Experimental Methods in Fluid Mechanics
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Lecture 19
Thermal Anemometry (hot wire/hot film), Hot wire anemometer

Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics. Today, we will continue our discussion on Flow Measurements. In fact, we have started our discussion on Flow Measurements. But today, we will discuss another module that is Thermal Anemometry. And we will see, that the measurement technique rather how we can measure, you know flow.

Flow measurement, if we try to recall what we have discussed that flow measurement is basically 3 important flow characters, like it may be volumetric or mass flow rate or it may be a point velocity measurements or it is the determination of the flow stream line. In the last lecture, we have discussed about the volumetric flow measurement, volumetric flow rate measurement and for that you have discussed about this flow obstruction flow meter. And also, we have discussed about that how we can measure flow rate using drag.

But today we will see, another flow measurement techniques by which we can measure flow velocity using thermal anemometry. And, this thermal anemometry which is used to measure flow velocity by, you know heat transfer using in general 2 important methods that is either by hot wire or hot, hot film methods.

A hotwire, which is approximately one tenth diameter of human hair and a hot film is a very thin film or metal film on a class of state. And these elements, whether it is hot wire or hot film, these elements are electrically heated and placed in a flow from where the heat transfer, heat transfer is measured and measuring heat transfer that can be measured by using you know I square R.

Now, measuring heat transfer we can measure what will be the flow velocity. Today will see that, if you would like to measure flow velocity, either using of course using thermal anemometry, maybe hot wire or hot film we will see their geometric structure, their operational principle how we can measure. And also, will see the limitations those we need to consider while using these instruments to measure flow velocity.

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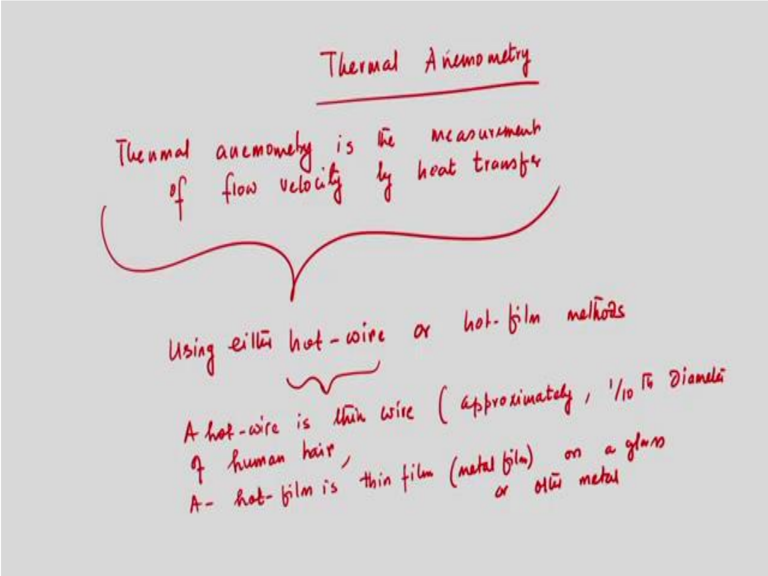

So today, we will discuss about the thermal anemometry. So, this thermal anemometry as I said, this thermal anemometry, this is the measurement, measurement of flow velocity this is by using heat transfers, by heat transfer. Now, so thermal anemometer which are used to measure flow velocity. Now, this is the measurement of flow velocity by heat transfer using either hot film or hot wire methods.

So, how we can measure flow velocity, it depends rather, the measurement of flow velocity is directly related to the measurement of heat transfer. When you are talking about measurement of heat transfer that is either using hot, you know wire or, so I can write, using either hot wire or hot film methods.

So, either hot wire or hot films. Hot wire is basically you know, hot wire, hot wire is a thin wire, which is approximately one tenth diameter of human hair, so, so thin. And, a hot film is thin film, metal film rather, metal film on a glass substrate or other metal. So, these elements whether it is hot wire or hot film these elements are heated rather electrically heated and placed in a flow field.

Then, we need to measure the heat transfer because these hot mass of the, thermal mass of the hot wire, the thermal mass of the hot wire is, you know very small so, that heat transfer adjust itself instantaneously with a change in flow velocity. So, what we have discussed, this anemometry is one of the, you know reliable instruments which is used to measure velocity.

Now, the thermal anemometry is used to measure flow, flow velocity using heat transfer. And using heat transfer now, how can we measure heat transfer, we can use by, we can use either hot wire or hot film methods. And this hot wire is a thin wire, which is approximately one tenth diameter of the human hair. And hot film is a very thin film basically a metal film, which is, you know a thin film on a glass substrate or any other material.

Now, these elements are electrically heated and a placed in a flow field. And as I said, that very low mass of these, you know thermal mass of these hot wire, they adjust instantaneously with a change in velocity. Now, we will discuss that when you talk about flow velocity, whether can we place these instruments in a flow field, which is highly chaotic in nature or we need to place, even if we place this instrument, rather thermal anemometry in a flow situation where flow field is highly chaotic, then how we can measure the actual flow velocity using this instrument.

And, at the beginning I said that when we talk about flow measurements because in this module, we are discussing the flow measurements technique and this is the sub module where will be discussing flow measurement but not the volumetric or mass flow rate, rather is a point velocity measurement.

So now, we will try to draw a schematic depiction of the hot wire or hot film thermal anemometry and from there we will try to see how we can measure heat transfer, and from there we can measure the flow velocity.

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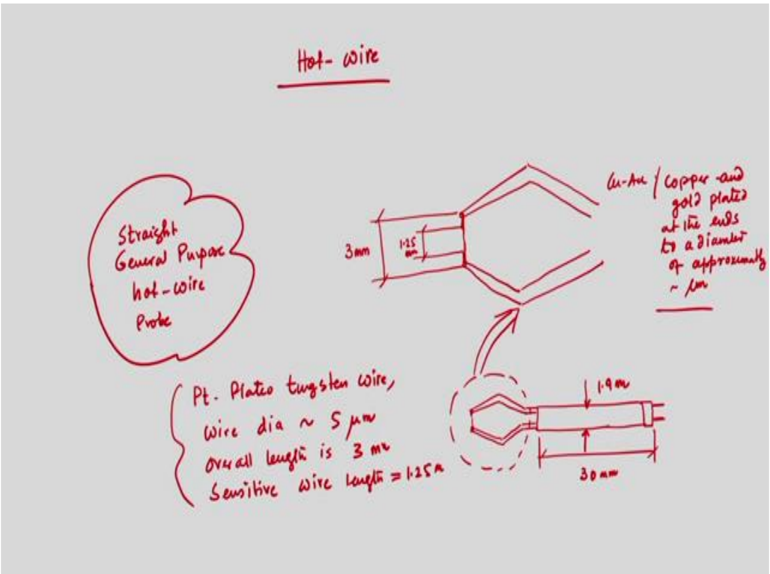

We will write, hot wire. So, if I try to write hot wire and, now these 2 dimensions are very important, that this is typically of the order of 3 millimeters and this is 1.25 mm. And if I try to draw, these are the few typical dimensions. So, this is the, you know and this is shown in a, in an enlarged view, that is zoomed in view of this part is shown over at the, at the top, the schematics shown in the top panel is the zoomed in view of the portion which is shown by circle in the, at the bottom panel.

Now, the, this is typically this is 1.9 mm and distance is 30 millimeter. So, this is a straight basically, this is a straight general purpose hot air flow. So, this is straight general purpose hot air flow and so, this is the straight general purpose hot air flow. Now, a few important dimensions are shown in the schematic and this is the, you know thin, rather thin wire and that is 1.25 mm, that is shown the length.

Now, the dimensions which are shown over here are the characteristics dimensions. Now, this type of probe, the problem with this probe is in fact, I did not mark other things. So, if we look at this is platinum plated tungsten wire. The wire diameter is, wire diameter of the order of 5 micron overall length is 3 mm and sensitive wire length, you know sensitive wire length is 1.25 mm.

So, the wire is platinum plated tungsten wire, wire diameter is 5 micron, overall length that is shown in the enlarged view is 3 mm and, but out of this overall length there is a small length which is known as sensitive length and that length is 1.25 millimeter. Now, there are copper, gold plated, copper gold plated at the ends to diameter of approximately micron.

So, I can write copper or I can say copper gold plated, copper and gold plated, copper and gold plated, Au gold plated, you know at the ends to a diameter of approximately micron. So, the, at the ends when these wires are connected, copper and gold plated and diameter is of the order of micron.

Now, this is a basically a straight general type, general purpose order probe and the dimensions which are shown are the characteristics dimension. But this probe is not suitable in places, you know very close to the solid boundary. I mean, if you really would like to measure flow velocity very close in a region or in the zone which is close to the solid boundary, this probe cannot be placed. And, this is because of the geometrical structure of the probe.

And so, probe with offset diameter, the offset you know, stem that was developed only to measure, only to use rather, this probe in places where the, where would let, rather in fact you would like to measure flow velocity which is very in a zone, which is very close to the solid surface.

So, that means, this general purpose hot air probe is not suitable for those cases, where we would like to measure flow velocity in the region very close to the solid surface to circumvent that problem, an offset stem, I mean probe with a offset stem was developed and which is geometrically different from this you know straight general purpose probe.

Now, we need to see that geometrically that probe I mean the probe with offset stem which is also known as boundary layer probe, how the probe looks like. Now, I would like to, would like to see the schematic depiction of the boundary layer probe.

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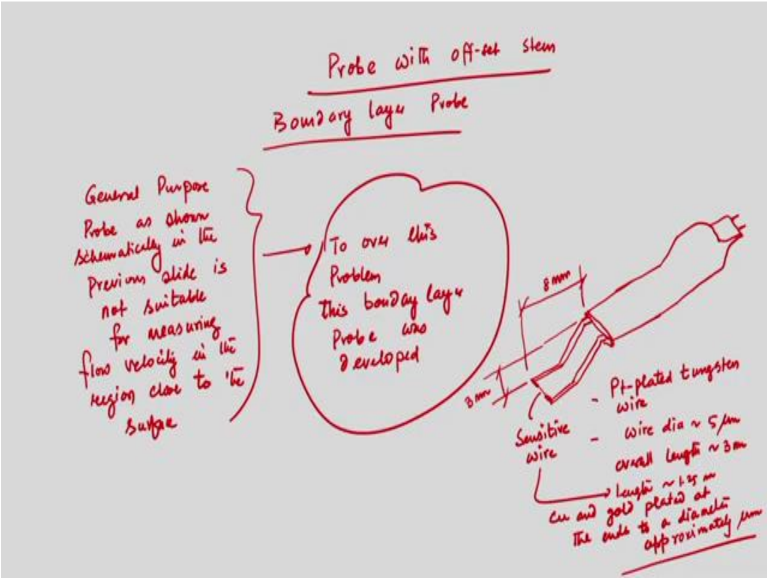

So, probe with offset stem which is also known as boundary layer probe. That means, the general purpose probe, general purpose probe as shown schematically in the previous slide is not suitable for measuring flow velocity in the region, in the region close to the surface. So, to overcome this problem this boundary layer probe was developed.

So, the objective of having the special type probe is that, the general purpose probe that we have seen in the last slide with all its characteristics dimensions is not suitable to measure flow velocity in place where, rather in places where which is close to the solid boundary. Now, we will see the schematic depiction of the boundary layer probe.

So, if you try to draw, so this is basically a boundary layer probe, the schematic depiction. And this distance is 8 millimeter and this offset distance is again of the order of 3 millimeter. So again, this is platinum so, this is you know sensitive wire, platinum tungsten plated, platinum plated tungsten wire, platinum plated tungsten wire and wire diameter of the order of 5 micron, overall length of the order of 3 mm and sensitive wire length 1.25 mm and copper, gold, copper and gold plated at the ends, which are, because we need to pass current through this.

So, which are at the ends, to a diameter approximately micron. So, now from the geometrical structure of this probe, which is known as boundary layer probe. We can see, that the offset distance allow this probe to be inserted even in the place which is close to the surface or even in the places are which is closed, which are close to the surface and this is used to measure the flow velocity using the same principle.

And the characteristic dimensions are almost similar, which we have seen for the general purpose probe. And, but, the only special one important objective that is being fulfilled, rather that was, that, and that was the objective. For designing this probe is that, it will be used to measure flow velocity in the region close to the surface.

Now, we have discussed that whether it is general purpose probe or it is boundary layer type probe, these 2 are basically hot wire probe. And now, these probes are used to measure heat transfer, essentially to predict the flow velocity. And the, you know, as I said that the elements hot wire and hot film, these elements are heated electrically and then placed in a flow field.

So, analysis and experimental, I mean when any equipment is designed then it is secured to calibrate that particular instrument before it is used directly for the, directly or indirectly for the flow parameters, flow parameters measurement.

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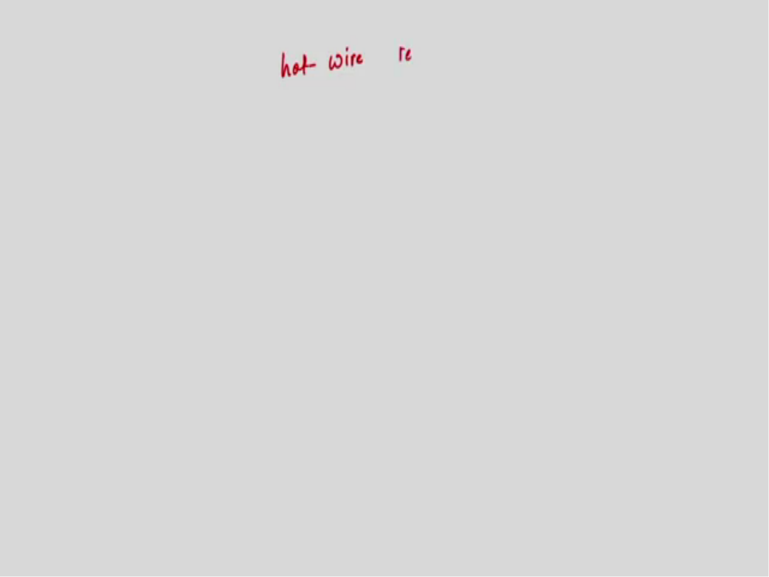

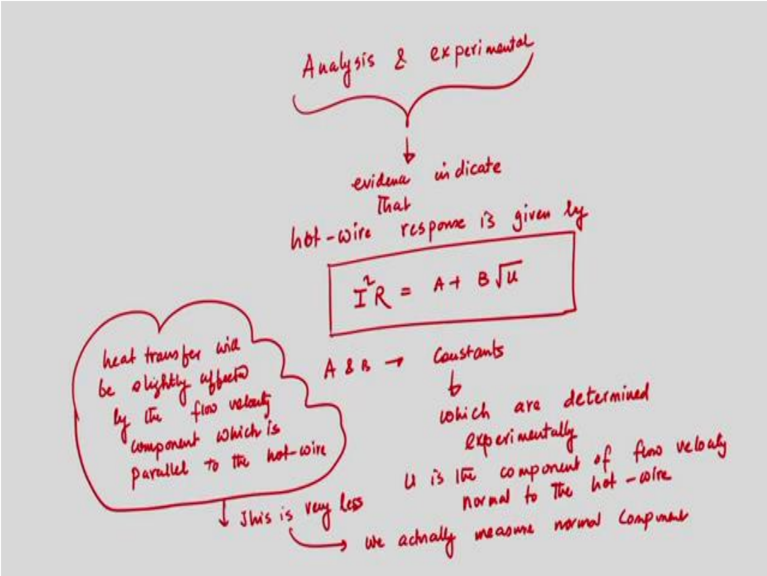

Now, the analysis and also experimental evidence indicate that the hot wire, so hot wire, hot wire response. So, I am writing analysis and experiments, analysis and experiments. Which are, I mean these 2 evidence indicate that hot wire response, hot wire response is given by I square R that is A plus B root of U. So, as I said that these elements are electrically heated, so, that is I square R. Because if we, if we you know pass current through this element I, and if the resistance is R, the heat will be I square R.

This heat, I mean heat, if we place them in a flow field that heat transfer will be there by the fluid. So, that is related with the flow velocity by this response that is I square R is equal to A plus B root U, where A and B, these are the constants and which are determined experimentally, which are determined experimentally. And U is the component of, component of velocity, I can say flow velocity normal to the probe, or normal to the hot wire.

So, what we can see that, analysis through, for analysis and experiments, experimental rather I can say, I can write experimental not experiments, experimental evidence, experimental evidence, this response, the response that a hot wire response is given by I square R is equal to A plus B root U, A and B these 2 are constants which are determined experimentally. Now, use the component of flow velocity which is normal to the hot wire. Very, you know important to mention here that, it is not always the fact that flow will be always normal to be hot wire.

So, there might be probe in a velocity component which is parallel to the wire. Now, heat transfer will be affected. So now, we are essentially measuring, we are measuring flow velocity, essentially, we are measuring the heat transfer. Now, if the heat transfer, so, if you place in a flow field, where it is not expected that the flow velocity will be always normal to the probe, normal to the hot wire.

So, the measured heat transfer may not be always equal to the velocity component which is normal to the hot wire. So, the heat transfer because of these, because of the velocity component, which is parallel to the hot wire will affect the total analysis. So, what I would like to say, the heat transport that we are measuring, that is not only because of the velocity component which is normal to the hot wire, but the heat transfer will be slightly affected by the flow velocity component which is parallel to the hot wire. But this is very less and this is not, you know, you know high.

So, in fact the, that component is very less. So, we are correctly, I mean we can say that we actually measure normal velocity component using this measurement technique. So, but I should write at least that point that, that heat transferred we will be slightly affected by the flow velocity component, which is flow velocity components, component which is parallel to the parallel to the hot wire.

And if this is the case, then measurement that is we are interested in to measure only the normal velocity component, but, and that too is, that too by using the heat transferred. But, it is not the case always, that the velocity components will be always normal to the hot wire. So, the existence of parallel component of velocity, rather parallel to the hot wire slightly may slightly affect the measurement techniques, but this is very less, so we actually measure the normal component.

But so this is not, we cannot ignore, but at least this is very less, and we can say, we actually measure normal component. So, at least, I would like to mention another important point in this context here that, that if you would like to really measure 2 components, and it is quite obvious that if you would like to place the probe in any flow velocity field, I mean flow field, there flow field is a velocity component there, there will have I know, velocity components in 3 mutually perpendicular direction.

So, if you really would like to interested to measure, you know velocity components, rather 2, 2 velocity components. We can modify the design of the hot wire and with that, you know modified design we can replace the probe in that velocity field and from there we can, measure the velocity component.

So, the measurement of the two velocity component, which is not possible using this kind of, you know, you know, simple or even boundary layer type probe. But we need to modify the design of the boundary layer type probe or the, you know, simple general purpose probe which is used.

But, again, before I like to, you know stop my discussion today. I would like to you know, summarize my today's discussion is that, so, we have discussed today the flow measurement. In fact, we have started our discussion on flow measurements in the last week. Flow measurements include the measurement of volumetric flow rate, mass flow rate and also the point velocity measurement and finally, the determination flow stream line also, falls in the category of flow measurements technique.

Now, the flow measurements, I mean which is you know which is you know nothing but the, measurement of volumetric flow rate and mass flow rate that we have discussed in last lecture, using you know flow obstruction flow rate measurement and also by using drag. Today, we have discussed about that how we can measure flow velocity, the point velocity using another important instrument that is thermal anemometry, thermal anemometry is used to measure flow velocity by using, by measuring the heat transfer.

Normally, you know adapting 2 methods either hot wire or hot film. Hot wire which is used to measure having diameter one tenth of the human hair or hot film which is metal film on a glass substrate or other material. And we have seen that, we have rather, we have schematically depicted the geometrical structure of the probe and the characteristics dimensions. We have also discussed the general purpose flow is not suitable for measuring flow velocity in places where flow field is, I mean in places where I mean we would like to where the flow velocity would like to measure is close to the solid surface.

And, if we really interested to measure flow velocity in that, in regions which is close to the solid surface for that we need to modify the design and that is you know, probe with offset stem and which is known as boundary layer probe. And all these probes are basically depends, are all these probes are, you know use to measure flow velocity components.

Now, I can say of course, if I really interested to measure flow velocity components, then again you need to modify the design. But at least this general purpose probe and the boundary layer probe, these 2 probes are used to measure normal component of velocity and the hot wire is electrically heated and placed in a flow field.

Now, by measuring the heat transfer, that is nothing but I square R and this response is given by analysis and experiment using through this formula. Rather, by this formula A plus B root U where A and B are constants, which are determined experimentally and use the velocity component. But the velocity component U that will be measuring using this probe is the normal component, which is normal to the hot wire.

It is also a case that, even though the component which is parallel to the probe will be very less, but the presence of that velocity component which is parallel to the hot wire will affect the heat transform measurement, which in turn might affect the measurement of the flow velocity component. But, but as I said that this component is very less. So, we actually measured normal component rather velocity component which is normal to the hot wire.

And finally, we have discussed that we are, if you are really interested to measure 2 component of velocity, which is that one is normal to the wire and another is parallel to the wire, for that we need to modify the design and that aspect will be discuss in our next class. So, with this I stop my discussion today and we will continue our discussion in next class. Thank you.