

**Fundamentals of Acoustics**  
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**Lecture – 51**  
**Designing of Dissipative Mufflers**

Hello. Welcome to Fundamentals of Acoustics. Today is the third day of the current week, and yesterday we had developed an expression for transmission loss for a muffler which is reactive in nature.

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The image shows a whiteboard with the following content:

$$TL = 10 \log_{10} \left[ 1 + \frac{(m-1)^2 \sin^2(k_2 l)}{4} \right]$$

① For given  $m$ ,  $TL = TL_{max}$  when  $k_2 l = \pi/2 \rightarrow l = \frac{\pi}{2k_2}$

② If  $m > 1$ ,  $TL$  goes up with increase in  $m$ . ( $A_2/A_1$ )

③  $TL = 0$  at  $k_2 l = 0$  and  $k_2 l = \pi$

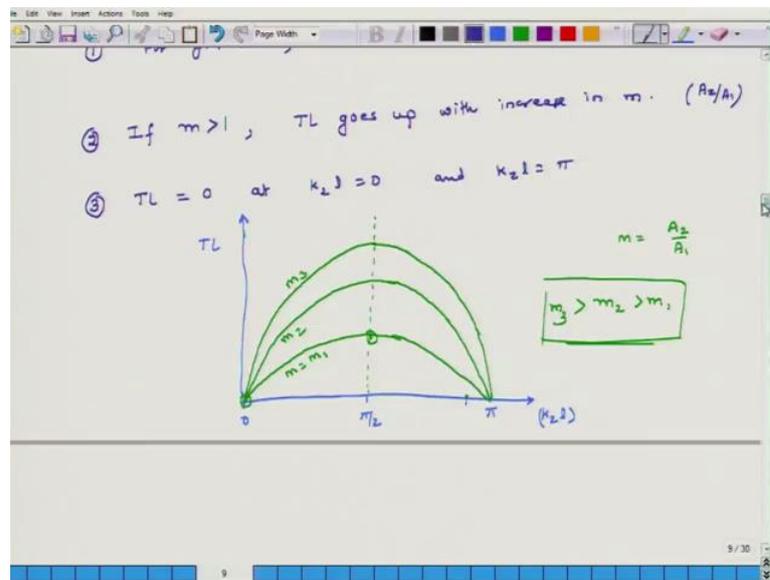
And the expression says that transmission loss for a muffler can be defined as  $10 \log_{10}$  of 1 plus  $m$  minus 1 over  $m$  whole square. So, that is  $m \sin^2 k_2 l$  divided by 4. So, that is our transmission loss. Now this transmission loss is going to be maximum. So, for given  $m$   $TL$  is equal to  $TL_{max}$  when  $k_2 l$  equals  $\pi/2$ . So we have to maximize transmission loss, we have to choose the length in such a way that. So, this essentially means that  $l$  is equal to  $\pi/2k_2$ . So, you have to choose the length in such a way that this equals  $\pi/2$  divided by  $k_2$ .

Now what we will do is we will, so the other observation we notice that if  $m$  is more than 1, so this is 1 observation. The second observation is if  $m$  exceeds 1, if  $m$  exceeds 1 then  $TL$  loss; transmission loss it goes up with increase in  $m$ . As  $m$  increases transmission loss increases. So if I have a longer section which is section two of the that is what a

guarantee, but if I increase the cross sectional area and as I keep on increasing the cross sectional area of the middle portion because  $m$  is what  $m$  is a 2 over a 1. So, as I keep on increasing the middle portion of the overall reactive silencer the transmission loss will keep on increasing.

The third thing is TL equals 0 at  $k_2 l$  equals 0 and when  $k_2 l$  equals  $\pi$  radian. So, what we will do is we will develop a plot.

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So, on the x axis I am going to plot  $k_2 l$ . So, typically  $k_2$  is fixed for a particular frequency we know  $k_2$  and I am just essentially what the x axis means that for a given frequency I am increasing in the length of the middle portion. And on the vertical axis I am going to plot transmission loss.

So, when  $k_2 l$  is 0 radian, then at  $\pi/2$  radian, and at  $\pi$  radian. So, this is  $\pi$  radian. So, when at 0 radian the transmission loss is 0 at  $\pi/2$  it is maximum, and at  $\pi$  it is again 0. And may be the distance between  $\pi$  and  $\pi/2$  is not same so I have to relocate it, so this is  $\pi$  radian. So, the curve would look something like this, and let say this curve corresponds to  $m$  equals  $m_1$ ; some value of  $m_1$ . Where,  $m_1$  is equal to the ratio of a 2 over a 1.

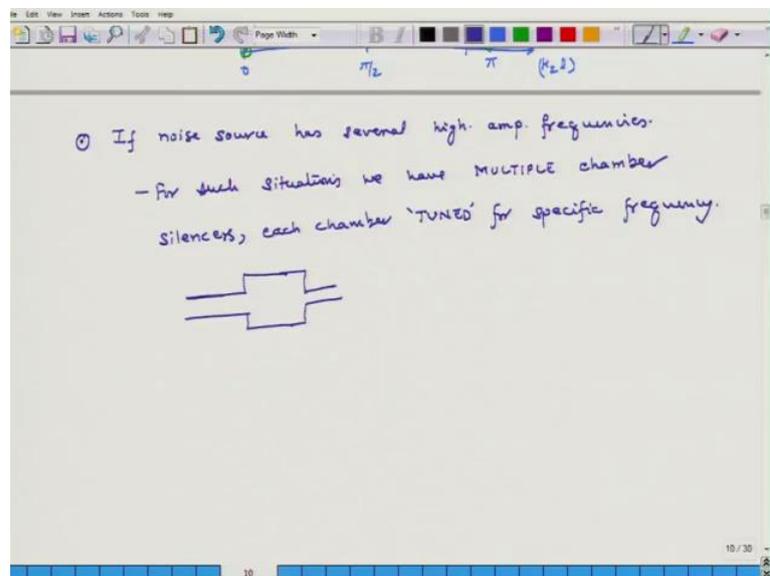
So, what will be the performance of the silencer if I increase  $m$ ? So, if I increase  $m$  my transmission loss curve will look something like this. So this is  $m_2$ , where  $m_2$  is more

than  $m_1$ . And if I increase my cross sectional area further for the middle portion then the transmission loss curve will become  $m_2$ ; so that is are  $m_3$ . So, as I keep on increasing the cross sectional area of the middle portion which is region to the transmission loss keeps on increasing and for a specific value of  $m$  transmission loss is maximum when length is such that  $k \cdot 2 \cdot l$  is equal to  $\pi / 2$  radian.

So, using this understanding we can develop a reactive muffler. And if we know that a particular engine or noise source is producing most of the noise for at a particular frequency then for that frequency we can design a reactive muffler which has a length such that  $k \cdot 2 \cdot l$  equals  $\pi / 2$  radian. And for that length I can increase the transmission loss as much as I want if I keep on increasing the cross sectional area of the middle portion. So, that is important to note.

The negative effect of this approach is that as I have keep on making the cross sectional area of the middle portion the overall system becomes bulkier and bulkier. So, that is there.

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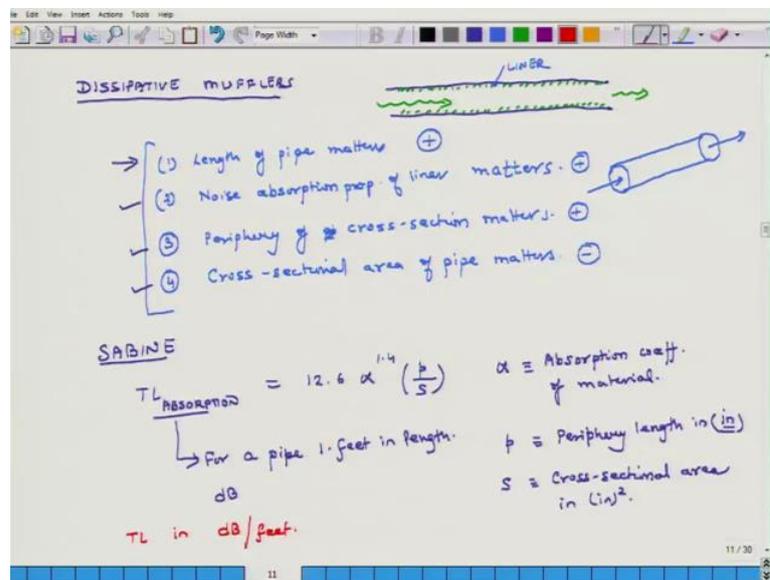


So then the other question is so if noise source has several high amplitude frequencies. So, suppose there is a noise source which is producing a lot of noise at 50 hertz, it is also producing a lot of noise let us say at 130 hertz and the lot of noise at 170 hertz. Then one single muffler may not do the trick right, it may not necessarily do the trick. So, in that case, for such situations we have multiple chamber silencers. So, you can have; so one

chamber can address a particular frequency, but if you have several silencers in a series then those can cancel individual frequencies. So, each chamber tuned for specific frequency.

So I think, I hope this gives you a fair idea of how reactive chambers work. So, this is the basic treatment of reactive chambers and their work mechanism. And this will give you some idea of how to design reactive silencer or a reactive muffler. What we plan to do next in today's class is we will discuss dissipative mufflers.

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So, how do dissipative mufflers work? So, we have discussed this or talked about this in the last class. Let us say we have a long pipe and I can coat or put on the inner surface of this long pipe some noise absorbing material. So, this is the simplest way to do it. And the properties of this material should be that it should be able to here, bear high temperatures especially when the application is for engine exhaust because the temperatures of gasses coming out of engines are pretty hot. So, as sound travels through this it gets absorbed through the pipe and less noisy gas exits out of the pipe.

So, the first thing which is important to notice that if I have a pipe which is longer than more noise will get absorbed, a shorter wave pipe will absorbed shorter smaller amount of noise. The second thing to notice; so what are the important parameter; first is in dissipative mufflers length of pipe matters, second thing which is important in such situations is that noise absorption property of liner. So, this is what we call liner. So,

noise absorption property of liner matters. If I have a material which absorbs more noise then it will be more effective and vice versa.

The third important property is that these cross sectional area; so let us look at this pipe like this. So, this is my inlet and this is my exit, so noise is coming in from here and it is getting out from here. So, it will depend on the periphery, length of the periphery of the pipe. If this periphery is larger then it will get absorbed more right, so it depends on periphery. Because periphery times length of the pipe will be the noise absorption surface. So, periphery of cross section matters, higher the periphery better it is right. And the forth one is, cross sectional area pipe matters but thing about it. If I increase the cross sectional area if I increase the cross sectional area and assume for some reason that alpha absorption properties are same periphery is same, but cross sectional area has gone up; will in percentage terms less noise get absorbed or more noise will get absorbed. More noise will be entering and flowing through the system right. So, the relation between noise absorption characteristic and the length of the pipe is a positive one; you increase the length more noise gets absorbed.

Similarly, the relation between noise absorption property and transmission loss in a pipe is a positive thing; higher absorption more transmission loss. Same thing for periphery larger is the periphery larger is the noise absorption area it is larger, but this guy cross sectional area is negative, because if I have bigger pipe more noises flowing through right. So, the attenuation will be lesser. So, with these four parameters in mind there was a person and his name was Sabine or Sabine's he developed the transmission loss for absorptive in mufflers. So, he said the transmission loss for absorption mufflers, so absorption absorptive devices is equal to, so this is an empirical relation 12.6 or semi analytical relation times alpha to the power of 1 by 4 times perimeter divided by cross sectional area.

So here alpha, what is alpha? It is the absorption it is absorption coefficient of material; it is absorption coefficient. In our next class or one of our subsequent class is will define and we will discuss what is this absorption coefficient, but right now we will just assume that its specific number. And if this number is higher it means material absorbs more energy and if it is less then it absorbs less energy. So, that is there. P, so here p is not pressure it is periphery. Length; in inches, and s is cross sectional area in inch square.

So, Sabine's said at the transmission loss is equal to 12.6 times alpha to the power of 1.4 times p over s, so he talked about second parameter noise absorption, he talked about periphery, he talked about cross sectional area what about this. So, for this he said that this transmission loss coefficient is going to be for a pipe. So, this is the transmission loss for a pipe 1 feet and length. And what is the unit of this transmission loss, it is going to be in decibels. So, what this formula gives us is transmission loss in dB per feet. So, if have a 20 feet long pipe I can multiply this TL by 20 and that is what I am going to get in terms of transmission loss.

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**EXAMPLE**

$\alpha = 0.08$

$m = \frac{A_2}{A_1} = \left(\frac{12}{3}\right)^2 = 16$

TL for REACTIVE PORTION ONLY

$$\rightarrow TL = 10 \log_{10} \left[ 1 + \frac{(16 - 1/16)^2 \sin^2(k_2 l)}{4} \right] = 10 \log_{10} [1 + 63.5 \sin^2(k_2 l)]$$

TL for reactive muffler.

f	40	50	60	70	80	90	100
RPM	2400	3000	3600	4200	4800	5400	6000
TL	5.4	6.4	7.1	7.7	8	8	7.8
TL <sub>TOTAL</sub>	8.4	9.4	10.1	10.7	11	11	10.8

If duct is lined to absorb sound  $TL_{Abs} \text{ (dB/ft)} = 12.6 \times (0.08)^{1.4} \times \left[ \frac{(\pi \times 3)^2 \times 4}{\pi \times 3^2} \right]$   
 $= 0.49 \text{ dB/ft} \approx 0.5 \text{ dB/ft}$

$TL_{Absorbed \text{ (TOTAL)}} = 0.5 \times 6 = 3 \text{ dB}$

So, let us look at an example. So, what we will discuss is a hybrid muffler. In this muffler we have a long pipe and then there is an expansion chamber and then we have an exit. So, this is region 1, this is region 2, this is region 3. This pipe is 3 inch in diameter, so this is dimension is 3 inch and here it is again 3 inch and in the middle portion it is 12 inch. The other thing is that this pipe is lined with some noise absorbing material in portion 1 uniformly. And the alpha for this is given as 0.4, sorry it is 0.08. So, this dimension this pipe is 6 feet in length, in the middle portion is 1 meters long and we are not bothered about the length of the exit portion.

So first what we will do is, we will find transmission loss for reactive portion only. So, initially we will assume that this alpha is 0 so there is no dissipation happening in this thing and we will figure out the ratio transmission loss for this entire thing assume that it

is a purely reactive muffler. So, in that case TL equals  $10 \log$  of  $10^{1.4}$  plus, now what is  $m$ ?  $M$  is equal to  $\frac{2}{3}$  or more accurately it is a 1. So, this is what it will be  $\pi$  times  $12$  square divided by  $4$  divided by  $\pi$   $3$  square divided by  $4$ . So, it is equal to  $12$  by  $3$ , so it is equal to  $16$ .

So, that is equal to  $16$  minus  $1$  over  $16$  square  $\sin$  square  $k^2 l$  divided by  $4$ . And  $l$  is in this case how much  $1$  meter, so this relation we have to use either units the only thing is that if I take  $l$  in feet when I have to calculate the wave length also in feet otherwise this does not depend on units, but the relation for absorption here we have to one do everything in inches because  $p$  is given that it has to be in inches and also  $s$  should be in inch square. So, this is unit specific formula. So,  $l$  is in this case I take it as  $1$  meter and what this gives me is  $10 \log$  of  $10^{1.4}$  plus  $63.5$  and  $l$  is  $1$  meters, so I will just write  $\sin$  square  $k^2$ ; so this is the relation.

So, this is the TL for reactive muffler. So now, we will construct a table. So, for different frequencies this  $k^2$  is going to change; so we will calculate for different frequencies what is the transmission loss. So what are those frequencies?  $f$   $40$  hertz,  $50$ ,  $60$ ,  $70$ ,  $80$ ,  $90$ , and  $100$ . And my RPM; if this is connected to engine then  $40$  hertz corresponds to  $2400$ ,  $3000$ ,  $3600$ ,  $4200$ ,  $4800$ ,  $5400$  and  $6000$ . And if corresponding to these frequencies TL; transmission loss is going to be what. So, I have to just put the value of  $k^2$  for corresponding to each frequency.

So, I have to for each frequency I have to find out the wave length and then  $\frac{2\pi}{\text{wave length}}$  is  $k$ . So, once I know  $k$  I can calculate this transmission loss. So, this transmission loss is  $5.4$ ,  $6.4$ ,  $7.1$ ,  $7.7$ ,  $8$  and  $7.8$ . So what does that mean? That if sound is coming at  $100$  decibels from here at let us say  $80$  hertz or when the engine is running at  $4800$  RPM, then the output sound pressure level will be  $80$  minus  $8$  that is  $92$  decibels that is what it means.

Now what we will do is, we will say that now if duct is lined to absorbs sound, then what is it? Then TL absorption and we units are dB per feet that is equal to what is the relation it is  $12.6$ ; this thing  $12.6$  time alpha to the power of  $1.4$  times  $p$  over  $s$ . So, this is equal to  $12.6$  times alpha is  $0.8$  to the power of  $1.4$  times perimeter is  $\pi$  times  $3$  inches area is  $\pi$  times  $3$  inch square into  $4$ . So, if you do all this math it comes to be  $0.49$  dB per feet or it is roughly  $0.5$  decibels per feet. So now, the overall pipe length is how much; so TL

absorption. So, where is this noise absorbing material put? It is put over this distance of 6 feet; so this is total. So, this is equal to 0.5 times 6 is equal to 3 dB. So TL total that is going to be 8.4, 9.4, 10.1; I have just adding 3 dB extra 10.7, 11, 11, 10.8 decibels. So, that is how you can develop expressions for transmission loss, for mufflers which are having reactive as well as absorptive components.

So, I think that concludes are discussion for today. And starting tomorrow we will shift gears and again from an application stand point we will start discussing how to analyze a noise signal and break it down into its a specific Fourier components. With that we conclude our discussion for today, and we will meet once again tomorrow.

Thank you. Bye.