

Experimental Methods in Fluid Mechanics
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Lecture 34
Measurement of Pitch Angle

Good afternoon, we will continue our discussion on the Measurement of Flow Angles using mechanical probes. In fact, today our discussion will be on the effect of the Flow Angles, which is very important in the context of turbo machines. And if we need to characterize the turbo machines flow field, there, in addition to the measurement of pressure another important parameter need to quantify that is the change in angle flow angle.

The changes in flow direction, again in the context of turbo machines is very important and the changes in flow direction are directly related to the phenomenon of work interchange. And because of this, it is important, if you can say that why you need to study the measurement of the angles. I would like to say that, because the changes in flow angles there are different angle, pitch angle, yaw angle, so the changes in flow angle are very important to measure.

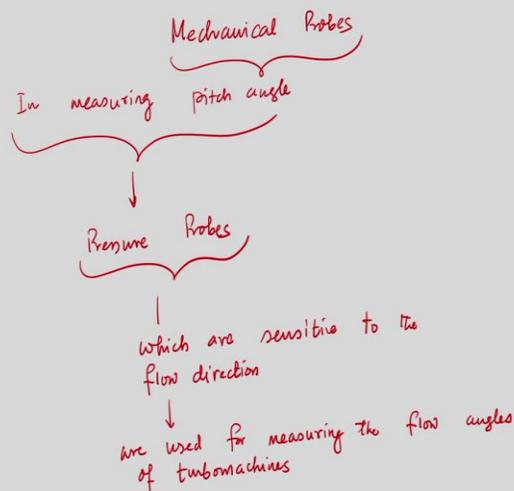
In the context of turbo machines operation, because they are directly related to the phenomenon of work interchange, and because of this, we must focus on this aspect, at least in the paradigm of experimental fluid dynamics. And we will try to see that how we can measure the changes in flow angle using mechanical probe. If we try to recall in one of the previous classes, we have discussed about the operational principle of mechanical probes.

There, we have also discussed, the constructional feature, and to some extent, the calibration of the mechanical probes. So, today what we will do, try to briefly recall what portion, what part I mean, we have discussed in the previous class and our understanding on the operational principle of the probes, constructional features of mechanical probe is not required for today's class.

But at least our understanding on the operational principle of mechanical probes will be required to explain, to understand again in measuring the flow angles in the context of turbo machines.

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Measurement of Flow Angle of Turbo machines: Measurement of pitch angle



So, today we will start that if we now, interested in measuring the flow angles using mechanical probe. So, we will be this discussing today the mechanical probes and use of these probes in measuring pitch angle. I have discussed that there are three-hole probes, four-hole probes and five-hole probes. The problem associated with the three-hole probe

is that we cannot measure pitch characteristics and which is very important for turbo machines, for the characterization of flow field in the turbo machines flow field.

You will find a very few turbo machines in which the flow field is two dimensional. Rather, I can say that for most of the turbo machines, flow field is highly three dimensional. And for these three dimensional flow field one important flow parameter is the measurement of pitch angle. If you would like to measure the pitch angle, then mechanical probe is essential. In fact, I can say the pressure probe.

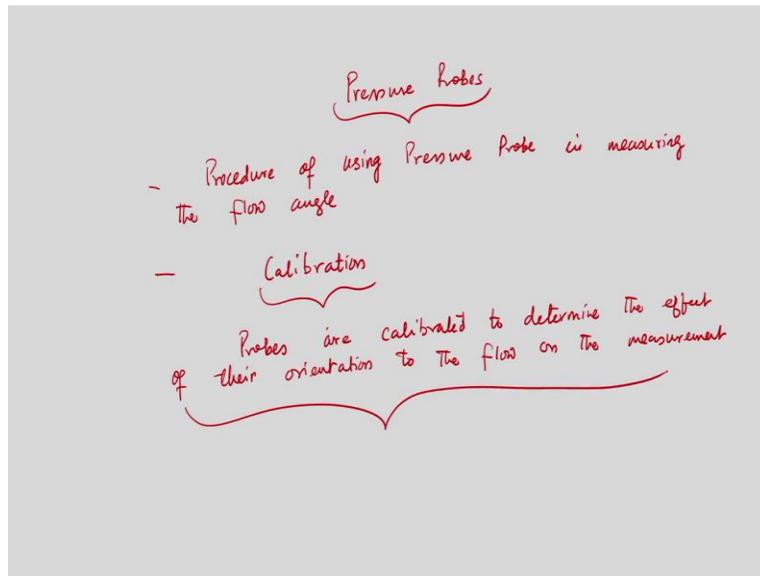
So, in measuring the pitch angle we will be focusing our discussion. But I can say the probes are used to measure the flow angles in general, so when we say the flow angles their pitch angle is one of the flow angles so we will be using pressure probes. See, we cannot use all pressure probes to measure the pitch angle. That means we will have a few pressure probe, the pressure probes which are sensitive to the flow direction, those probes can only give us the measurement or information about the change in angle.

So, that means, what is important to note over here that the pressure probes, all pressure probes cannot be used to measure the flow angles. The pressure probes which are sensitive to the flow direction, sensitive to the change in flow direction, those probes can be used to measure the flow angles. That means, I am writing the pressure probes which are sensitive to the flow direction.

And these probes are used for measuring the flow angles of turbo machines flow field, turbo machines in general, but if I would like to focus today's discussion on the pitch angle then of course, pitch angle will be in particular. So, this is what is very important. Now, as I said that I am not going to discuss the constructional feature, rather, I am not going to discuss the geometrical shape of the probes.

And also I am not going to discuss about the operational principle, we have discussed about the operational principle in detail in one of the previous classes where we have discussed that the probes can be fabricated essentially to measure flow parameters, which is static pressure, total pressure, and importantly the flow angles.

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So, if we write that, if we use pressure probe, using pressure probe, we can, using pressure probes which are sensitive to the flow direction, to the change in flow direction, we can use those probes to measure the flow angle. Now, if we use those pressure probes, then of course, there will be certain procedure by which we can estimate the change in flow direction.

So, what will be, what are those procedures? I mean, if we just insert a probe in the turbo machines flow field, it is not so easy that we will directly get reading from the probe what is the change in flow direction? So, there are certain procedures of using those probes. And if we follow those procedures then only we can estimate, we can calculate the change in flow direction and which is very important to calculate the work transfer.

If we try to recall our undergraduate fluid mechanics and food machinery knowledge then, we know that in fluid machines, what is happening there is in a fluid machines are basically mechanical device, fluid machines are different mechanical devices in which energy is converted from one form to the other form, if we talk about pump, pump is also a turbo machine, hydraulic turbine is also turbo machine.

So, if we talk about a pump, pump is a turbo machine, where the mechanical energy is converted into the stored energy to increase the potential energy of the fluid is being

handled by the pump. Now, if we talk about the turbine, the reverse is true, that means, we are using the stored energy of the fluid, the potential energy of the fluid is utilized to rotate the wheel that is to convert the mechanical energy.

So, the stored energy of the fluid to be precise, the potential energy of the fluid in general is used, rather is taken to be converted into the mechanical energy by a turbo machine, which is hydraulic turbine. So, very important to know the change in direction of the flow, in one case definitely from this basic understanding, we are very much sure that there will be a change in flow direction.

Then only that means there will be transfer of momentum then only we can get the work output from the machine. So, there will be change in flow direction. So, we need to measure those. So, what are the procedures to measure the flow angles of a turbo machines using pressure probe. So, now I will try to outline the different procedures which you need to follow, at least to measure flow angle in a turbo machines.

So, procedure of using pressure probe in measuring the flow angle. What are those? So, as I said, I am not going to discuss about the constructional feature, and I am not going to discuss about the operational principle in a greater detail. Rather we will briefly touch upon the operational principle of course, because the probe is there. So, what is done?

First of all, if we considered that we have understood the operational principle then what is done essentially an important part of the experimental research, experimental measurement, experimental technique is that before we going to use any particular device to measure any particular parameter, any particular flow parameter, at least we should be aware that, that particular device has been calibrated.

So, calibration, this part we will be discussing towards the end of this course. So, the calibration is that the probes will be calibrated and the probes are calibrated. Why these probes are calibrated? Probes are calibrated to determine the effect of the flow direction rather effect probes are calibrated to determine the effect of their orientation to the flow on the measurement.

So, this is very important point, we should know that before we go to use any particular probe, not particular, that means why it is particular, particular probe means that probes are sensitive to the flow direction, to the change in flow direction. So knowing the fact that the probe is sensitive to the change in flow direction now, we will be using that probe. But before we use that probe, we need to calibrate it. Why?

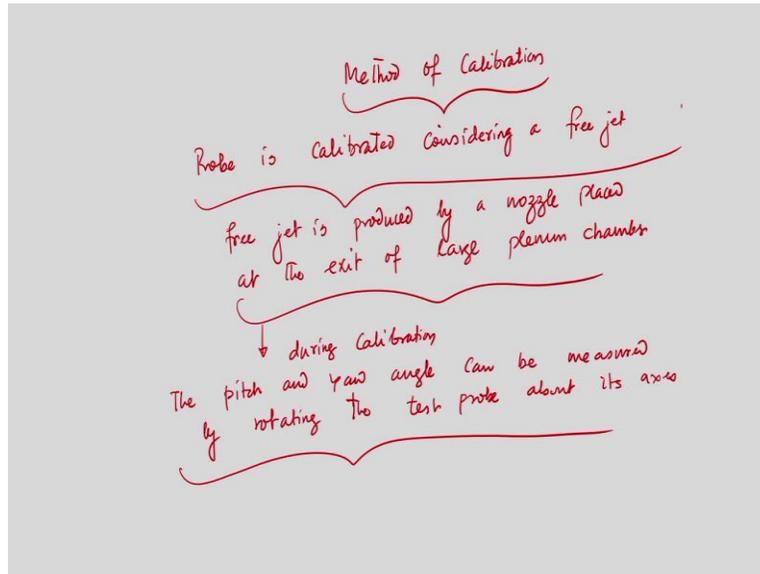
Because we need to ensure, we need to confirm that the probes are calibrated to determine the effect of their orientation to the flow. That means, if we insert the probe, we need to rotate the probe either manually or mechanically, but when we are rotating the probe, by rotating the, I mean when we are rotating, so there will be change in orientation.

So, effect of the orientation to the flow on the measurement, whether the probe can sense or probe cannot sense that is very much important. So, that means we will see very soon that by inserting probe in the flow field, in the turbo machines flow field, if we try to rotate the probe, we can measure the flow angle, pitch angle and the yaw angle.

So, it is very much important, it is very much needed that we need to ensure before we go to insert, before we go to use the probe for the real experience, at least probe that, which you are going to use should be sensitive to the effect of the orientation to the flow on the measurement, which you are going to consider. So, this is important. Now, if that is important, since the course is experimental methods in fluid mechanics, so the time has come.

At least know that okay, we are inserting the probe is now calibrated to confirm that the probe can sense, probe is sensitive not resistive, probe is sensitive to the effect of the change in orientation to the flow on the measurement, that is what we are going to do. Now, at least we should know that one important part of that, of this module is that probes should be calibrated. So, how we can calibrate probe, calibrate a particular probe before the probe can be used in real experiments. So, that is very important.

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So, the method of calibration is another important topic. So, you have understood that the force should be calibrated. Now, it would like to calibrate a probe before we take that particular flow for the real experiments, how we can do? So the probe calibrated considering, I can say considering a free jet of air, probe is calibrated considering a free jet of air.

So, that means, we have a free jet of air, fluidic environment and the free jet is produced by a nozzle, the free jet is produced, it is not always air it may be in the water also, free jet, I am writing free jet, not specifically I am mentioning that it should be air. So, probe is calibrated considering a free jet of fluid, free jet it and free jet is produced by a nozzle and at the exit, placing a nozzle at the exit of it at the, free jet is produced by a nozzle placed at the exit of a large plenum chamber. So, this is what is done.

So, when we calibrate it is calibrated in a laboratory scale. So, we need to produce a free jet and that is done that is performed by a nozzle which is placed at the exit of a large plenum chamber. And once we calibrate it, then we can certify that the probe is ready for the actual measurement. So, this is what is done and if we calibrate, so once we have calibrated now, the probe is ready to measure the pitch angle and yaw angle in the real experiment.

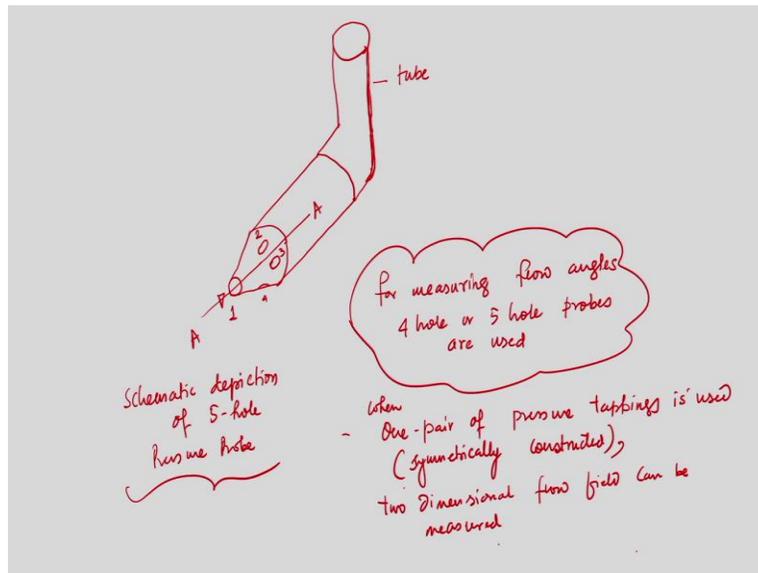
So, now the pitch and yaw angle can be measured during calibration. We are doing calibration the objective is, objective for the calibration is to measure the pitch and yaw angle. So, we need to provide a calibration curve. So, the pitch angle and yaw angle can be measured by rotating the test probe about its access. And that is what we will see from the schematic diagram.

Now, that means, till now have understood that before we go to use a probe in measuring the flow angle, flow angles rather, in a turbo machines flow field, we need to first calibrate it. If you would like to calibrate it, we can calibrate in a laboratory scale setup, by doing a laboratory scale setup and it is done by a free jet which is produced by a nozzle and the nozzle is placed at the exit of a large plenum chamber.

And during the calibration process, we need to measure the flow angles, change in flow angle so that the probe can, the probe is sensitive or not sensitive and that is you need to ensure and for that this calibration is done. Now, during calibration, we should measure the pitch and yaw angle and to measure the pitch and yaw angle that is pitch characteristics of the flow, yaw characteristics of the flow and that is measured by rotating the test probe about it axis.

So, before we go to before at least to understand this, we need to draw the schematic and by depicting the schematic then we will explain the remaining part of this module.

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So, if we try to now draw the schematic then we will get like this. So, this is tube, this is A A. Now, what we can see from this is schematic, depiction of pressure probe. So, if this is a five-hole probe. Before we go to draw the other things at least we should discuss now, that for measuring flow angles, again if you try to recall in one of the previous classes where we have discussed about the mechanical probes.

We have discussed that rather we have tried to differentiate between three-hole and four-hole probes and we have discussed that the inclusion of, the addition of extra hole that is there in the four-hole probe that is a name is four-hole, that means in three-hole probe there are three different holes, in the four-hole probes there are four different holes, so the inclusion or addition of the extra probe, extra hole that is extra pressure tapping is important to obtain the pitch characteristics of the flow.

That means, for measuring the flow characteristics to characterize the flow, to measure the flow angles, the flow angles either four-hole or five-hole probes are used, either four-hole or five-holes. So, this is the schematic depiction of a five-hole pressure probe, if it is five-hole then, one central hole that we can see, if I give the name this is 1, this is 2, this is 3 and this is 4 and that will be there in the other direction that is that is very difficult to draw in this schematic.

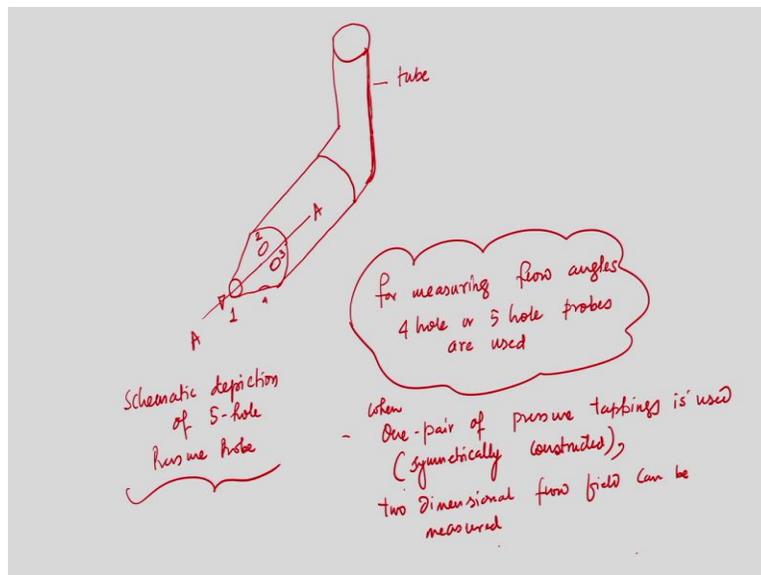
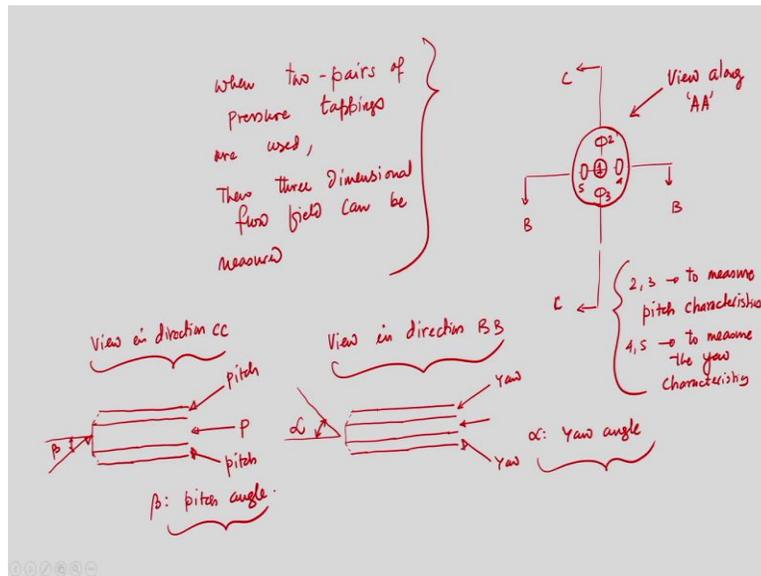
Now, this is the five-hole mechanical probe and that is used to measure the pitch characteristics. So, now question is, if it is four-hole probe then the addition to the central hole there will be at another three different holes, if it is five-hole probes in addition to the center hole there are four different other holes, that means either there will be one pair or two pair.

So, the important so there will be, if it is four-hole probe, in addition to the central hole, there will be three different holes. Out of these three different holes one pair of pressure tappings, that is one pair of pressure tapping or pressure holes will be used, one pair of pressure tappings I can say constructed symmetrically, that is very important constructors symmetrically pressure tappings, which are symmetrically constructed.

So, if it is four-hole of probes in addition to the central hole we will have one pair of pressure tapping or pressure holes which are symmetrically constructed and that is used only to measure the two dimensional flow field. So, that is two dimensional. So, I can say the when one pair of pressure tappings is used, one pair of pressure tappings and one additional hole that is three-hole probe.

Then two dimensional flow field can be measure but if it is four-hole then, we may have in addition to the central hole, if it is central hole then we will have only three different holes. If it is not a central hole then we will have two pair, two pairs of symmetrically constructed holes. And if it is five-hole probe, advantage of the five-hole probe is that in addition to the central hole which is important to measure the pressure and that is what we have discussed in the context of probe in our previous class so, we will have arrow the four different holes.

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So, I am writing that when two pair, two pairs of pressure tappings are used then, are used in the probe that means the probe is constructed in such a way that there will be two pairs of pressure tappings, two pairs of holes in addition to a central hole, then three dimensional flow field can be measured. And in this context again I will repeat that, that is why three-hole probes cannot be used to measure, to characterize the pitch angle of the flow.

That means three-hole probes cannot be used for the pitch characterization of the flow instead, if you would like to measure the pitch characteristics, we should use the formal probes and that is why the addition of the hole. So, now, we have drawn the schematic diagram five-hole probes, here in addition to them a central hole that is hole number one we will have another four-holes and another four-holes means the holes are constructed symmetrically, symmetrically constructed.

Now if we try to draw the cross sectional so, we will have and I am drawing here only. So, this is the central hole, we will have two pairs of symmetrically constructed pressure tappings. So, if you try to recall this is 1, this is 2, this is 3, this is 4 and this is the 5. So, this is five-hole probes, there are five distinct holes in the probe. Now, if we try to look at it from two different perspectives, say this is C, this is C.

So, if we now look at from two different angles that is, we will get this is the view, along AA that is what we have drawn over here that is A so if you take the view along A we will get, this is the view. Now, if we take the view along CC and BB, this 2, 3, 2 and 3 these two holes are used to measure the pitch characteristics and 4 and 5 these two holes are used to measure the yaw characteristics. So, this is the thing. So, if we now try to take another view, that means view along CC and BB then it will be much more clear.

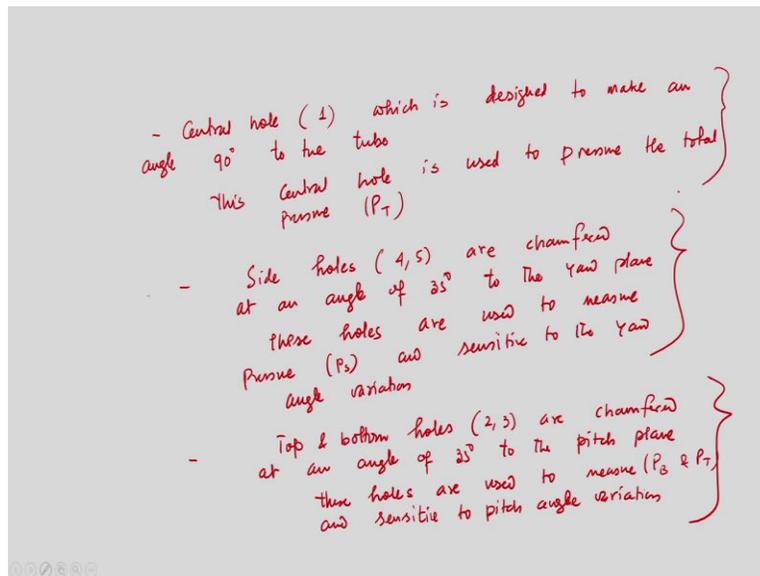
So I am writing, view in direction BB so, this is yaw, that is if I try to, this is yaw so, this is view direction BB, so this is alpha is yaw angle so, the probes tappings 4 and 5 will give the direction of the yaw, that is yaw angle, yaw direction of the flow. Similarly, if we take another view which is along CC, we will get similar kind of view and this is view in directions CC. Now, this is P and that is very important is the pitch.

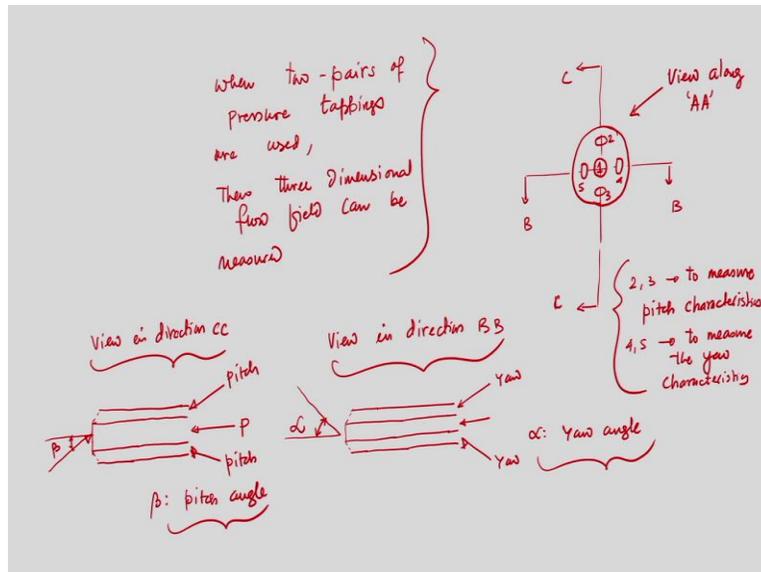
So, this is pitch characteristics of the flow so, this is pitch and that will be the pitch angle beta. So, beta is the pitch characteristics or pitch angle. So, what we can see from the schematic that means, if we take the view along A then we will get the clear, I can say clear picture of five different holes, central number 1, number 2 and 3 these two holes are basically used to measure the pitch characteristics and that can be you know seen from the view in the direction of CC and pressure tappings, the pair of pressure tappings that is

tapping number 4 and 5 these pressure tapings is used to measure the yaw characteristics or yaw angle of the flow.

Now, we have understood that this probe can be inserted in the turbo machines flow field, the probes, this probe is calibrated a priori before its direct use in the experiment and just by rotating the probe now, we need to know if we place this probe which is calibrated a priori. And then of course, we need to rotate the probe and if we rotate, we will get information from the pressure tapings 2 and 3, pitch characteristics pitch angle that is beta and from the pressure tapings 4 and 5, the yaw characteristics or yaw angle of the flow.

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Next what is done that is very important that if we now look at the five different holes, so the central hole, the hole number 1 that means the center hole that is number 1 which is used. I can say which is designed to make an angle 90 degree to the tube and the central hole, the central hole is used to measure the total pressure P_T , that is we have discussed in the context of construction and the operational principle of mechanical probes.

Now, side holes, if we go to the previous slide, side holes if we look at it if we take the view along A then what are the side holes, 4 and 5. So, the side holes 4 and 5 are chamfered an angle of 35 degree, almost 35 degree to the yaw plane, to the, if we go to the previous that is 4 and 5 that is the yaw plane. So the plane BB that is the yaw plane now, to the yaw plane that is the BB plane.

Now, these holes are used to measure pressure P_s and sensitive to the yaw angle variation. And finally, again if we go to the previous slide, if we consider the view along A, then pressure tappings 2 and 3 that means hole 2 and 3 are the top and bottom holes that means top and bottom hole that is 2 comma 3 are chamfered at an angle of 35 degree to the pitch plane, it will be clear, if we go to the previous slide.

So, the 2 and 3 that is if we have already drawn the view in direction CC and the CC plane CC is the pitch plane then by measuring the pressure at 2 and 3, we can characterize the pitch angle, we can measure the pitch angle of the flow, that means pitch

plane and these holes are used, these holes means the hole, holes 2 and 3 are used to measure P bottom and P top and, I am writing top and bottom pressure and sensitive to pitch angle variation. So, this is the pitch angle this is the yaw angle and the top one is essentially to measure the total pressure.

So, this is the, I am not going to discuss the constructional feature that we have discussed that they are readily drill hole and then they are corrected that leads to pressure leads. Now, so, if we use this five-hole probe, which is important, I mean if we use the five-hole probe to measure the pitch characteristics specifically, but we can measure pitch as well as the yaw characteristics of the flow, in the turbo machines flow field.

Then, what are the different procedure? First of all, we need to ensure that the pressure probe which is used to measure the flow angles. That pressure probe will be sensitive to the change in flow direction, then only we can use this probe. Next thing is that knowing fully that the probe is sensitive to the change in flow direction by how? We can calibrate and for that we need to calibrate.

So, calibration is done only to check whether the probe is sensitive to the flow direction or not because we can design, we can fabricate a probe keeping in mind that, that probe will be sensitive to the change in production. But, after manufacturing it may so happen that the probe is not sensitive at all so, we need to calibrate, we need to check it. So, to calibration is done to ensure that the probe, the fabricated probe is efficient to measure, to measure the flow direction.

Then calibration is done to ensure that the probe can measure and second thing if we now calibrate it, for the calibration, what is done, we can use the free jet and the free jet is produced by the nozzle and nozzle is placed at the exit of a large plenum chamber. Now, when you are using the nozzle, then by changing the angle, the jet angle, we can characterize her that the probe, which is now which we will be using in the real time experiments can really sense that angle, which is produced by the nozzle.

So, the nozzle will produce a free jet at an angle and that angle will be now, measured by the probe, by a test probe, which is calibrated now. So, before we go to use this probe, we

are now calibrating, by tuning the angle, nozzle angle, we can change the jet angle, the angle of the free jet. If we do the calibration we will get a calibration curve. So, by changing the angle of the jet which is produced by the nozzle we will measure the pressure by the test probe, we can calibrate a curve.

So, we will calibrate the curve, we will measure the pressure. So, either 2 and 3 and 4 and 5 what we will do while we are measuring the say, we are measuring the using this probe the pitch angle in specific so, the probes 2 and 3 which will be used to measure the pitch characteristics of the flow. Now, what is done, the probe will be rotated. So, that the jet is produced by the nozzle, we know what is the pitch angle of the flow now, probe will be rotated and until and unless pressure at these two probes, at these two holes so, there are five different holes, holes 2 or 3 are used to characterize the pitch angle of the flow.

Now when the probe is calibrated, so we know what is the pitch angle and that will be confirmed by the nozzle. Now we will be measuring pressure at five different holes. Now the probe will be rotated until pressure at holes 2 and 3. So, 2 and 3 these holes will be connected to the, these holes will be connected to the pressure tapplings, the probe will rotate until the pressure at holes 2 and 3 will be equal.

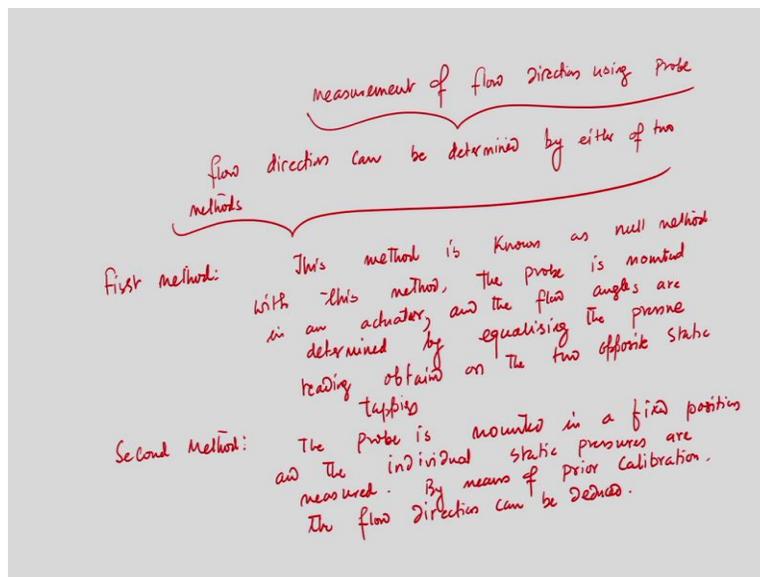
And at that point we will be measuring what is the angle and when we are rotating, so we will know measure what is the angle so, we will continuously measuring the angle and we will be monitoring the pressure at hole 2 and 3. Now we need to measure at which angle the pressure holes 2 and 3 is equal and that is the pitch characteristics. So, and this is done. Now, once we get the calibration curve by knowing the calibration curve, we know the pressure and the angle β .

So, if we have the calibration curve with us, if we use this particular probe in the real experiments, now, only by measuring the pressure at point 2 and 3 just we can calculate what will be the flow angle, what will be the pitch angle of that particular flow field. So, when we do a calibration we tune the flow angles using the nozzle. We measure the pressure and when pressure at holes 2 and 3 will be equal, we measure the angle because probe will be rotated continuously.

And using this technique we can generate a calibration curve. Now, this calibration curve will be supplied to the probe and when the probe will be used in the real time experiments then just we will be measuring the pressure in the turbo machines flow field and we need to rotate the probe again until unless the pressure at, probe pressure at orifices 2 and 3 will be equal at that time just we know that, just by knowing the pressure, we can say what will be the angle from the calibration curves.

So, this is what is the basic principle of using mechanical flow in categorizing the flow angles, in general the pitch angle to be specific in the turbo machines flow field. So, this is important finally, I would like to add a few other two important points that the calibration is important. In the context of calibration what is done?

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So, I will be writing the measurement of flow direction using probe. So, we have discussed the basic principle, but at least I will try to give a few points and rather I will try to write a few lines and which will help you to remember the principle rather the operational principle of these probe in measuring the flow angles. So, these flow direction measurement that means, the flow direction so, what are the different procedure first of all the probe will be fabricated, then probe will be calibrated.

So, after fabrication, fabrication will be done keeping in mind that the probe is sensitive to a change in flow direction, then we have to benchmark we have to ensure that the probe can really sense the change in flow direction and for that we need to go for the calibration. While we are doing calibration, we also need to prepare a calibration curve and that will help us to use this probe in the real time experiments. That is what we have discussed till now.

Now, this flow direction can be determined by either of two methods, what are those? First method, what is the first method? This method is known as null method and what is done using this method, with this method the probe is mounted in an actuator, actuator and the flow angle, flow angles are determined by equalizing the pressure reading obtained on the two opposite static tapping, that is what I was telling.

So, we can rotate the probe using a mechanical actuator and this is the process is continued until the pressure on; pressure reading which will be obtained on the two opposite static tappings will be equal. So, this is a fast method. In addition to the method another method is available that is the second method. Second method and in this method the probe is mounted in a fixed position and the individual static pressures are measured.

Now, that means, in this case we do not required to place the probe on a mechanical actuator instead we can place the probe on a fixed position and the individual static pressures are measured. And for this it is very important to calculate, very important to know the calibration. So, now by means of prior calibration the flow direction can be deduced.

So, this is what I was discussing that means, there are two different methods to determine the flow direction, in first case we can place the probe on the on a mechanical actuator and the mechanical actuator will try to will rotate the probe and the process is continued until the pressure readings which are obtained from the two opposite static tappings which are symmetrically placed will be equal and that is known as the null method that means, pressure will be there would not be any pressure difference, the pressure difference is null.

Second method is that when, this second thought is very much important, rather this is placed in, this is used in places where it is not possible to rotate the probe and in this method the probe is mounted on a fixed plane, fixed position and the individual static pressures are measured. Now, by means of the prior calibration we can deduce, we can obtain the information about the flow angles.

So, to summarize today's discussion, we have discussed about the use rather applicability of mechanical probes in measuring the flow direction, which is very important, we have discussed about the basic operational principle and then defined essential as well as important features, which are I mean, I can say integral with the measurement technique. And finally, we have discussed about that, what are the different methods available to determine the flow direction in the context of three diamonds flow field.

So, with this, I stopped my discussion today and we will continue our discussion in the next class. Thank you.