Experimental Methods in Fluid Mechanics
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Lecture 38
Transient and Frequency response consideration

Good afternoon, we will discuss today the response characteristics, that is the transient and frequency response consideration. In fact, if you try to recall that in one of my previous classes, we have discussed about the dynamic response consideration and today we will discuss in detail about that aspect.

But before we go to discuss about the response characteristics and our response characteristics in the context of fluid flow analysis, we need to know what is the dynamic response consideration and why it is important to know and perhaps if we need to consider this aspect while using any experimental, using any instrument or device for measuring any flow parameter. So we will today discuss what is dynamic response consideration.

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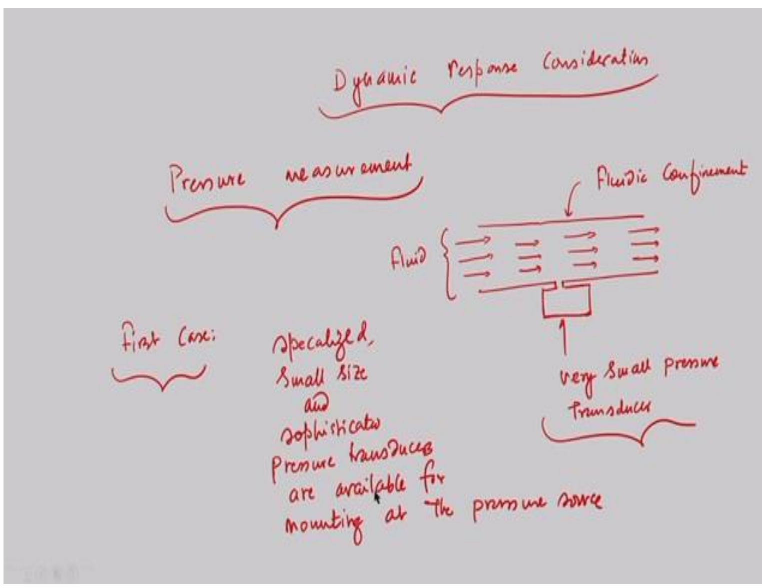

So dynamic response consideration. What is that? We will discuss this and while we will be taking an example to discuss why this module is important and why we need to consider this aspect in measuring flow parameter, say pressure. If you try to recall that when we have discussed about the pressure measurement, then we have discussed several issues involved with the pressure measurement like mechanical probes which are used to measure the pressure, then other instrument like u tube manometer, which is also used to measure pressure. And then we have discussed about mechanical probes, that is 3 hole, 4 hole probes.

If we need to measure pressure, since this course is focusing on the experimental methods in fluid mechanics, so when we are interested in measuring the pressure in a flow condition, that means if we consider a situation where liquid is flowing or any particular fluid is flowing through a confinement and if you need to measure what is the pressure, that is the total pressure or the dynamic pressure. Now, if we need to measure pressure in a situation where there is a continuous flow, in that case there are ways by how we can measure pressure.

First case, we can consider that we can consider a very small pressure probe rather very small pressure transducer, and we can place that pressure transducer probe, size is so small that we can place in a particular location and we can measure the pressure, we can sense the pressure.

Of course, we need to have kind of (())(04:00) we need to have kind of puncture and we can place that specialized, I can say small size pressure transducer in that particular area where this, our small hole is created and we can measure pressure. But this specialized pressure transducer are very costly and most of the time what is done, the pressure is measured using a tap so we can take a tap and the tap is now connected with a flexible line and ultimately we connect with the pressure transducer.

So, there are two ways by how the pressure can be measured in a situation where there is continuous flow. As a first case I have told that the specialized small size pressure transducer can be placed in the area where you would like to measure the pressure, but this pressure transducer are very sophisticated, very costly. Our way of measuring pressure is that, we can take a pressure tap and that means you are having small hole and that hole is now connected to the pressure measuring device using a flexible tube.

What will be the problem? If we measure the pressure using the first, rather following the first case, first method, what will be the another different other kind of problems if we measure pressure using following the second case.

So dynamic response consideration, our object, our focus today's discussion is to see the importance of dynamic response consideration in the context of mechanical measurement, measurement of flow parameters and if we, if we are essential, if we are focusing, if we are requiring to consider this aspect, then what are the different ways of considering this? So pressure measurement that is what I was talking about.

Now, as I said that if we consider the measure, mechanical measurement of a pressure. Say, we have, so this is, so this is one fluidic confinement, fluidic confinement and this fluid is allowed to flow from left to right, say using a pump. So one, driving mechanism is there and that driving mechanism allowing liquid or any fluid to flow from left to right and we are interested in measuring the pressure of the fluid inside this confinement.

So what we can do? We can take a small tap and we can have sophisticated and very small pressure transducer, so this is very small pressure transducer. And if we put this pressure transducer over here, we can measure the pressure which is being developed because of this fluidic environment. Now, this specialized sophisticated small size, so as a first case, as I said we have specialized small size and sophisticated pressure transducer are available for, which is very important for mounting at the pressure source.

So the first case, that is what I have shown in the schematic that we can have rather this is really available, specialized small size sophisticated pressure transducer, which we can mount at the site of the pressure source. But the problem of this method, that means this case of course is, are suitable in measuring pressure, but the problem associated with this measurement technique with this method is that the specialized sophisticated pressure transducer are very costly.

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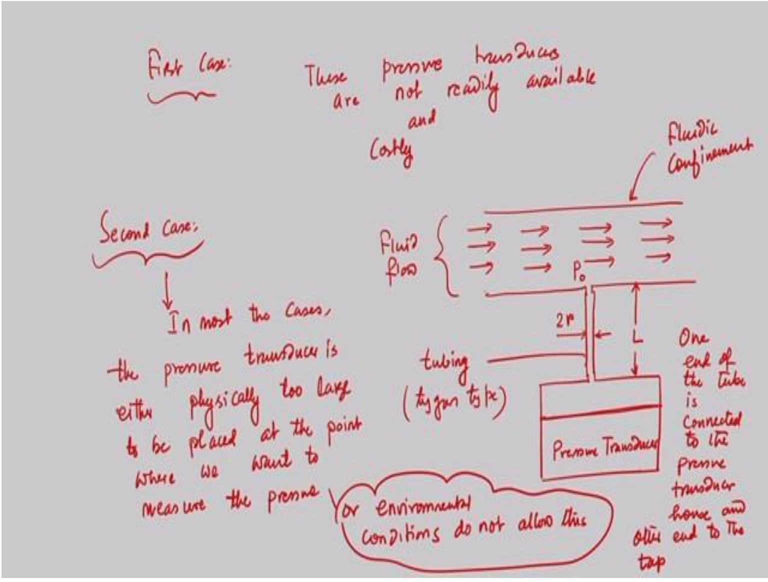

So that means if we now go to the next slide and we can write. So first case we are discussing, then what we can write that this pressure transducer are very costly and as a result of which what is done, this is not the, although this method is suitable but this is not used in practical application.

So this pressure transducer are not readily available and costly, and because of this reason this method is not popular one in measuring the pressure. So second case, second case that is there that which is largely used in most of the practical applications that from that tapping, so if we now again draw the schematic, so this is fluid flow and so now that pressure taping is there, instead of inserting, instead of mounting, a sophisticated pressure transducer at the site, what is done, the pressure tap from this pressure tapping connection is taken and this is now.

So this length is say L and diameter of the tube is, say, 2r and say volume is this is pressure transducer. So this is pressure transducer. So what is done in this case? From the tapping, connection is taken and this connection is done normally using tube, so this is done using tubing, so this is tubing to the pressure transducer. So instead of mounting the pressure transducer directly at the site of the pressure source, a connection is taken through the pressure taping, from the pressure taping and this is made to the pressure transducer, this connection is taken from the tapping to the pressure transducer using a tube that is Tygon type tubing, so this is Tygon type tubing.

Now say, pressure is, here is P naught that is what we would like to measure. So in this case, in second case, which is very important and this is the popular case in most of the practical applications. I can write, in most of the cases or most of the cases, the pressure transducer is either physically too large to be placed at the point where we want to measure the pressure or environmental condition, I can write conditions, do not allow this.

So either this is the case that the environmental condition or conditions do not allow this, which is that is the placing of the pressure transducer directly at the site where we would like to measure the pressure and that is why this arrangement is done. Now question is, using this method what we can see? A small pressure tap is taken and from the pressure tap using tube, we can connect transducer and we can measure the pressure.

Now question is, that means one end of the tube, so I can write, one end of the tube is connected to the pressure transducer house and other end to the pressure tap. So using this arrangement we can measure pressure and this is what is done in most of the practical applications. What will be the problem if we follow this method using pressure? And which is largely followed in the experimental fluid dynamics paradigm.

So what will happen? See, we have a tube and when we have tube, tube is having certain length which is shown in the schematic the length is L. What will be the problem? Now fluid is flowing in the fluidic confinement, so this is fluidic confinement, fluidic confinement. What will be the problem? Now since it is now connected to the tube, it is unexpected that just by switching on, this device we can measure pressure instantaneously. It will take some time. Not only that, there are a few important issues, which need to be considered while measuring pressure using this device. What are those?

Now we will be discussing those issues slowly, but before we go to discuss that aspect, those modules, those issues, before we go to discuss the critical points, which we need to considered, which we need to consider, so one important point that I would like to mention here that the pressure transducer which is here.

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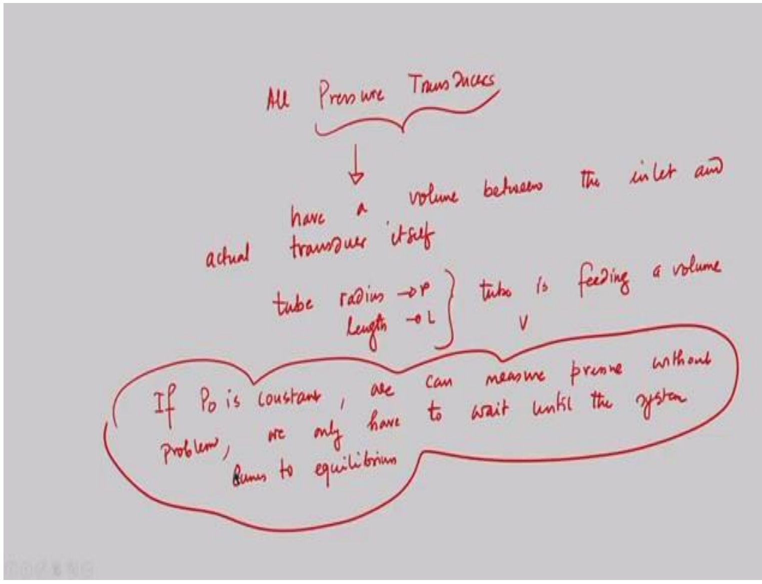

So if I go to the next slide, the pressure transducer, So this is have, rather I can write all pressure transducer have a common volume or I can write it have a volume between the actual inlet and, between the inlet and actual outlet, between the inlet and I can write actual transducer itself, which is clearly seen from the schematic that. So this is the inlet and this is the actual transducer, so we have volume. So this is the volume which is there. So this is the inlet to the transducer and this is the actual transducer, so in between these two places, there is a volume.

Now the tube that is shown over here which is having radius r, which is used to feed and which is used to feed the fluid, that means the tube is feeding the volume v. So if we consider this volume, so this is the volume, so this is volume v. So tube is now feeding the volume v, tube is having radius r and length l. So tube radius is r, length is l and tube is feeding a volume v. Now question is the pressure p naught, which is shown over here, that we would like to measure. So our objective is to measure p naught using this arrangement.

If the pressure p naught is constant, then there is no problem. It will, we have to wait until the pressure, as the pressure transducer become equal to p naught. So if the pressure p naught is constant, we can measure pressure using this arrangement, of course we have to wait for some time until the system reaches at equilibrium.

What is important in this context is, the pressure p naught is not a constant. So there is a continuous fluctuation or since we will be using this arrangement for measuring pressure, now what will be the situation if there is a sudden increase in pressure? So if the pressure p naught in the fluidic confinement, which is, which if the pressure p naught remains constant, then there is no problem. We can safely measure this pressure and we will come off with the correct result using this arrangement, and what we need to do? We need to wait for our, we need to wait for some time until the system reaches at equilibrium.

But this would not be the case if the pressure p naught which is in the fluidic side, which is in the fluidic confinement, rather if there is a rapid change in pressure, rapid increase in pressure in the fluidic confinement, then how we can measure pressure using this arrangement?

So what will happen? If p naught is suddenly increasing, then in this volume, volume is, volume is v and pressure is p, pressure is p. Now, that means I am writing if p naught is constant, we can measure pressure without problem. We only have to wait until the system comes to equilibrium. So this is an important point we should keep in mind. That means if p naught is constant, no problem, we can measure pressure, we need to wait for some time until the system comes to the equilibrium state, fine.

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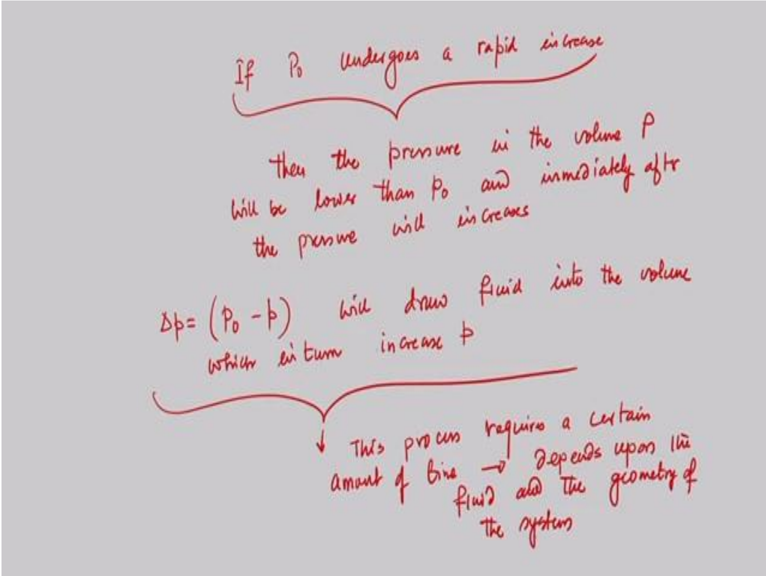

Now second case. If rather I can say, if there is or if p naught undergoes a rapid increase in pressure, rapid increase, then what will happen? So that is what we need to consider. What will happen? If we try to recall the schematic that is shown over here is that volume, the intermediate volume, that is the volume between the inlet and the actual transducer and that volume is v and pressure is p.

Now what will happen? If p undergoes a rapid increase, than the volume pressure p, the pressure in the volume, then the pressure in the volume p will be definitely lower than, will be lower than p naught, there is no doubt about it, lower than p naught and this pressure and this p will and lower than p naught, the pressure in the volume p which his lower than p naught, will be lower than p naught, and I can write and immediately after the increase, and immediately after the pressure will increase.

So p naught if it increase suddenly, rapid increase, volume pressure, that is a pressure in the volume, intermediate volume is less, no doubt, the intermediate pressure will definitely be, will be increased definitely, but it will take some finite time and within this time what will happen? Now the p naught is higher than p and this p naught minus p that is the delta p, so this pressure difference will now allow or will create a situation which will allow fluid to flow into the volume. So this is obvious situation. If p naught undergoes a rapid increase, what will happen?

It is not the case that immediately the pressure transducer will sense that increase, as long as p naught is remaining constant there is no problem. But the moment p naught increases rapidly, the pressure transducer cannot measure pressure instantaneously if we would have followed the first case, first method, perhaps we would have calculated, measured the pressure instantaneously, but the situation is not similar for this case and because of this tubing, the pressure difference p naught minus p that is the driving pressure difference will allow or will create a situation for fluid to flow through the tubing towards the volume.

So this pressure difference will draw fluid into the volume which in turn increase p. That is what we have understood. Question is, this process, this process requires a certain amount of time and that time depends upon the fluid which is flowing into the confinement and the geometry of the system. So this is the case. So we have understood till now that if there is sudden change in pressure, system is not in a position to adjust the rapid change in pressure and that will give us an instantaneous measurement, instantaneous increment, increase in pressure information.

Now, for that what will happen? Since the system is now connected to the pressure tapping through our tubing and the pressure difference will allow liquid or fluid to flow from the tapping side into the transducer volume and it will take some finite amount of time, and that time that, that amount of time at which the system will be at equilibrium that will depend upon the geometry of the system and the type of fluid which is flowing into the tube.

Now, until and unless the system is coming at equilibrium, we cannot measure pressure. So even if we measure pressure during that time, we would not be able to measure the correct one. So there will be a continuous fluctuation kind of thing. So system will be allowed to be at the steady state, after then only you can measure the pressure and we can calculate other parameters if we are requiring. This is very important.

Now, we have understood that the system requires finite amount of time to reach at the equilibrium. What is the time required for this system to come at the steady state? And even for the steady state, I mean even if we assume that the system is coming at the steady state, then even if the input is steady now, so p naught suddenly increases, suddenly changes to the p naught dash, and p naught dash is steady I can say.

So if the, if there is a change in pressure, what is the time required? And precisely how long the system will take time to become steady? Even after changes, even after the sudden increase in pressure, even after this change that is p naught to say p naught prime, if p naught prime is steady then is the response that will be given by the system will be oscillatory?

So there are a few important questions, those questions need to be addressed and for that we need to consider the dynamic response characteristics of the system. Perhaps, this is the most important part of the experimental fluid dynamics, before we go to discuss, before we go to use any particular equipment or system in measuring any flow parameter, say pressure, temperature or flow velocity, we need to know what is the dynamic response consideration.

That means, if the system, if there is a change in the system, sudden change in the system, sudden change in the flow parameter, flow variable, can system accommodate that change suddenly? No, answer is no. There will be requirement of finite time, and after that finite amount of time, only this system will be at equilibrium condition.

Now question is what will be that finite amount of time? If we need to calculate that time response, so the how fast system will response that. So that means if we try to measure, if we try to measure the pressure within this time, we would not get the correct one. So we need to wait for the steady value and if we need to wait, how long we should wait? And that is the dynamics response of a particular system. So by studying the dynamic response of a particular system, we can predict the time which is required for a particular system to give a steady output.

So this is very important, that is why this is very important to know. And we will discuss this aspect again taking an example in the next class. But at least today we have discussed this aspect that if there is a sudden improvement in pressure in the fluidic confinement from today’s analysis, we have understood that the system requires finite time to become steady and only after the system becomes steady we can calculate, we can predict, we can measure the parameter, which we would like to measure using that particular device.

Now, we have understood rather we have studied basic fluid mechanics in our undergraduate days. Now if we now go back to the previous slide where we have drawn the schematic, what will happen? See, what I said, say I will draw the schematic again and I will explain.

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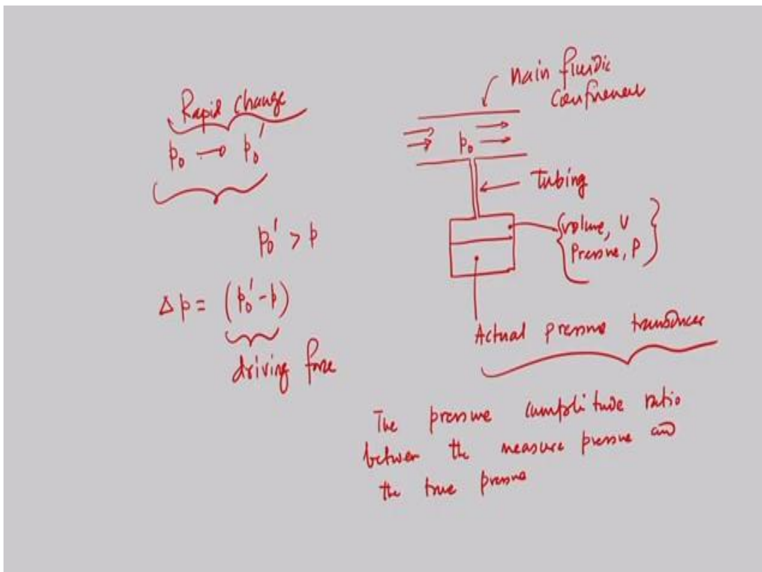

So we have fluidic confinement through which a fluid is flowing and we have taken pressure tapping and this pressure tapping is used to measure pressure and we have seen that this volume is v, pressure is p. So the volume between the inlet and the actual pressure transducer, so this is the actual pressure transducer, so this is actual pressure transducer.

Now this is p naught. In the steady case, now p naught if it suddenly increases to p naught prime and this p naught prime is greater than p and this p naught prime minus p, that pressure difference will now allow fluid to come into the volume and that will take some time.

If this, the tubing, which is used to connect this taping to the, which is used to connect the pressure taping and the pressure transducer, the tube has fixed radius and fixed length and these tubes are basically Tygon tubing. Now, if the change in pressure is very fast, rapid change, then the pressure difference p naught prime minus p, so this is rapid change. If I write this is rapid change, rapid change, so this is delta p, that is the driving force.

Now, the rapid change, because of the rapid change there will be a mass of fluid that will now enter into the tubing from the main confinement, so this is main fluidic confinement. So because of this pressure change, sudden change, much of the fluid that will, so the pressure difference will allow fluid to flow from the main fluidic confinement through the tubing into the pressure transducer. So this is tubing, but change is so rapid, the mass that will now, mass of the fluid that will flow from the main fluidic confinement through the tubing into the pressure transducer will vibrate.

So it will vibrate because of the sudden and rapid change, but the system is such that the fluid which is flowing through the main confinement, the same fluid is now flowing through the tubing. So the fluid is have viscosity, so the viscosity because of the viscosity and the, this is the solid boundary so we cannot trivially ignore the frictional effect. So the mass of the fluid will now vibrate because of the sudden rise or sudden increment in pressure, the vibration will be dampen out by the frictional effect that is that will be produced because of this flow phenomenon.

So the phenomenon of the flow, fluid flow from the main fluidic confinement through the tubing into the transducer because of the sudden increment in pressure, we will allow the mass of the fluid that, mass of the fluid will vibrate. Now the vibration will be dampen out by the frictional effect that is there within this tubing.

Now if we consider this effect and the frictional effect that we can consider using Laminar frictional resistance and the pressure amplitude ratio. So the pressure amplitude ratio between the measured pressure and the true pressure we can calculate. So mass of the fluid will vibrate that will be dampened out by the fluid friction, but this competition will continue and the pressure which we will be measuring using special transducer may not be the correct one. So we need to wait for a longer time for this. We cannot wait for the longer time.

So that means we need to study the dynamic response consideration dynamic response characteristics of the system but what we have understood from today's discussion is that the rapid change in pressure will allow mass of the fluid that will flow from the main confinement to the pressure transducer will vibrate, to vibrate in the tubing and the vibration will be dampened out by the frictional effect.

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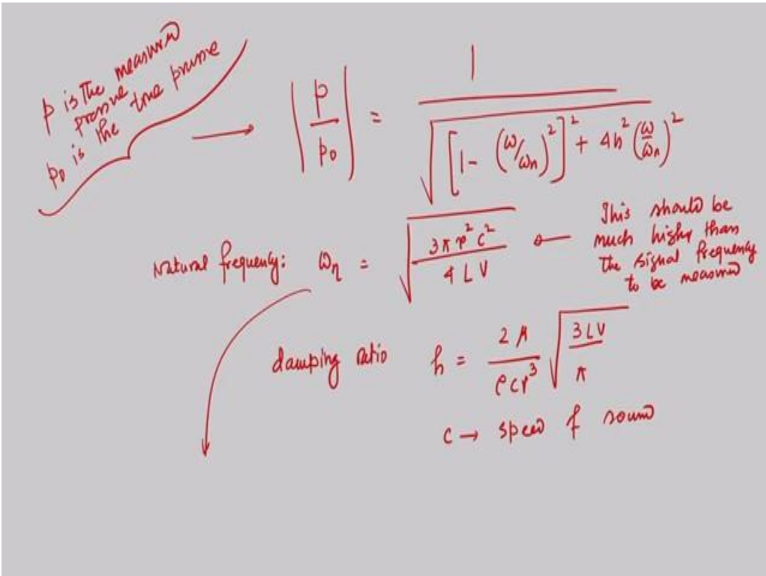

Now because of this phenomenon the pressure amplitude ratio between the measured pressure and the true pressure that we can calculate and if we calculate that is not in the scope of this course, but we can calculate this p by p naught, this expression I used in one of my previous classes that is nothing but 1 upon root of 1 minus omega by omega n square plus 4h square square, their natural frequency omega n, this is the, that is 3 pi r square c square by 4 L into V under root.

And damping ratio h that is twice mu rho c r cube under root 3 L V by pi. So this natural frequency should be much higher. So this should be much higher than the signal frequency to be measured. So what I would like to say that, when mass of the fluid will vibrate, the system will vibrate so the natural frequency should be much higher than the signal frequency that will be measured and that is very important. So as the sudden incremental pressure will allow mass of the fluid to be accelerated in the fluidic, in the tubing. Because of the sudden acceleration, the system there will be vibration although the frictional effect will try to dampen out the vibration but that will lead to the ratio between these two measured and the true pressure.

So this is the measured pressure, p is the measured pressure and p naught is the true pressure. So this is what we have calculated and this natural frequency should be definitely higher than the signal frequency that we would like to measure, of course, otherwise the system will never come into the equilibrium.

Now, where c is the speed of sound, rho is the density, v is the viscosity of the fluid, this r, r is the radius of the tube, this is speed of sound. R, l and v these three quantities we have certified in the schematic, r is the tube radius, l is the tube length, v is the volume of that intermediate volume and mu is the fluid viscosity, rho is the fluid density and c is the speed of the sound.

Now this, so what we can see from this explanation is that if we increase the tube radius, so if we increase the tube radius then natural frequency will be increased but this is not important. So we should not increase the radius of the tube, if we increase then the natural frequency will be, will increase with the tube radius.

Now this natural frequency definitely should be the, should be higher than the signal frequency that we would like to measure. So definitely r, if r increases that will be the case, favorable case. Now l and v what we can see if we increase l the natural frequency will be reduced, so this is not a desirable condition, so l should not be very large and of course volume should not be very large.

So that is why from this analysis, we can now draw one important conclusion that the first case we have seen that if we somehow can place, if we somehow can mount the pressure transducer at this site where we would like to measure pressure, that is the ideal one and there will be no problem. But this is not the case always that the pressure transducer are not readily available and these transducers are very costly and because of this reason first case or first method is not adapted frequently rather, but the second case which is mostly used in almost all the practical applications.

Now if we look at this explanation of the natural frequency, what we can see if we increase the length then the natural frequency will decrease and that is not good for the system. So we need to always keep in mind that the length of the tubing, the length of the tubing should be decreased. And on the other hand, l also should be increased so that the natural frequency can be increased and always natural frequency should be higher than this single frequency essentially to increase the system stability.

So from today's discussion at least we have understood that this dynamic response consideration is very important, at least we need to study. So why we need to study the transient and frequency response characteristics? There are three important reasons.

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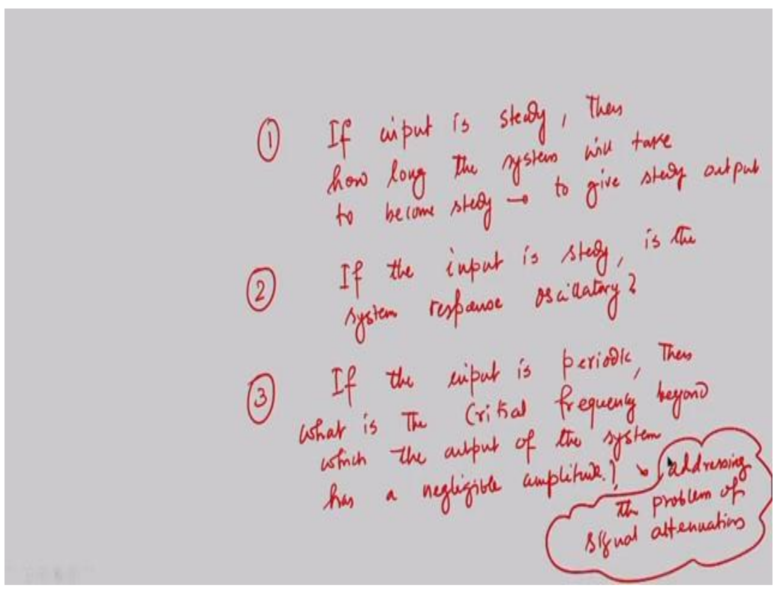

First one is that, if input is steady, so if p naught is remaining cost and the p naught is steady, then how long, then how long the system will take to become steady? To be precise, to give steady output. So that means when the system input is steady, then definitely system will take some finite time that is what we have discussed in the beginning of this class that although p naught is remaining constant, we can wait, we will definitely get result without any problem but we need to wait until the system becomes steady. So how long the system will take time to become steady or to give steady output?

Number two, which is very important. If the input is steady, is the system response oscillatory? This is another important question. So we have discussed one case that although p naught is steady, now we have seen that we are measuring using a system where we have tubing and though if we inset that system and if we start, if we allow the system for its functioning, system will now give result that will measure the output parameter, so it will take some finite time. Even then is the system responses oscillatory? That we need to know. So that will depend upon the system frequency.

So when we talk about question number two, then very important role is there, so the natural frequency will play an important role to play about there. That means, even if the input is steady, then depending upon the natural frequency of the system we can say whether the output will be oscillatory or not. So if the natural frequency of the system is very less, then system will never come into the steady state and we will get always fluctuating results. So we cannot expect the steady output.

Number three. Number three is very important. If the input is periodic, then what is the critical frequency beyond which the output of the system has a negligible amplitude? That means if the system, if the input is periodic, input is fluctuating, then what is the critical frequency beyond which output of the system has a negligible amplitude?

This is very important question. In fact the question three is addressing the problem of signal attenuation, signal attenuation. So although the input signal is periodic, but when we are measuring using that signal, maybe pressure is oscillatory pressure, if we now measure the pressure using pressure measuring device, then what is the critical frequency beyond which the output will have negligible amplitude.

So that means the signal frequency with signal will be as the signal is passing through the measuring system, measuring equipment, then and the measurement system then the signal will be attenuated and that is very important consideration that we need to know. Because we always need to, so we need a very negligible amplitude. So our objective should be to attenuate the signal to and if we need to attenuate the signal then what will be the critical frequency of the system through which is signal is passing. So the example I have given, if the pressure is oscillatory of fluctuating pressure that we need to measure, then what will be the critical frequency of the system for which the amplitude of the output should be, will be negligibly small.

So, we have discussed today about the dynamic response consideration and we have critically discussed why we need to consider this aspect in the paradigm of experimental fluid dynamics and even if you need to consider this aspect, I mean of course you need to consider then what are the different issues, aspects involved with the measurement system? And we have discussed the different critical issues which should be considered during measuring flow parameters using mechanical system where dynamic response plays an important role.

We will discuss this issue again by taking an example and that part we will be discussing in the next class. So, with this I stop my discussion today and we will continue in the next class. Thank you.