 2 difference wire and these wires are placed right angle to each other. So, this is I mean, hot wire having 2 wires and these 2 wires are at right angle to each other.

Now, a few important things that we should note that these hot wire response to, rather I can say hot wire only response, I can write these things that hot wire only response to change into the magnitude of the velocity I can say to the magnitude of the velocity. So, we have discuss about hot wires. Now, hot wires means, we have seen that only single wire. And then we have seen that, if the, you know if we need to place this wire, hot wire anemometer to measure flow velocity in a flow field where the flow field is highly chaotic, then the measurement may not be the correct one.

But when the, I mean if we the, if we consider that the, you know disturbance rather I can say you know, the heat transfer for measurement, which will be affected by the component which is parallel to the wire, if it is very less then we can measure the velocity component. But, it may not in the case always that I said many times, so we need to modify the design and this is the schematic or you can see that 2 wires are, dot 2 wires that this hot wire anemometer is having 2 wires which are you know, placed right angles to each other, right angle to each other.

Now, a few important things that we need to note that hot wire only response to the magnitude of velocity, but very important thing that if you need to really know whether the reversal of velocity is there and that the hot wire cannot you know, I mean cannot be used at all. So, if we really, if we need to measure only the magnitude of the flow velocity then this instrument can be used, but if we need to know the flow reversal, then that means a directional change the flow. So, that means, I can say if we need to measure directional change, that is flow reversal the hot wire can be used.

And I know think, so these are the important things we should note this hot wire, we can use to measure point velocity, this response only to the magnitude of velocity, if we need to know that directional change of the flow velocity component that is the flow reversal is there, this hot wire cannot be used. And also, the free convection effect, the free convection imposes a lower limit on the velocity that can be measured. So, the free convection also limits rather emphasis lower limit on the velocity that can be measured, I mean velocity that can be measured.

So, these are the important points we should note, at least when you are discussing about the thermal anemometer. This is one of the most important instruments which is used to measure point velocity, that we will discuss again today. And we have discussed about the geometrical safe and of defined hot wire, hot wire is having only single, only 1 wire that is single wire. And we have seen the limitation of the hot wire anemometer when it is having only 1 wire because in, at that time, because mostly rather I can say not mostly, this instrument is used to measure flow velocity by heat transfer.

So, the heat transfer that will be there because of the, you know other components, I mean, it is not the fact that always there will be heat transfer because of the normal component of flow velocity. So, if we really need to measure the velocity components in a flow field and that is more practical in different situations. So, in that case we need to modify the design that in that case, we need to have at least 2 wires and wires will be placed right angle to each other, and we can measure components of velocity.

But, while we have discussed this hot wire technique which is used to measure, we also should discuss the limitations of this, limitations which are there rather which are associated with the, with these instruments to measure the flow velocity components. That is hot wire can only, you know used other this wire only response the change in rather magnitude of flow velocity but the change in direction that is flow reversal cannot measured.

And of course, free convection that will be there that cannot be you know eliminated, there will be always a free convection effect. So, that effect imposes limits on the flow of velocity that can be measured. Now, we have discussed about the hot wire, in fact, we have discussed about state general purpose hot wire flow. I mean, we have shown its different dimensions and we have discussed about the case where we need to have, we have only 1 wire, we can measure.

We have also discussed that the requirement of 2 different wires because the flow field may not be always the you know, I mean there will be it is not, I mean flow field may not be always very laminar where only a single component with it. If it is highly laminate, then the flow field which is you know, they are parallel to the wire, that will definitely affect the heat transfer but we can ignore because of its magnitude but this only the case for the you know, chaotic flow scenarios. So, in the, in those cases, we need to modify the design that we have seen.

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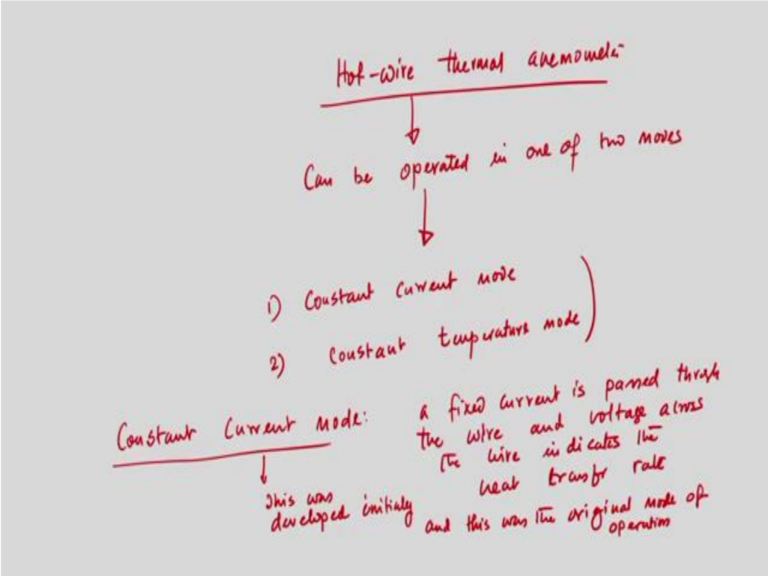

But we should know, that this hot wire thermal anemometer these can be operated based on 2 modes. So, this can be operated in, in one of the 2 modes I can say, in one of the 2 modes, 1 is constant current mode, number 2 is constant temperature mode. So, this instrument can be operated in one of these 2 modes, either constant current or constant temperature mode. Now, if we, but at least we should know that what is happening in constant current mode.

So, if we now talk about constant current mode, so constant current mode, in this mode, again I am telling 1 hot, the thin wire is there. So, these are, these wires are heated electrically by passing current through them and then the, this instrument is placed in a flow field. So, when the fluid is approaching that current there will be heat transfer and that heat transfer that we have seen analytically and experimentally evidence indicate that, that is nothing but I square R that is a heat transfer and that is A plus B route U, A and B are constant that is obtained experimentally.

So, knowing the heat transfer, now we can calculate the flow velocity component by, since A and B are known. So, in constant current mode what is done, a fixed current is passed through the wire and voltage across the wire indicates the heat transfer rate. So, our objective is to know the heat transfer rate I square R. Now, knowing this heat transfer rate, we can obtain the flow velocity component, I mean whether it is, if only one component is there but if it is, you know kind of chaotic flow then there will be multiple components.

But again, we have seen that 2 wires can be placed right angle to each other to measure the, you know, normal component as well as the lateral component. But, in the constant current mode, what is done, a fixed current is passed through the wire and voltage across the wire is where that is an indication of the heat transfer rate. Now, this constant current mode that is that was developed initially. So, I can say that this was developed, I mean initially, and this was the original mode of operation.

So, the hot wire thermal anemometer when it was developed, it was developed on the basis, rather that it can be operated using constant current mode, that meant a fixed current is passed through the wire and the voltage across the wire is measured, at which is nothing but the indication of the heat transfer rate. So, this was the original mode of operation of the hot wire thermal anemometer.

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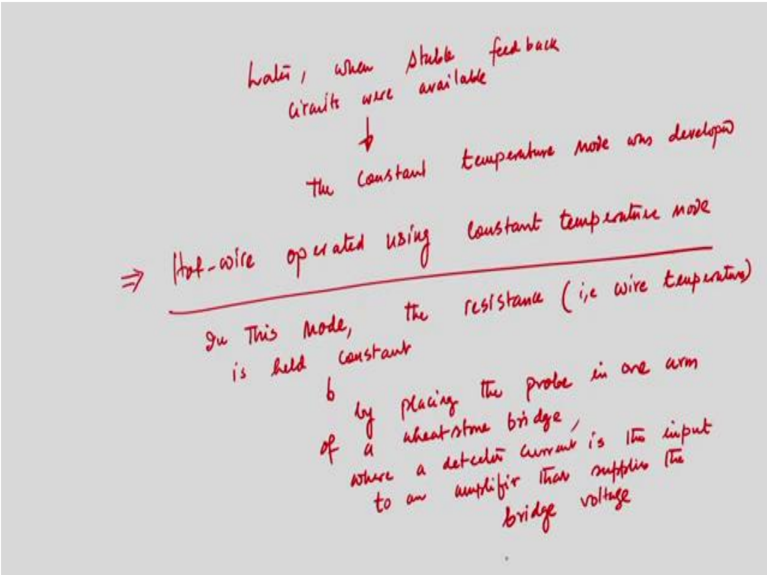

But I can say that when, but later when stable, when stable feedback circuits wire available, then the constant temperature mode, that is another mode the constant temperature mode was developed. So, when the stable feedback circuits wire available, then constant temperature mode was developed and again I need to know what is, what is new in this mode, and if we follow this mode to measure the flow velocity using hot wire than what is done. So, the hot wire operated using constant temperature mode and in this mode, in this mode the resistance, that is the wire temperature is held constant.

So, constant temperature, resistance of the wire is held constant. So, and the voltage rather by how, by placing the probe in one arm of a Wheatstone bridge, that we have studied in our class 2 level physics.

And so, the objective is to maintain a constant temperature of the wire by how, by placing the flow of in one arm of a Wheatstone bridge. And the detector current, rather I can say where detector current is the input to an amplifier that supplies the bridge voltage. We will now try to see it schematically, but so this is different than, this is different from the constant current, where we have fixed current is passed through the wire and that is what we have discussed in the last slide that a fixed current is passed through a wire and voltage across the wire is measured and that is the indication of the heat transfer rate.

But in this mode, the resistance, temperature of the wire is held constant by how, we can make it, we can make the, rather we can consider or we can maintain the resistance of the wire is constant, by placing the probe in one arm of the Wheatstone bridge where a detector current is the input to an amplifier that supplies the bridge voltage. So, now, if you try to look at, rather if you try to you know see the schematic depiction of the constant current hot wire anemometer, it will look like this.

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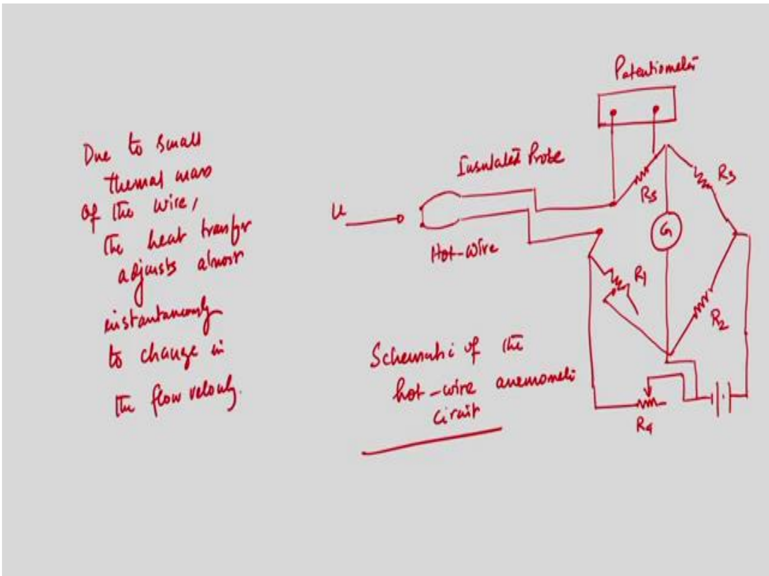

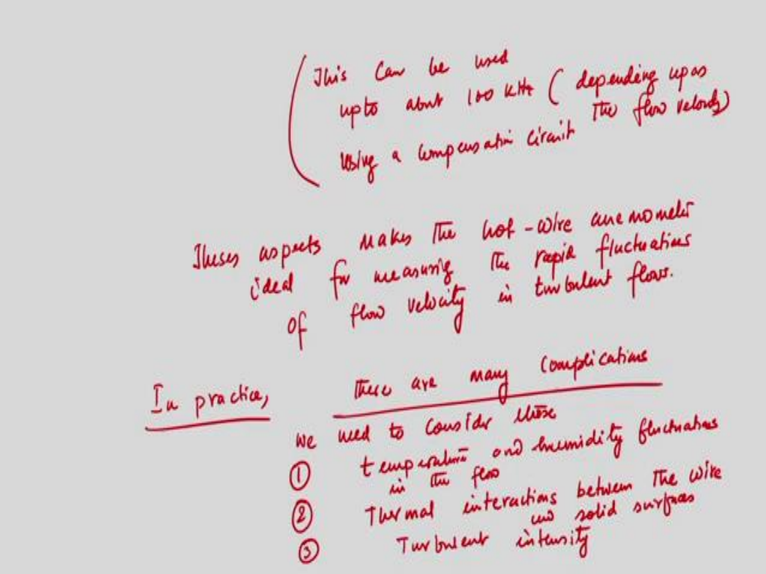

So, there is no any, so this is hot wire and so the, this is placed in one arm of the Wheatstone bridge. I am not going to explain because we have studied this in class 2 level, 10 plus 2 level you have studied this. But at least, I am trying to draw the schematic and say this is R2, this is R3, this Rs, this is R1 and this is R4. Now, this is hot wire and this is the flow velocity u and this is insulated probe. So, they are not in a heat loss insulted probe and these 2 points as I said, that these 2 points and that is potentiometer

So, this is potentiometer. So, this is a schematic of the hot wire anemometer circuit. Now, as I said that here the temperature of the wire is maintained constant by placing it in one side of the Wheatstone bridge. And next is, the detector current is the input to an amplifier. So, a detector current is an input to the amplifier and that supplied the bridge voltage.

Now, so using now again by measuring the heat transfer, we can calculate the flow velocity, but again the design will be modified, if you really would like to measure, I mean if the, if you would like to measure the 2 components, in that case, we need to have 2 wires which will be placed right angle to each other. And the, in a design, geometrical shape of the hot wire whether we are like to interested to measure velocity components.

In that case, we need to have 2 wires but if we ignore that the, that if we ignore that means that the heat transfer that will be affected by the distance of the lateral component of velocity and that is really small, I mean, if we can ignore if the flow field is highly laminate. In that case, that aspect can be ignored. In that case, this is the actual schematic to measure the flow velocity of (())(34:28) flow velocity and here we are maintaining the, you know temperature constant and we are placing this probe in one arm of the Wheatstone bridge.

Now, again another a few important aspects that we need to know that, you know small thermal mass of the wire. So, I can say due to small thermal mass of the wire, the you know heat transfer adjust almost I can say instantaneously, instantaneously to change in the velocity, flow velocity. So, due to a small thermal mass, mass is not very high, so the, that effect due to the inertia that is the inertial effect is not there. That means, this is very sensitive instrument that is what I would like to convey, that the thermal mass of the element is very small.

So, the moment when it the flow velocity that, I mean that the component of velocity is there, so heat transfer will adjust instantaneously to change in the velocity. So, with the change in velocity component, the heat transfer that will be there that will change itself, you know that the heat transfer will adjust, so fast that we can measure accurately. That means, that effect of inertia, the lagging that aspect should not be there. So, I mean the flow velocity I mean, when the, I mean when the wire, we are placing wire in a flow field, so velocity is there but it is not the case that we can measure the, you know heat transfer after some time because that effect is not there.

So, the inertial effect because of the thermal mass that is not there due to the very small amount of thermal mass, very thin film, thin wire. So, that aspect is not there. And because of this, this is one of the most important that I can say, very accurate. This used to have, used to measure velocity competent accurately. And not only that, this because of this, I can say that it is so fast that a 5 micron diameter uncompensated wire will response well to 1 kilo hertz, velocity fluctuation. So, only a 5 micron diameter uncompensated wire will respond well to 1 kilohertz velocity fluctuation.

But if you try to compensate it again, I mean now I will write it that if we try to compensate that means and not only, and this also I can say that this can be used to, rather up to about 100 kilo hertz depending upon the fluid velocity, depending upon the flow velocity, using a compensation circuit. So, the response is very fast that is what I would like to convey over here that, this wire can still be used up to the 100 kilo hertz depending upon the flow velocity using a compensation circuit.

So, these aspects, so I can say these aspects makes the hot wire, you know anemometer ideal for measuring the rapid fluctuation of velocity, I can say flow velocity in turbulent flows. So, this is one of the important point that it can, I mean thermal mass is negligibly small and because of this, a 5 micron uncompensated wire can, that is what I have written will respond well up to 1 kilo hertz velocity fluctuation, but this still can gives up to the 100 kilo hertz, depending upon the fluid velocity components using a compensation circuit.

And this feature I can say, this important feature makes the hot wire anemometer ideal for measuring, you know rapid fluctuation that is there in a highly chaotic flow environment that is in the turbulent flow. But we have discussed many important points, we have discussed the design, I can say we have discussed the operational principle of the hot wire anemometer. We have discussed about the modes of operation; we can use either in constant current or constant temperature mode.

And we have seen that if we really need to measure the velocity components which are there, that is a normal component and the you know, lateral component, then we need to have slight modification in the design that we need to have 2 wires, which are right angle to each other. Then also, we have seen that this wires are I mean, can respond well with a change with a magnitude of flow velocity, but if you need to really measure the, you know directional change that is the reversal, just precisely I can tell, that cannot be used.

And then, we have discussed that this because of the very small thermal mass, the inertial effect can be ignored and this heat transfer adjust so instantaneously the flow velocity that even a 5 micron diameter uncompensated wire can respond well up to the 1 kilohertz velocity fluctuation and if we need to, you know, use it for even for a larger fluctuation that can be used using a compensation circuit. And because of this, you know, advantages features, the hot wire anemometer is much more suitable to have a flow velocity measurement, in a chaotic flow environment that is in a turbulent flow.

So, we have discuss so many points, but finally, we need to know that there are a few, you know, complications, rather I can say there are many complications that have to be considered, while we are using this instrument to measure the flow velocity. So, in practice, there are, I can say many complications and we should know this, at least if you know them then when you are using this instrument rather hot wire or I mean hot film anemometer in a flow field, we should take precautions. So, there are many complications and those complications we need to consider. So, we need to consider those.

Number 1 is, you know temperature and humidity fluctuations, in the flow. So, if we have, rather if you need to measure flow velocity component in a flow field wire, temperature and humidity will fluctuate. I mean, if the temperature and humidity fluctuates then we will have, rather we will face, you know, difficulty, rather to measure flow velocity. And, because temperatures change if that is there then I mean, because we are measuring flow velocity by measuring the heat transfer.

So, if that temperature is change of the fluid, then it will be very difficult. Number 2 is very important that the thermal interactions between the wire and solid surface. So, that means, if we go back to the schematic, you can see the small wire is connected between 2 ends. So, this wire is, the wire is connected with the solid surface. So, the you know, thermal interaction we cannot stop, the mass, thermal mass is very small, but we cannot really ignore the thermal interaction between the wire and the solid wall.

And that interaction we may not give us the correct, I mean if that interaction is still there that might leads to, you know error and complication in the measurement procedure. And finally, that is the turbulent intensity, turbulent intensity that means, as I said that this is this instrument is really suitable to measure flow velocity component, rather flow you know velocity in a turbulent flow environment.

So, depending upon the intensity of the turbulent flow there will be different issues like you know, dissipative effect and so many other things and those effects if we really need to considered, then, I mean these are the complications I can say, I mean those issues cannot be I mean, considered while we are measuring this, measuring flow velocity using these components.

But at least what I can say that the, you know large amount of I can say research this not only the, you know theory, but large amount of research on understanding the physics of the, you know hot wire anemometer have made this instrument much more popular, much more reliable instrument in measuring the, in flow velocity. So, when we talk about the thermal anemometer, it is not the case that defending rather, relying on the theory you are telling that this instrument is suitable for to, suitable to measuring flow velocity components, even for the turbulent flow field.

But a large amount of research that has been done, so I mean I can say large amount of research on the understanding of the physics, of the thermal anemometer that is very important, have made this instrument much more reliable, much more popular in measuring the flow velocity components in the other flow velocity, enough in different flow fields like, laminar and turbulent.

And I can say that, we have started our discussion to measure the flow measurements. In fact, we have started our discussion using the, you know flow obstruction fluid measurement and then flow measurement using the, you know drag. So, those 2 important instruments we have discussed, those instruments are use only to measure the flow rate, volumetric flow rate, mass flow rate. And then, we have started discussing using, we have started discussion on the point velocity measurement.

And I can say, that the thermal anemometer is one of the most important instruments which we can use, which is more reliable I can say and to measure the point velocity and if it is a laminar flow, even if it is not laminar flow, by designing, by suitably designing the, by suitably modifying the design of a thermal anemometer, it can be used to measure the velocity component, even in the chaotic fluid environment. So, with this I stopped my discussion today and we will continue our discussion next class. Thank you.