Acoustics & Noise Control
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Module – 22
Lecture – 27
Electro Mechanical Analogies - part 1

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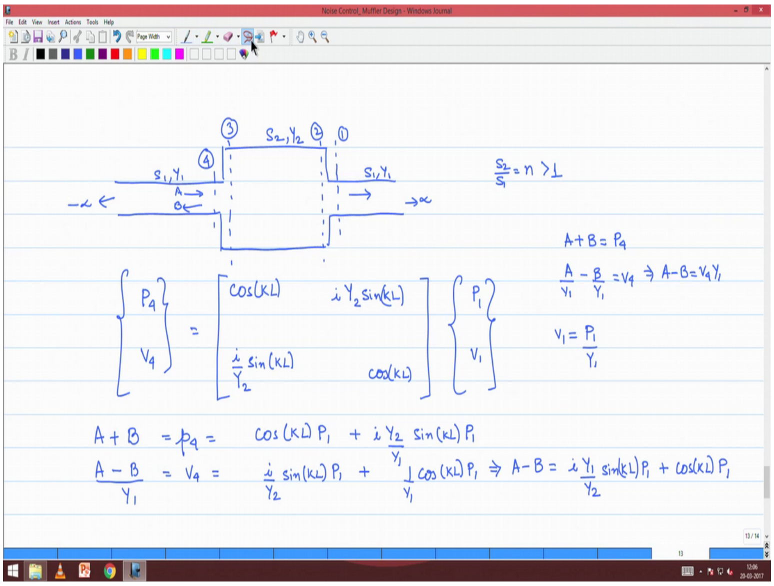

In the last class we looked at a simple expansion chamber muffler of this kind. Within inlet duct and in outlet duct which is going to infinity in both directions. And the expansion chamber had then area cross section S 2 whereas, the inlet and the outlet had an expansion had an area which is S 1. And we said that S 2 by S 1 is equals to n which is greater than 1 and we took the transfer matrix at each of the sections, this was our first section this is the second this was the third and finally, this was the fourth right.

So, effectively the transfer matrix between 3 and 4 and between 1 and 2 are identity, if we frame it in terms of mass velocities rather than particle velocities. So, the transfer matrix would relate the state variables at station 4 which is P 4 V 4, with the state variables at station one which is P 1 V 1. And here you will have the entries as cos K L, cos K L i Y sin K L and here we had i by Y sin K L right. Just to make sure that we do not confuse between the 2 Y's, remember that the cross section area in there are 2 cross section areas that we are talking about the cross section area of the expansion chamber is denoted as S 2. The cross sectional area of the inlet and the outlet are S 1 right. Accordingly the characteristic impedance in both these segments will be different. The characteristic impedance in the expansion chamber segment will be marked as Y 2 and the characteristic impedance in the inlet and the outlet will be marked as Y 1 ok.

So, just to make things specific we will put a 2 subscript along with Y because the Y that, we are talking about is due to the expansion chamber and will call it as Y 2 rather that keep it open as Y because we will see another Y 1 coming due to the expansion chamber. So, this is roughly where we left, we also realize that in this portion there is going be only one wave, that is going to be transmitted outwards. But in the inlet section there will be an incoming and out going wave right. So, A plus B together should give us P 4 and A by Y 1 minus B by Y 1 should give us V 4 right. Or A minus B should give us as V 4 into Y 1. That was the relation that we could have and also in the other outlet section we had P 1 as the outgoing wave, which means that the mass velocity in the outlet section is going to be P 1 by Y 1. So, that part was understood.

Now, what we will do is we will open this matrix equation up. So, this would mean P 4 cos K L P 1 plus i Y 2 sin K L into V 1, but V 1 is P 1 by Y 1. So, I could as well write this as P 1 by Y 1 over here right. So, this is P four, but then P 4 is also known to be A plus b. So, A plus B is now related in terms of P 1 right which is the final transmitted wave and similarly if we open out V 4 this V 4 is given as i by Y 2 sin K L P 1 plus cos K L into V 1, but V 1 is P 1 by Y 1 right. So, this is what it comes and V 4 also has been already written as A minus B divided by Y 1. So, in other words I could simplify this equation to be A minus B is equals to i times Y 1 by Y 2 sin K L into P 1 plus cos K L into P 1 right.

So, this is A minus B and we are already formed the equation of A plus b. So, together we should be able to find a and B in terms of P 1. So, that is the next job which we will do in the next page.

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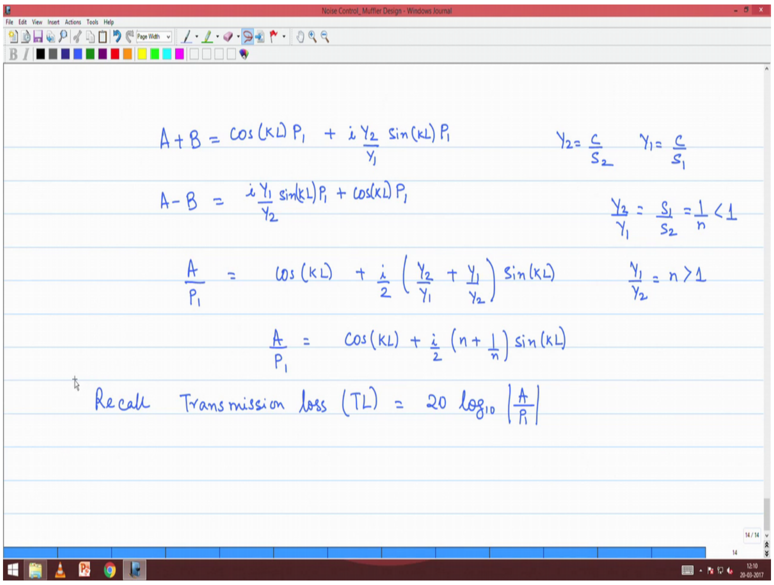

So, collecting the 2 equations once again A plus B is given by this expression. And A minus B similarly is given by the other expression. So, therefore, it is clear that A by P 1 is going to be cos K L plus i by 2 Y 2 by Y 1 plus Y 1 by Y 2 into sin K L from these 2 equations right.

And please recall that Y 2 is C by S 2 and Y 1 is C by S 1. S 2 and S 1 being the area of cross section of the appropriate portions of your exhaust line right. So, therefore, this fraction Y 2 by Y 1 would read as S 1 by S 2 which is 1 by n lesser than 1 and similarly Y 1 by Y 2 is n which is more than 1. So, as a result A by P 1 is going to read as cos K L plus i by 2 n plus 1 by n sin K L right. And this is exactly what I mean, this in terms of the logarithm is exactly what is transmission loss. Because what is a and what is P 1 A is the incident wave P is the outgoing wave, because in the outlet section there is no other wave there is only a transmitted wave which is going in the outlet section. And we define this ratio to be the transmission loss. So, remember transmission loss recall transmission loss was defined to be, and I will abbreviate this as TL to be 20 log base 10 A by P 1 modulus of it right. You cannot take the real or imaginary you should take the modulus of it.

So, now we see that we have actually sitting right. In front of us the expression for transmission loss this, remember we were unable to do it with the hand calculation in case of method one wherein we took all the 4 waves 4 or 5 waves whatever that was, and it led to a system of 4 by 4 equation. We left it at that point saying that the equations have been obtained one can solve those equations using a computational package. But we are saying that the transmission loss can be readily given as like a formula, if we appeal to the transfer matrix method which is the second method that we are going through. But more than the formula what is interesting to realize is that we will take some special cases out of this, and try to figure out how the plot of this transmission loss will look like.

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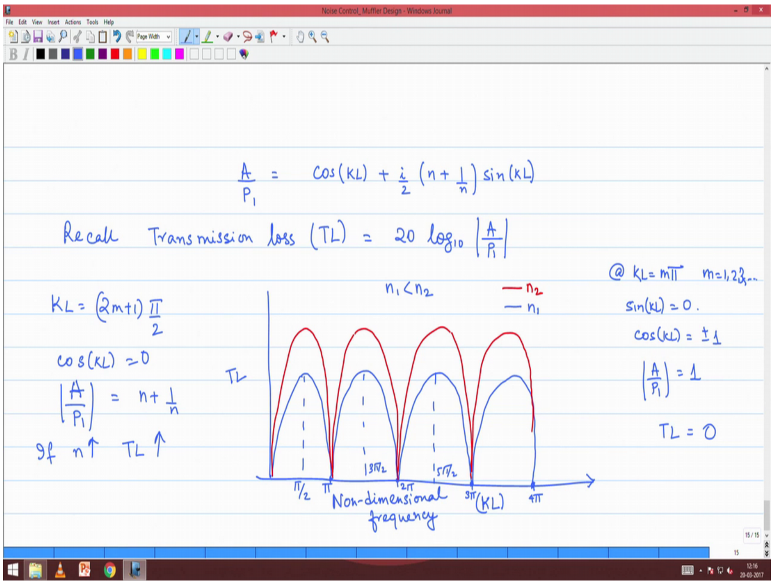

So, this is the formula for the transmission loss you will recall. What we wish to do is that we wish to make A plot of transmission loss against frequency. You know K is the parameter which; obviously, changes with frequency right. So, the non dimensional frequency will be denoted as K L this is very important. You should not always talk in terms of dimensional terms sometimes non dimensional analysis is far more generalized and it will give you much more insight than dimensional terms.

Please understand for a fixed length K L changing basically implies frequency changing right because K is directly proportional to frequency omega. So, non dimensional frequency is K l. So, there are many interesting cases first let us try to understand what happens at KL equals to pi, and 2 pi, and 3 pi. What happens at these values? And 4 pi. At these values of K L sin of K L will go to 0 right. So, at K L equals to n pi, I should not use n, because n stands for something else in this analysis. M pi m is 1 2 3 whatever. So, if K L equals to m pi then sin K L will go to 0 cos K L will be plus or minus 1.

So, therefore, A by P 1 magnitude of it is going to be 1. So, therefore, A by P 1 magnitude is going to be 1. And what will be the transmission loss 0. So, the transmission loss for these frequencies these non dimensional frequencies are supposed to be 0, there is actually no transmission loss. Whatever is the incident wave amplitude a the transmitted wave amplitude remains just the same. So, the muffler is completely in effective, at this frequencies it is not working like a muffler whether it is there or whether it is not there it does not make a difference, because it completely transmit is the incident wave right. So, this is very interesting to note that TL is going to go to 0 transmission loss goes to 0. What happens at the other in intermediate frequencies, now K L is equals to 2 m plus 1 pi by 2 right.

So, if you now take the other intermediate frequencies that is odd multiples of pi by 2 right. Then the cos K L term will vanish, and the sin K L will remain. So, sin KL is going to be either plus 1 or minus 1 does not matter because when you take magnitude it is anyway going to get to plus 1. But now you get to see that A by P 1 the magnitude of this is going to be n plus 1 by n right. So that means, if n which is the ratio of the cross sectional area between the expansion chamber and the inlet and outlet is rising what happens to n plus 1 by n that also will rise right.

So therefore, transmission loss will also be high right. So, at these numbers you can expect that you will get a maximum of the transmission loss. So, the transmission loss curve will look something like this right. So, the maximum will happen at odd multiples of pi by 2, pi by 2, 3 pi by 2, 5 pi by 2 and so on right. And all of those maximums will be at the same height, you can plot this to verify my statement. And if you change the value of n to a higher number then you will get more height of these lobes. The lobes will further increase in height. So, you will get more transmission loss if you have more height sorry, if you get you will have more transmission loss if you have more if you introduce a further high change of cross sectional area you will get more transmission loss. So, in my drawing in red I would have plotted for n 2 and in blue, I would have plotted for n one and then n one is less than n 2 right.

So, if you introduce large cross sectional change you will get larger peak values of transmission, but the nature of this curve will look exactly like this is right. So, this is the transmission loss versus frequency curve. Now how do you make use of this fact in the design of exhaust system? And design of muffler systems for exhaust. The answer lies in this fact that please understand that if your exhaust noise happens to show frequency content around these values, where K L equals to pi, then this expansion chamber muffler is useless. So, you should rather choose an l. So, remember L is a design parameter you could this length of the expansion chamber is your choice what you give as the length of the expansion chamber.

So, the idea would be to first determine what is the frequency of your interest wherein you have an exhaust noise problem determine the corresponding wave number, and then choose the length such that K L becomes pi by 2, or 3 pi by 2, or 5 pi by 2, whichever is feasible; obviously, you would like to keep the length as small as possible. But you cannot make it very small. So, make it choose this value L such that K L happens to hit and odd multiple of pi by 2. What is a bad design is that if K L happens to hit even multiples of pi by 2 or K L happens to hit pi or it is multiples right. In that case whatever area of cross section change that you choose will render itself in effective for the control of the exhaust noise because the transmission is just complete at those frequencies. But the first thing is choose the length of the expansion chamber such that you are at K L equals to pi by 2 the second thing as is that give as much expansion as is possible. Choose the expansion chamber area to be as high as possible such that your n value is also increased. With a higher n value which is the ratio of area between the expansion chamber and the inlet and outlet duct you are supposed to get a higher transmission loss right.

So, if you give a higher expansion ratio you will get a higher transmission loss. So, these are like 2 elementary design guidelines which arises in the principles for design of exhaust muffler. But then when I say high expansion is preferred. So, you give as high as possible 100, 200 what stops you from giving a very high cross sectional area. One is space definitely you cannot give a very high area for the expansion chamber, because the ground clearance in the vehicle will not permit so, but let us say you are talking about a tractor where the muffler is actually on the outside right. Muffler does not go on the ground it goes upwards. So, there is no space constraint. So, what prevents you to put a very large expansion chamber in a tractor back pressure right.

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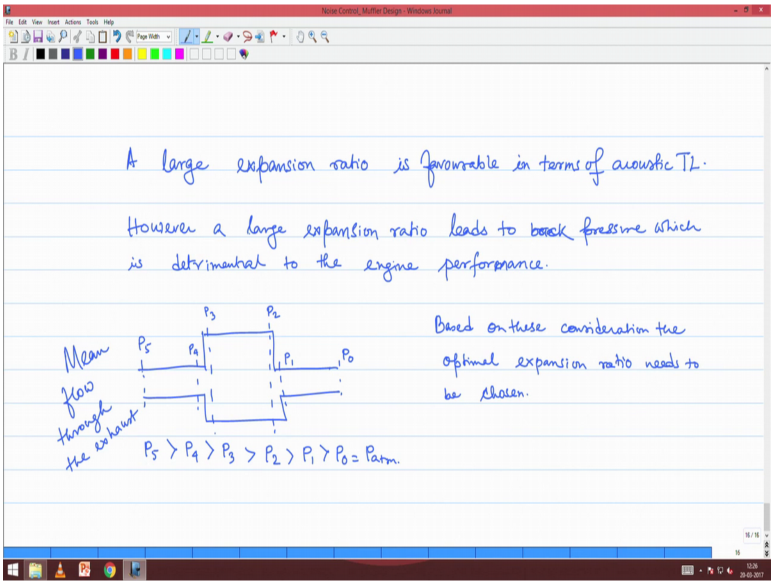

So, please understand that this very important aspect that a large expansion ratio is favourable in terms of acoustic transmission loss; however, a large expansion ratio leads to back pressure which is detrimental to the engine performance. Let me just explain this second aspect a little more. So, remember the purpose of the exhaust line is 2fold, I mean the rather the primary purpose of the exhaust line is to make sure that the burnt out exhaust gases do escape from the engine into the atmosphere right.

Now obviously, at the atmospheric outlet you have exactly atmospheric pressure. This time I am talking about mean flow I am not talking about the acoustic component of the fluid flow I am talking about mean flow. So, you have exactly the atmospheric pressure as you know from principles of fluid mechanics that, when you have a mean flow through happening through a pipe, because of the viscosities that are there in the flow situation there will be a pressure drop as the flow happens to the pipe right. Which means the pressure at each progressive station would be higher right. So, P 1 must be higher than P 0 only then the flow mean flow is going to happen otherwise the mean flow cannot happen.

Similarly, in fluid mechanics it is well known that when you have a sudden contraction or a sudden expansion, either way you suffer some head losses right. The flow I mean the flow suffers from some head losses which means at each of these progressive stations the pressure must be higher. So, that the mean flow can happen because associated with each of these cross sections there are head losses the head losses due to a pipe flow the head losses due to sudden expansion the head loss due to sudden contraction. Which means that finally, if you look at the engine outlet condition which I can say it as station 5, this P 5 will have to be greater than P 4, will have to be greater than P 3, will have to be greater than P 2, will have to be greater than P 1, will have to be greater than P 0, but P 0 is forced to be the atmospheric pressure which means if you make a higher expansion ratio this difference between P 3 and P 4 and similarly P 2 and P 1 will keep cropping up.

You cannot change this ordering by any means this is not given this is as I said this is for the mean flow, mean flow through the exhaust. So, for mean flow through the exhaust you must have this situation asserted. So now, what happens is that if you use a large expansion chamber, then P 5 is definitely at the pressure at the outlet of the engine will be very large.

And what happens if the pressure at the outlet of the engine is very large the exhaust gases will not find a way to escape. It is like someone will block the escape of exhaust gases. So, some part of the exhaust gases may actually not escape, but tend to recite back in the combustion chamber at least partial right. What how will that affect the performance of the engine is easy to understand, if you have the combusted gases the burnt out gases not getting evacuated from the engine they will definitely deteriorate the combustion process in the next cycle right.

So, the combustion process in the next cycle will be much less in inefficiency because now I mean part of this combustion chamber is actually filled up not with the new fuel air mixture, but with the old fuel air mixture which is already burnt up. So, therefore, the efficiency will go down drastically. So, therefore, engine designers will not permit for the sake of efficiency of their engines will not permit a buildup of the back pressure, they will have a hard constrain which you cannot defy that a back pressure for the engine should be kept within a certain norms.

So, as I said sometimes our envies requirements is more a refinement than a design state solutions. So, we have to wait for that guideline to come from your engine designer or whoever the engine vendor is. And then you need to choose your muffler such that it does not conflict the back pressure requirements of your engine. Otherwise if you are doing a muffler design in isolation or if you are really putting a muffler such that the noise which is come you record the noise from the engine put it in a speaker and play it out, then you will actually see that a larger expansion chamber is; obviously, better provided the space permit is, but I think wherein commercial vehicles at times space is not a problem you have lot of space to put a large expansion chamber, but what becomes a problem is this sufficiency issues of the engine right.

So, based on these 2 consideration one has to choose these consideration the optimal expansion ratio needs to be chosen. So, this is about the one of the simplest form of exhaust muffler that is the expansion chamber mufflers. But obviously, there is much more to it than meets the eye at this stage, and we will come to definition of some more technical aspects, but before we do that, we will take few steps backwards. And we will try to put you put this muffler design context in a very important perspective the way this field has evolved is that there has lots of machinery that actually has been borrowed from electrical circuit theory. And even if you look at the mechanical vibration theory there is lots of analogies very interesting analogies which comes between mechanical vibration and electrical circuit theory.

So, it is true even for the acoustics because acoustics has sort of span of from the vibration theory also. So, much of these ideas related to impedance has actually cropped up or has actually been introduced in the context of AC circuit theories, and we will make good use of these circuit theories. And be able to take a little more detailed analysis about mufflers where we talk about insertion loss.

Till now we have been talking about transmission loss, but possibly a better design quantity is the insertion loss. So, before I introduce to you these ideas of insertion loss I will just take a step few steps backward for a few classes.

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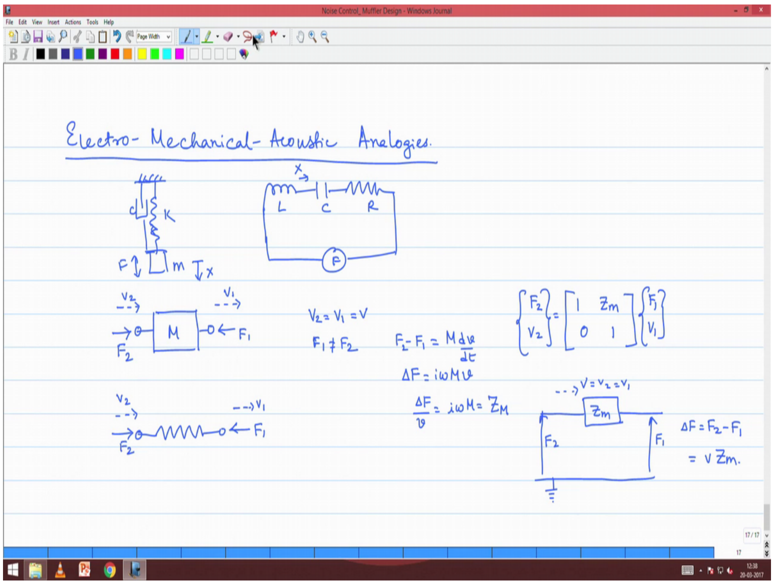

And talk about electro mechanical acoustic analogies. This is this is something which is very, very classical it is very old, but for some reason it has not found much flavour in as of today somehow for some strange reason which I do not know why I do not think we are using this analogy techniques. So, very effectively, but maybe things will change with you.

So, let us just quickly go through these ideas 1 by one. So, one way to do the analogy is; obviously, something probably you would be aware of. So, given a spring mass system you could you would know that this spring mass system has the same set of equation as this LC circuit and with a damper it also becomes like an LCR circuit. So, this is L, this is C this is R. So, this part of it is usually given in books and therefore, I would not reiterate much. If you just write the equation of this spring mass damper system driven by harmonically forced oscillator f that equation will turn out to be exactly the same as the LCR circuit, driven by an AC harmonic voltage source F.

The analogy being that the charge is going to be equivalent to the displacement, the velocity of the mass is going to be equivalent to the current in the circuit. But then what probably is not talked about is what happens when you have an interconnected system. Very rarely do we experience systems which is just like a single degree of freedoms spring mass system. More often than not we are encountering situations, which are collection of such spring mass systems right.

And we want to have an electrical circuit theory analogue wherein, you have an electric circuit which is analogous for a assembly of connected spring mass systems right. And we need a step by step methodical approach by which we can construct such electrical circuit analogies; obviously, if you have a multi degree freedom system then you it is very difficult to contemplate by looking at the equations. One after the other after the other and coming up with that AC circuit which exactly resembles the equations of the multi degree of freedom mechanical system. We need a little more elegant approach than such a naive method which is what I will directly jump into.

So, towards that end let us build our get our building box in place. So, the first building block is that of mass right. Now mechanical system now please note that we are have this is what we will call it as 2 port elements. So, whether it is a mass or it is a spring, it has an input and an output right. And what we are interested in is to again relate the force and velocity at the input end of this mechanical elements to the force and velocity at the output ends of this mechanical elements.

So, here again just like we introduce to the transfer matrix method. We would like to understand how the force and velocities. So, let us call this F 1 and this as I will indicate velocities by dotted line. And I will indicate forces by solid arrows. We wish to understand how the forces and velocities at either side of this mechanical element the left and the right. End of the mechanical element is related right. Both for the spring as well as for the mass as well as for the damper ok.

So, we would like to relate just like transfer matrix method. We would like to relate how V 2 and V F 2 is related to F 1 and V 1 in each of these cases right. So, can we quickly do it for a mass element, what is it that happens, what can you say about V 1 and V 2? You have a mass element and you are talking about V 1 which is on the right. Phase of the mass and you are talking about V 2 which is on the left phase of the mass how should V 2 and V 1 be related. They should be equal there is no other way out V 2 should be equal to V 1.

How about F 2 and F 1 should there be equal why can you not apply 2 different forces in the 2 different directions yes you can right. There is nothing which is stopping you to apply 2 different forces on the 2 different direction you may say then the mass will fly away, So be it. So, be it at this stage, but there is nothing which is stopping you to apply

2 different forces at the 2 different phases right, but actually it will not fly away because this mass will be connected to a spring and this spring will be connected to another mass and eventually something will get constraint.

So, the concern of the mass flying away will actually not turned out to be a realistic concern right, but physically there is nothing which forbids us. To apply 2 different forces to the mass at the 2 different phases, but then how is the forces and in general F 1 need not be equal to F 2 right, but then how do you relate? The forces with the velocities. So, this V 2 equals to V 1 equals to V let say, how do you relate the forces with the velocities? Good old nektons law says that mass times rate of change of velocity is equals to total force right. What is the total force F 2 minus F 1 right. That should be equals to mass times dv dt right, but then if you come to the harmonic exemption which is what we have been doing, dv dt is i omega times V right. Any dt operator can be replaced with i omega using the harmonic assumption.

So, F t F 2 minus F 1, or in other words the change in force from either side delta F is going to be i omega m times V. Or in other words delta F by V is going to be i omega m and this quantity we would like to denote it as Z m this is like an impedance. This is like an impedance and we would call it as Z subscript m. What was the impedance in the acoustic parlance pressure by velocity? Here the pressure is being replaced by force make sense right because pressure is after all force per unit area right.

So, therefore, if you have to write this is a transfer matrix, how do you write it? F 2 V 2 has got to be equal to some matrix multiplying F 1 V 1. V 2 is equal to V 1 which means on the bottom row I can write it as 0 1. What happens in the top row? 1 Z m right. Because Z m times V is equals to delta F what is delta F 2 minus F 1 that is exactly what you get as first equation. So, all these elementary ideas coming out of our fundamental mechanical system that is mass is captured through this simple transfer matrix relation which is going to read as F 2 V 2 is equals to 1 0 Z m 1 F 1 V 1. Note that this is the structure of the transfer matrix for any mass element. If it is a mass element this is what the structure of the transfer matrix should be.

Now, how do you make an equivalent circuit for this? The equivalent circuit will be exactly this Z m in line and we have a ground line and So, if this potential is F 2 and if this potential is F 1 and the current flowing is V which is equals to V 2 is equals to V 1, then F 2 minus F 1 is exactly V times Z m. This is exactly the circuit that we have been looking for, because all I am trying to say is that this mass element gives this transfer matrix, which basically says that the velocities at that the input and the output of this element is going to be the same as we know that the velocities are analogous to current.

So, therefore, if you put an impedance in this fashion the amount of current which is entering the impedance element should be the amount of current which is leaving the impedance element which means that V is equals to V 2 is equals to V 1 right. And similarly that drop in potential as this much current is flowing across this impedance is given by V into Z m which is delta F. So, this also says that delta F has got to be which by definition is F 2 minus F 1 has got to be V times Z m right.

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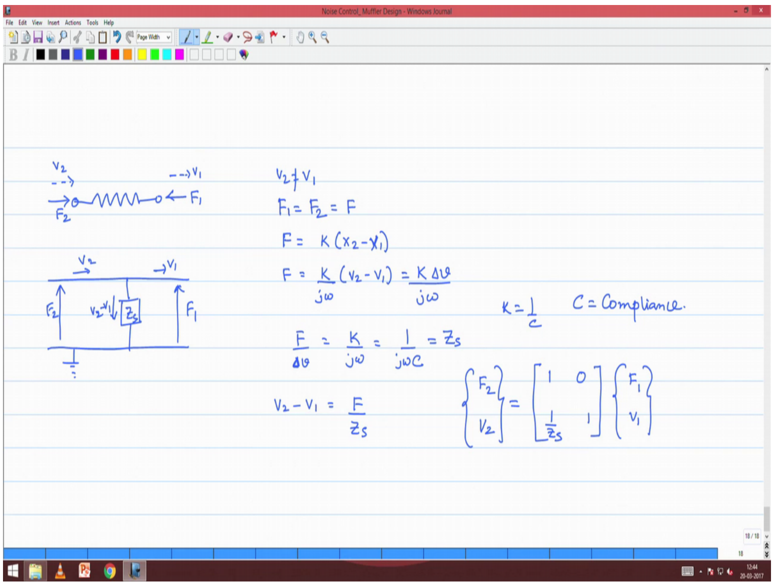

So, therefore, this is the equivalent circuit co corresponding to the mass element. Now let us do this spring element also parallely. So, for the spring element this is the situation first let us understand is there any quantity which will remain constant between the 2 ends of the spring element, is it expected that V 2 and V 1 has got to be necessarily the same? No the 2 ends can have different displacements and hence different velocities. So, in general V 2 is not equals to V 1, how about the forces? The spring mass transmit all the forces that it gets right. So, for the spring we will say that the spring will transmit all the forces that it is suppose to get spring is a transmission element right.

So, F 1 is equals to F 2. So, the here it is the other way round, the force is getting transmitted, but the velocity is being unequal right. So, F 1 is equals to F 2 is equals to F let us say, but then, how are the forces and the velocity is to be related? We know that the force has got to be the spring constant times x 2 minus x 1 right, but instead of talking in terms of the displacements x 2 and x 1 we wish to talk in terms of velocities, but then the displacements and velocities are related by a factor of j omega right.

So, this will be j omega in the denominator now because basically we are integrating not differentiating from velocity to acceleration we have to differentiate from velocity to displacement we have to integrate which means instead of putting j omega in the numerator will put j omega in the denominator. So, that becomes K times V 2 minus V 1 right. And this could also be taken as K time's delta V by j omega right. Delta V is the change in velocity between the input and the output ports just like delta F was the change in force between the input and output ports delta V is the change in velocity of the input and the output ports.

So therefore, finally, we get F by delta V is equals to K by j omega and just like electrical people do we would change over from stiffness to a compliance notion. So, K is 1 by C, C is called the compliance reciprocal of stiffness. And this we can denote it as Z S this is also another form of impedance, that is a ratio of force and velocity, but please understand that between the mass and the spring there is a very important difference in the mass we are taking the velocities are same forces are different. And therefore, the impedance is the ratio of change in force to the velocity of the mass whereas, for the spring it is the other way round we are taking the forces at the input and the output to be the same. And now we are saying that the velocity is at difference. So, force divided by the change in velocity right. So, that quantity as we have calculated is 1 by j omega compliance which is equals to Z s.

Now, what would be the transfer matrix for this situation? F 2 V 2 has got to be related to F 1 V 1 right. The top row is simple to write because F 2 is equals to F 1. So, 1 0 on the top row this time that is almost trivial. What happens to the next to the bottom row? The bottom row says that you must have V 2 minus V 1 to be equals to F by Z S right. So, therefore, V 2 minus V 1 has got to be F by Z s. So, therefore, 1 by Z S has to come here. So, this is the transfer matrix for a spring element right. What about the circuit for the spring element? The circuit for this spring element can be similarly derived, now you want the potential at the input side of the electrical element to be same as the potential at the output side of the electrical element right. So, therefore, if the potentials have to be remaining the same. So, therefore, what I am drawing on the bottom is the ground line what I am drawing on the top is the active line of the line which has the voltage. So, voltage 0 is the ground line ok.

So, therefore, now what we want is, that on either side of our electrical element you should have the potential being same, which means the element should be in a shunt position. So, this is our element Z c. So, this will ensure that the voltage across the input side and the output side is same right whereas, the current is not the same because a part of the current would have gone in the direction of the shunt right. So, this is V 2 minus V 1. So, again you can verify V 2 minus V 1 into Z C is becoming F right. Oh I should call this Z S yeah Z S is what we have defined. So, V 2 minus V 1 into Z S is basically F which is again coming out from circuit theory. So, both for spring as well as from mass we have derived the circuit we have also derived the transfer matrix right.

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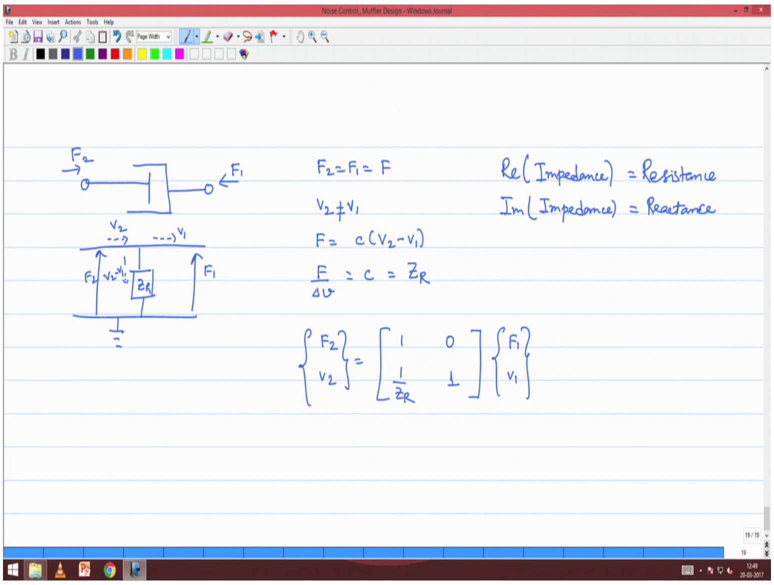

What about a damper? That should not be difficult again damper is a 2 port element right. This is how we denote a damper, just like 2 ends of the spring can have relative displacement 2 ends of the damper also you realize can have relative displacement right.

But the force has got to be transmitted. So, whatever is the force that is coming in must also go out right. So, therefore, we have F 2 equals to F 1 is equals to f, but V 2 minus is not necessarily equals to V 1 and the total force whether you call it F 1 or F 2. So, I will just call it F is equal to C times V 2 minus V 1. So, that again means F by delta V is equals to C and this we could call it as Z r out the resistance. Please note that the impedance for the spring is imaginary the impedance for the mass is imaginary, but the impedance for the damper is real right. And remember again picking up from electrical terminology real part of impedance is called reactance. And imaginary part of impedance sorry, real part of impedance is called resistance, and imaginary part of impedance is called reactance ok.

So, here you have the case that the impedance is virtually a resistance element it is actually an energy dissipation element. This is a very, very important to understand remember in the acoustic parlance. We had seen this when the intensity is having a real component it is actually showing that there is a time averaged power that is flowing out from the system. Same thing happens in circuit is or same thing happens in mechanical elements also. So, how would you put the electric circuit it is just the same you have to put it in shunt position with Z r as the equivalent impedance. So, this is F 2 this is F 1 and this is the ground line and here it is V 2 I should use the dotted lines, this is the V 2 current which is going in, but there is a V 2 V 1 current which is going out which means there is a V 2 minus V 1 which is flowing into the shunt element; that means, V 2 minus V 1 into Z r must be equals to F or the potential difference right.

So, this completes our derivation for the 3 primary mechanical elements the spring mass and damper. Next class when we meet we will do lots of examples of how to combine this spring mass damper elements and build up any arbitrary combinations to draw the electric circuit and also the transfer matrix method. The electric circuit and the transfer matrix method actually go hand on hand. So, the transfer matrix method is just the mathematical representation, but the electric circuit theory is a very powerful tool by which you can interpret the results and especially when we come to source impedance and radiation impedance. We can now therefore, talk about in very easily when we introduce this methodology.

Please understand I will repeat this once more, that the transfer matrix for the spring element the mass element and the damper element the damper element transfers matrix. I have not written, I will quickly write that part what would be the transfer matrix for the damping element. It will be exactly of the same form as a spring element right. Nothing changes just that I have to replace Z S with Z r right. That is all.

So, this is the structure of the spring element or the structure of the transfer matrix for the spring element for the damping element is same. Whereas, the structure for the mass element is in sharp contrast right whereas, the transfer matrix method can have an arbitrary structure right. So, this is basically a very important observation to note at this point as we go higher down the line we will be able to elaborate this difference, but at this stage you can note that this lumped elements will have a very specific form of the transfer matrix method. In other words what it means is that if the transfer matrix method is a generic sorry, if the transfer matrix has a genetic structure which does not conform to one of these structures, then you cannot have an electric circuit of this kind. You simply say that it is a distributed circuit. So, that that is also possible all these things we will do as we go along.