Experimental Methods in Fluid Mechanics
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Lecture – 06 - System response and distortion, Impedance matching

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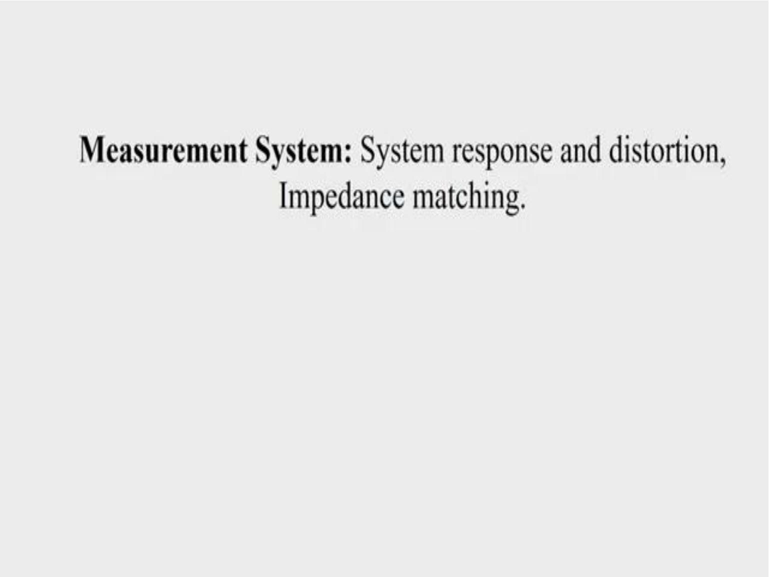

Good afternoon! I welcome you for the session of Experimental Methods in Fluid Mechanics. Today, we will discuss about system response distortion and impedance matching. So, to start with, we will recall that in the last lecture we have discussed about the static and dynamic measurements and the implication, issues with those measurements. So, today we will see that what is system response, what is distortions and then why we need to have impedance matching.

So, I will discuss systematically that whenever we have measured, rather when we have measured any quantity, physical variable, those are the variable, quantity which are not constant with time, rather which are changing with time and we have seen that if there, we have taken example and I have discussed what are the problems associated with that, if, and what we need to take into, what are the precautions we need to take into account while measuring those variables which are changing with time.

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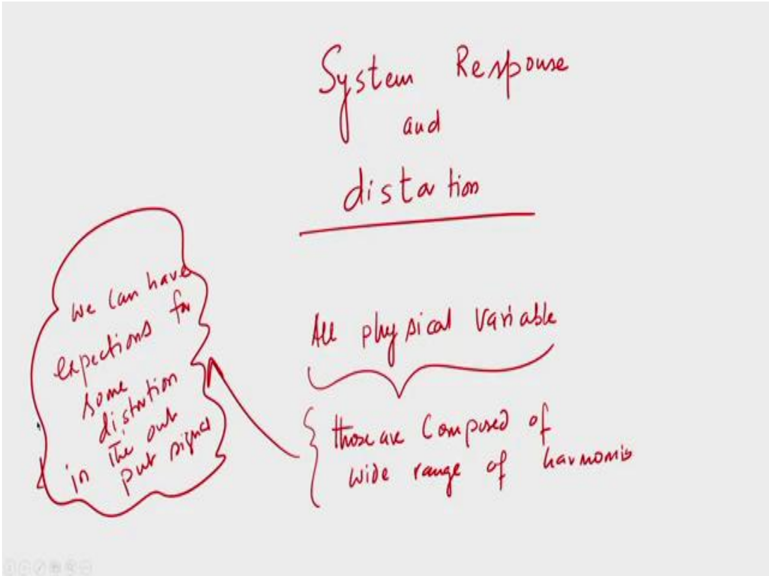

So, today we will talk, discuss about system response, system response and distortion. So, we will discuss this issue again towards the later stage of this course and but to have an understanding about this, why we need to know this, today we will discuss taking one example. So, we have seen that, there are measurement variables through which we have seen that measurement blocks, there are several modules and their functionalities.

Now, measurement variables, rather I can say the measurement of all physical variables which are composed of a wide range of harmonics can be expected to have some distortion in the output signal from a transducer. So, we have seen the measurement block, if we can recall in one of my last, one of my lectures that we have already discussed that one important module is transducer. So, there are as I said that almost all the physical variables those are composed of a wide range of harmonics can be expected to have some distortion in the output signal from the transducer.

Now, what is the distortion and why they are coming? I mean, what are the sources of those. So, what I said that, almost all physical variable, all physical variables, all physical variables especially those are composed of a wide range of harmonics, so those are composed of wide range of harmonics can have, rather we can expect to have distortion in the output signal from the transducer. So that means the physical variables which are composed of a wide range of harmonics, we can expect to have distortion, some distortion in the output signal from the transducer.

So, basically for this kind of variable we can have expectation for, we can have expectation for some distortion in the output signal, in the output signal. So, this is very important that those are having wide range of harmonics.

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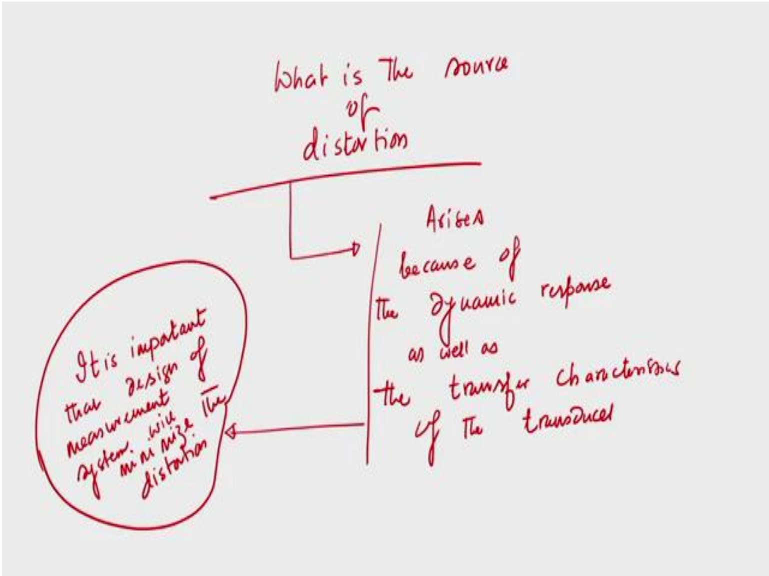

Now, as I said, what is distortion? That means rather what are, what is the source of distortion that is we need to know, what is the source of distortion? That distortion is, again I am telling the distortion arises because of the both dynamic response as well as transfer characteristics of the transducer. So, this is not only with the dynamic response or dynamic measurements but also the transfer characteristics of the transducer.

So, basically whenever we get signal from the transducer, physical variable might have multiple harmonics, not only that the transfer characteristics of the transducer itself also leads to distortion in the measured quantities or measured signal. So, basically that means I am writing that the, this arises because of the dynamic response as well as the transfer characteristics of the transducer.

So, this is very important that characteristics of the transducer, transfer characteristics of the transducer also leads to distortion in the measured signal. So, our objective, rather it is the objective of design of any measurement system should be that we have to minimise the distortion. So, it is not only always with the dynamic response, rather the variable what we would like to measure if that variables, that variable is having wide harmonics that is only, that is the source, not only that if the transfer characteristics of the transducer itself also leads to some distortion.

So, taking a note on this aspect, what we should do? This is very important that we have to design our measurement system in such a way that the distortion can be minimised irrespective of the fact that whether it is coming from the dynamic response of the variables or the transfer characteristics of the transducer itself. So, I am writing that it is very important, it is important that design of measurement system will be such that, will be, it is important that design of measurement system will minimise the distortion, so this is very important. That means while designing the measurement system we should take a note on this aspect so that the distortions of the output signal should be minimised.

Now, I am briefly discussing about these aspects because many a times we need to know that I, we really do not know the variable which we are going to measure, whether we know a priory whether it is function of time or not, but while we are measuring those variables using any measurement system, at least we should have knowledge that what is distortion and if you would like to analysis the data after measurements to predict performance, to predict characteristics of any equipment, we should know about this.

So, now in that, in the last class we have examined the frequency response of a system, we have discussed taking an example of that second order simple, simple second order differential equation where the system is excited externally using a forcing function which is sinusoidal in nature that is what we have discussed in the last class. Now, that it is a time we should look for the types of responses.

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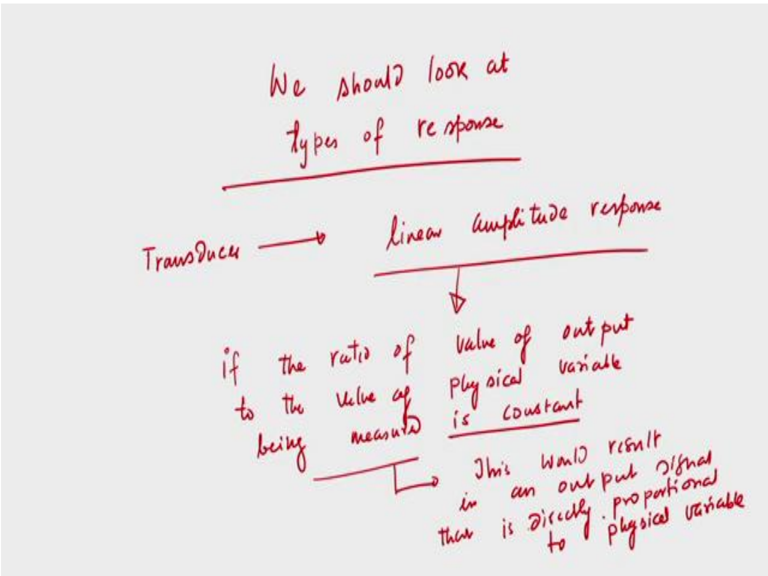

So, now we should look at types of response. So, say again I will discuss, take an example that if a particular transducer, say, a transducer that is there in the measurement system has linear amplitude response. Say, we have, where many a times we are using this that linear amplitude response. What do we mean by this linear amplitude response? That means it indicates that if a measurement system has a linear amplitude response, if rather if the ratio of value of output to the value of physical variable being measured is constant.

So, linear amplitude response we can say a transducer is having if the ratio, if the ratio of value of output to the value of, to the value of physical variable being measured is constant. So, that means if this ratio of these two quantities that is a value of output to the value of physical variable that we are going to measure is constant, then it is called that linear amplitude response.

This would result in an output signal that is directly proportional to the physical variable. So, output signal that we are getting from the transducer that is directly proportional to the input value that is the physical variable. So, that means this would result in an output signal, output signal is the most, that is a signal we are getting from the transducer and that will be directly proportional to the physical variable, because that is constant.

So, output signal is that is directly proportional to physical variable, instead of writing input I am going to write physical variable. So, now we have understood what is linear amplitude response and what it essentially indicates. That means, ratio of value of output to the ratio of value of the physical variables being measured if it is constant, then we have, we can say the transducer is having linear amplitude response. It indicates that the output signal rather a linear amplitude response will result in an output signal that is directly proportional to the physical variable.

Now, see linear response, linear amplitude response is easily obtained in measuring physical variable for not all the ranges. That means, linear amplitude response is obtained for a limited range of physical variables, it is not expected that all the physical variables, for all the (expec) physical variables we will have linear amplitude response. Now, once that means, that what I am telling that linear amplitude response is not possible for all the ranges of physical variables that means, that means we are having non linearity.

So, whenever we are talking about non linearity, that means the physical variables which we are going to measured that is having non linearity and one source of and we have to understand what are the common sources of those nonlinearities.

So, that means now this linear amplitude response, not, may not be obtained for all the physical variables we are going to, where we are going to have, I mean we are going to measure. So, we have so many physical variables but for all the physical variables we need to know that if you would like to know, if you would like to obtain response, that response signal or output signal from the transducer then it is very difficult them, it is very difficult to get response using linear amplitude, it is very difficult to get signal using linear amplitude response.

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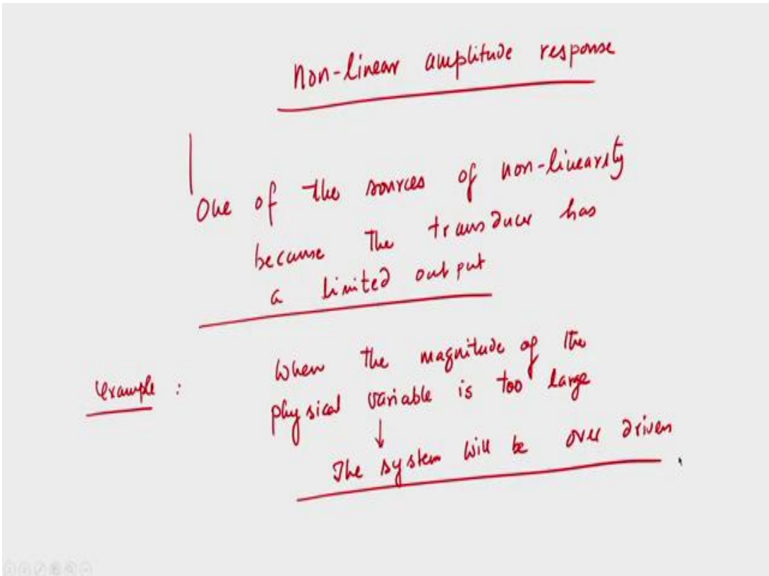

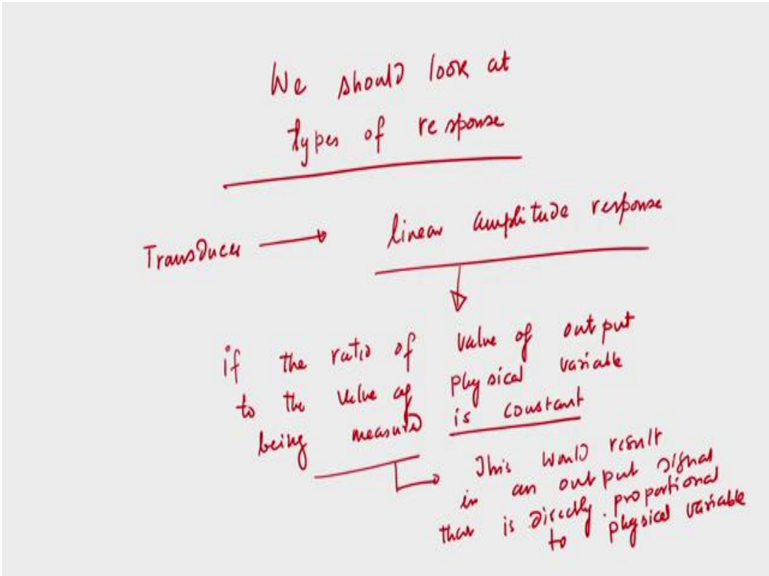

So, that means we need to know non-linear amplitude response, non-linear amplitude response that means linear amplitude response does not work. Now, one of the sources, one of the sources of nonlinearity, so there might be different sources through which this nonlinearity may arise, but one of the sources of nonlinearity arise because of the transducer that is there in the measurement system has a limited output.

So, that means transducer, just few minutes back I said that if I go to my back previous slide that distortion is also one of the, distortion may arise because of the transfer characteristics of the transducer. Now, I am telling that the nonlinearity may also be there because of the, because of the (transdu), because of the (trans), because the transducer has a limited output, because the transducer has a limited output.

So, when we face this kind of problem? Say, if the magnitude of a physical variable is too large, I mean too big the system will be over driven, so maybe the physical variable we are going to measure using the measurement system where we are having transducer, but the physical variable, the magnitude of the physical variable become too large. So, I can say one example that when the magnitude of the physical variable is too large then this system will be over driven.

That means the system cannot be, system can be driven but system can be run but the question is magnitude is too large that system will be over driven. In that case, transducer will be working but transducer will be working beyond his, beyond that, transducer will be working beyond it capacity, beyond its output. So, that means this is one of the source, one of the sources of having nonlinearity in the measurement system.

So, we really do not know a priori that the physical variable which we are going to measure is having large, whether it is large or small. Now, if the magnitude of the physical variable is too large, then if we would like to measure the physical variable using the measurement device system which is equipped with a transducer and the transducer has the limited output or limited range but in that case measurement system will run but it will run in a, in its overt design condition.

That means, that means it indicates that transducer will not be functioning properly. So, what will happen? The transducer will either give the maximum, minimum output response or may give a null response or it self-destruct.

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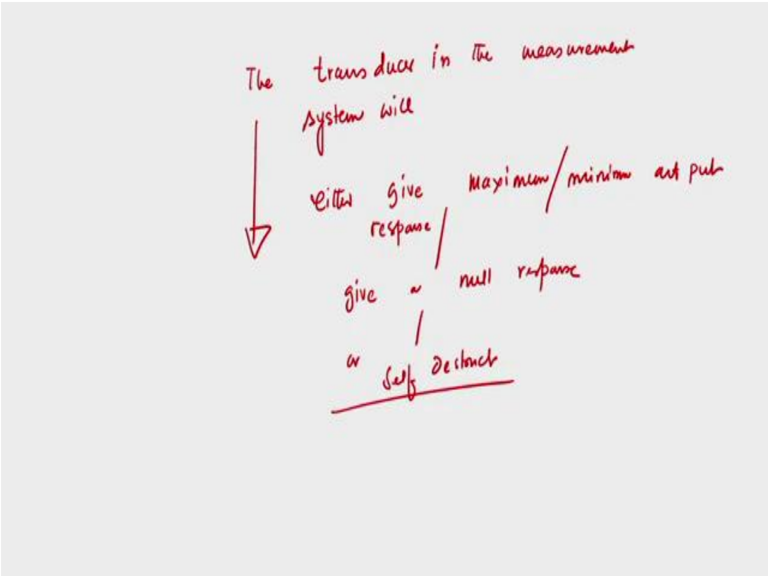

So, basically, in that case, the transducer in the measurement system, measurement system it may give (max) either give or it will, transducer in the measurement system will either give maximum or minimum output response or it will give a null response or it will self-destruct. So, that means the physical variable magnitude is so large that it goes beyond the transducer output level, output range. So, in that case transducer may give the maximum-minimum response or it may not give or it self-destruct.

So, say for example, an amplifier can produce an output signal within plus minus, it voltage maximum-minimum or any attempt to produce an output signal larger than it will be unsuccessful. In that case, output signal would be said to be clipped.

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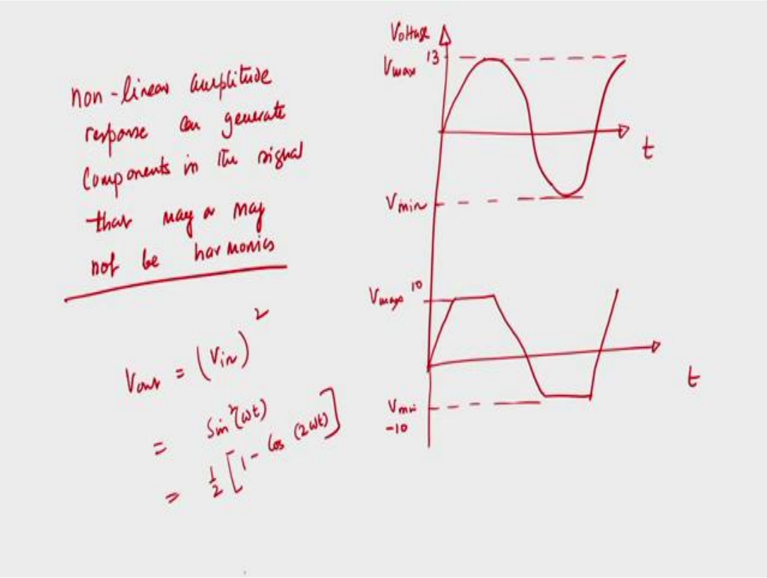

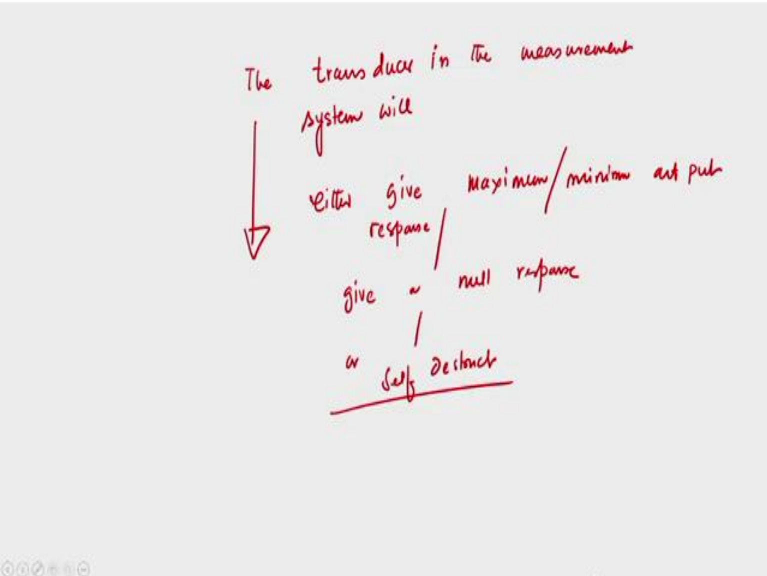

So, I mean say if I take an example that is what I am telling, say, we have, I am just drawing, so this is, so this is Vmax, say this is, so this is voltage V, so this is Vmax voltage and this is Vmin, so this is Vmin. Now, it may so happen that if the say it is time, it is time and it may so happen that see, say, this is 15 or and in that case it will be like this. So, this is Vmin, this is Vmax, this is we Vmin and say this is minus 10 and this is plus 10.

So, that means, for example an amplifier can give a value plus, minus V maximum or any attempt to produce an output signal larger than this will be unsuccessful. So, if I would like to get the larger value so it is showing, I mean it is giving within plus, minus say not 15, it is plus minus say 13, so if we would like to have measured value using this amplifier which is, which goes beyond this maximum minimum value that is out of this range, in that case, output signal would be said to be clipped that is what shown in the, this the figure.

Now, so what I can say that this is very important that non-linear amplitude response can generate components in the signal that may or may not be harmonics. So, for example, if the amplitude response is the square of the physical variable and the physical variable is sinusoid, a zero frequency component as well as a component at twice, the frequency will be produced and that is what very common example I can take that, see, see Vin, I mean input signal and input voltage is of the, that is sinusoidal. Then I can write that, what I am, what I told that non-linear amplitude response can generate components in the single that may or may not be harmonics.

So, nonlinear amplitude response may, sorry, can generate, can generate components in the signal that may or may not be harmonics. So, nonlinearity is there because of the transducer that is what I wrote that transducer has the limited output. If you would like to measure physical variable which is the which falls beyond the transducer output range, then we have seen that it can give either maximum-minimum output response or it can give a null response or it may self-destruct.

So, we have taken this example of amplifier and we have seen that if the amplifier can give any output signal within this plus, minus, maximum and minimum value. Now, any attempt in order to obtain output signal larger than this will be unsuccessful and that is what I have given example, if you would like to measure an output signal which is, which is larger than its specified range then output signal is that signal would be, would said to be clipped that is what I have shown.

Now, then I told that non-linear amplitude response can generate components in the signal that may or may not be harmonics and if the amplitude response is a square of the physical variable and the physical variable is sinusoid, a zero frequency component as well as a component at twice of the frequency will be produced. So, a typical example is say, output voltage or output signal is say Vin that square.

Now, if the input is sinusoid that is what I said, so I can write sine square omega t. Now, I can write it in terms of 1 and 2, 1 minus cos twice omega t. So, the statement which I said can be seen from the this following example. So, if the amplitude response of a square, amplitude response the square of the physical variable of the physical variable and the physical variable is sinusoid, then a zero frequency component as well as a component at twice the frequency will be produced and in that case the, I mean the non-linear amplitude response which is, which can generate, generating components which may or may not be harmonics. So, this is one of the sources that is what we have discussed.

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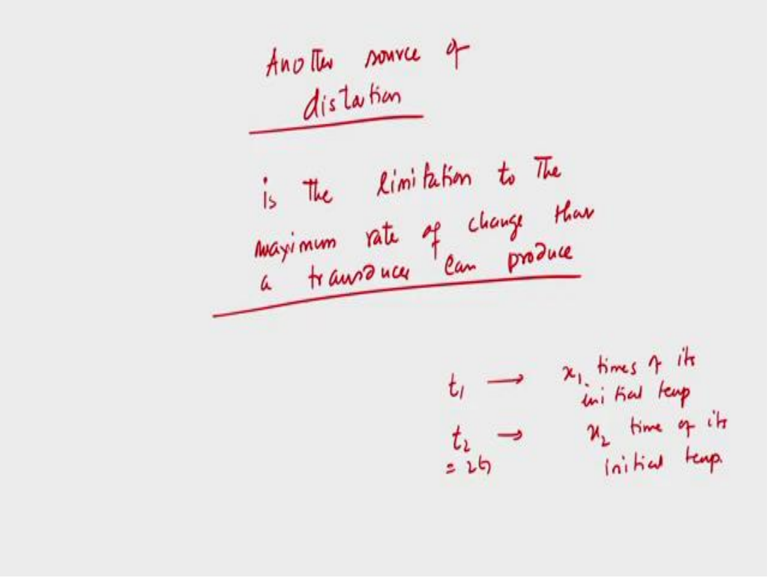

Now, an additional sources of distortion in the limitation is the limitation to the maximum rate of change that a transducer can reproduce. So, another sources of distortion, so that means if I write another sources, another source of distortion the first one is the, the first one we have discussed about that, what is that? Transducer has a limited output range, second one that is what I am telling that is very important that transducer can produce certain range of the signal, but that limitation that means transducer cannot produce signal beyond his design value.

That means, whenever a transducer is using to measure any, to give any, to give output, the transducer will give output signal but it will always give output signal with its design value. Now, if any single, if you would like to measure using the transducer which is beyond its design value then it cannot. So, similarly another source of distortion that I will write is the limitation, is the limitation to the, limitation to the maximum rate of change that a transducer can produce.

So, one is output range, another is limitation of the maximum rate of change a transducer can produce. Say, again I am taking an example, if an object is placed in a lower temperature bath, the temperature of the object will exponentially decay with time and maybe after t1 we will get say, after t1 we will get say x1 times of its initial temperature. That means, if the initial temperature is say t and it is placed in a low temperature bath then the temperature of the object will decay.

Now, after t1 it will be x1 times, say after time t2, I mean maybe just which is 2t1 it may be x2 times of the initial temperature. So, and typically we would consider the object to have nearly reached to its, to the bath temperature maybe after 3, 2, or 3 or 5 times constant, I mean the constant which you are taking x1, x2 after 3 or 3 to 5 times of the constant. Now, the amount of time it takes a transducer to change after a step change to the physical variable is called the rise time or the delay.

So, the maximum rate of change the system can handle is called the slow time. So, that means what I would like to say that another it may have distortion that may be the transducer can have maximum rate of change. So, say, if this object, if we know the initial temperature we are placing in a lower temperature bath, definitely temperature will decay down, it temperature will decay exponentially and with a time constant t.

So, that time constant maybe after x1 times it will be, after t1 time it will be x1 times of the initial temperature, up to t2 times that is twice of that t1, it may have x2 times of the initial temperature, so and so on. So, that is typically, I mean we would consider the object to have nearly reached the bath temperature after 3 to 4 times constant. Now, the amount of time it takes for a transducer to change after (())(37:40) of the physical variable is called the delay time.

Now, this maximum rate of change a transducer can produce if that is not equal to the change which a physical variable which we are measuring is having then perhaps, not perhaps then distortion will occur. So, we have understood that the distortion may occur because of the range of the output of the transducer, not only that limitation to the maximum rate of change of transducer can produce.

So, transducer may not be able to produce the rate of change which is occurring after physical time changing that is what this example I have given. And if the change, if the changes occur beyond the maximum rate of change that a transducer can predict, then distortion will be there. So, with this now let us move to see what is, what do you mean by impedance.

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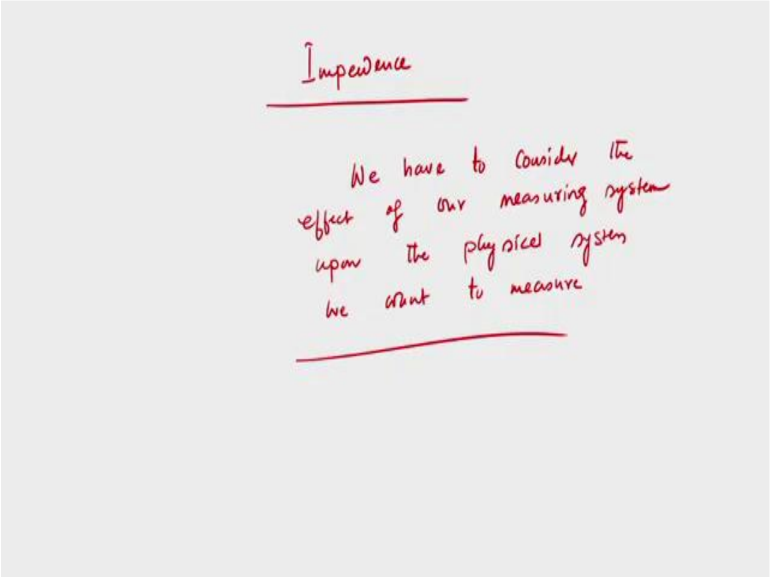

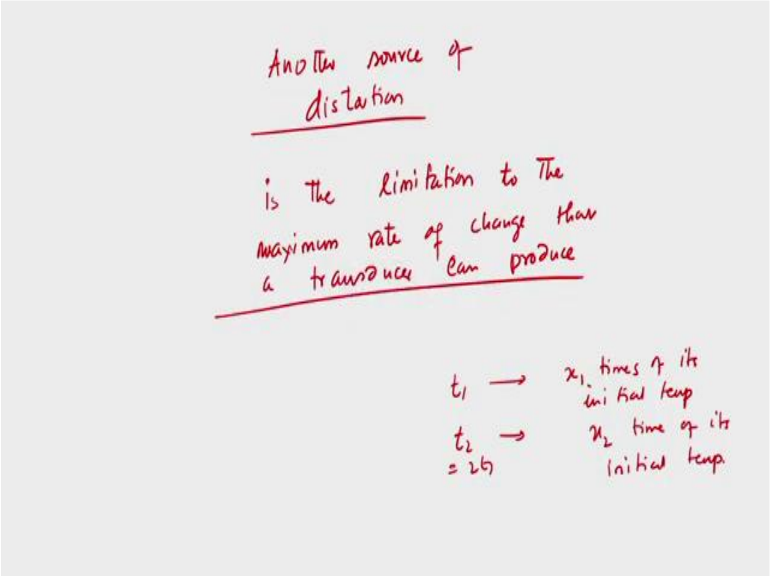

So, impedance is also another important term that we should be familiar with when you are having this course on, when you are studying this course on experimental methods in fluid mechanics. Any experimental methods, whether it is used to measure physical variables of any, of fluid, of any fluid mechanics of the, of subject fluid mechanics, whether it is measuring any physical variables of fluids, let us say velocity pressure, temperature, etcetera or it is measuring any other variables, we should be familiar with the term impedance.

So, what is impedance and why you should know and what is, what is done essentially when we talk about impedance matching? We have seen that we have to consider several effects of our measuring system upon the physical system we are going to measure or want to measure. So, just I am writing the sentence that is very important that we have to consider the effect of our measuring system, of our measuring system upon the physical system, upon the physical system we want to measure.

This is very important statement, we have to consider the effect of our measuring system upon the physical system we want to measure. If you really do not know it, we have rather we will come up with the results, we will come up with the data that is measured using any experimental measurement technique, following experimental measurement technique using device or equipment, we may get the wrong results.

So, it is very likely that we will have distortion that means the transducer we are having in our measurement system and that is having limitation in its range, output range, not only that it is also having limitation to the maximum rate of change that it can produce. So, many a times we have a physical measurement, measurement of physical variables and if the variable is too large and also that example that I have given just 2-3 minutes back that, if we place object to a lower bath, in a bath having lower (tempra), having a lower bath temperature, then of course the temperature of the object will decay and it will eventually reach at the lower bath temperature exponentially.

Now, if we would like to measure after say t1, then we make it sometimes of the initial temperature and another t1, maybe 2t1 will get x2 time, that x1, x2 may not be equal that constant is very important. So, this constant, I mean is, the constant will depend that and that the rate of change of that whether that rate of change is within the rate of change that a transducer can produce then we will get the correct result, otherwise we may not.

So, impedance we need to know and sometimes we to have, we need to have impedance matching, but before we go to see what do mean by impedance matching, just I have written this statement that initially need, we to have to consider the effect of our measurement, of our measuring system upon the physical system we want to measure, we are going to measure. That means, the measurement, measuring system, measurement, measuring device, measuring equipment we are using, we need to know what are the effect of that measurement system might or may should have on the physical system we are going to measure, only knowing that we can now adjust that we have talked about distortion and other things through impedance matching.

So, we will continue the discussion in the next class and we will see how we can have matching of the impedance through inclusion rather insert by the addition of external resistance we can have this. And we will discuss this issue in the next class. Thank you very much.