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ACTIVE CONTROL OF SOUND IN VENTILLATION DUCTS

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Sound propagates along ducts that are used for the transport of fluid. In many instances it is important to reduce their sound propagation without impeding the flow of the fluid. Conventional passive silencers, of a variety of different configurations, can be used to reduce the sound propagation but only at the expense of the impeding the flow of fluid by introducing a restriction.

The passive silencer thus introduces a conflict between the two objectives of minimising the flow impedance and maximising the sound attenuation. This conflict can be eased by increasing the size, and consequent cost, of the silencer and so the design will ultimately be a compromise between these three constraints. There are additional practical constraints imposed on the design of passive silencers when the fluid is hostile and these can lead to further compromises. The best passive silencer for a particular job may consequently be large and not particular suitable.

The possibility of using active silencers introduces an alternative which can change the emphasis of these constraints and make the best active silencer have clear advantages over the best passive silencer. There will also be circumstances where the best overall solution involves the combination of active and passive silencers. We will now demonstrate the constraints in detail and show where active silencers can be of most use.

CONVENTIONAL ABSORPTIVE SILENCERS

Absorptive silencers usually divide the duct into many parallel sub-ducts with splitters. These splitters have absorptive material on them which is designed to introduce damping to the sound propagation past it. Generally these parrallel sub-ducts attenuate the sound in proportion to the number of wavelengths they are long ie

$$\text{Attenuation} \propto \frac{L}{\lambda},$$

provided that the duct is longer then a wavelength. In addition the narrower the duct, measured on a wavelength scale, the greater will be the attenuation, ie

$$\text{Attenuation} \propto \frac{\lambda}{D}$$

Thus, ignoring the variation of material properties with frequency, the attenuation will be proportional to the ratio of length to cross dimension.

On the other hand, the pressure loss due to skin friction will be proportional to the length of the duct and the square of the flow velocity.

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$$\text{Pressure loss} \propto LU^2$$

For a fixed volume throughput this flow velocity can be reduced by enlarging the size of the duct, reducing the pressure loss for the same sound attenuation.

$$\text{Pressure loss} \propto \frac{\text{Sound Attenuation}}{D^3}$$

Now it is clear that the size of the attenuator must be increased to ease these constraints. However this will result in an increased cost. If the cost is proportional to the amount of material in the silencer then we have approximately.

$$\text{Pressure loss} \propto \frac{(\text{Sound Attenuation})^3 \, Q^2 \, D}{(\text{Cost})^2}$$

Where Q is the volume flow rate. Thus for a fixed cost and performance there will be a tendency to keep the silencer as small as possible.

It was recognised above that the silencer is ineffective when the wavelength of sound is larger than its dimensions and thus taking in to account all of the above constraints, the performance is likely to be poor at low frequencies. When the sounds covers a broad spectrum this results in a need for a second, larger silencer specifically to attenuate the lowest frequency sounds. This silencers is necessarily large and costly.

ACTIVE SILENCERS

An active silencer has a different set of constraints on its design. Loudspeakers mounted in the wall of the duct, are used to create a sound in anti-phase to that propagating down the duct. This results in attenuation of the sound beyond the loudspeaker and, in fact, reflection of the sound upstream. The space required for the silencer is primarily determined by the space required for the loudspeakers and this can be very much less than for the equivalent passive silencer. These loudspeakers will normally be mounted outside the duct, with openings into the duct wall. In that way they will not impede the flow and will be kept away from the fluid in the duct which may be hot.

In addition to the loudspeakers the active control system uses microphones upstream to detect the sound propagating in the duct. These microphones must be sufficiently far upstream to give the control system time to process these microphone signals and generate the loudspeaker signals. In practice this processing time is related to the period of the highest frequency to be controlled and ideal separation is found to be 2D. This upstream microphone would typically be mounted in the side of the duct with a nose cone to make it insensitive to turbulent pressure fluctuations. The silencer will therefore be quite compact even for the very low frequency attenuations.

Size and Cost

The loudspeakers must be able to produce the same sound level as the sound to be cancelled and thus their size is determined by these levels. In fact the ability of a loudspeaker to produce low-frequency sound is in direct proportion to its volume and thus the loudspeaker volume V, (and cost) has the relation

$$V \propto p\lambda D^2$$

Where p is the sound level, λ is the wavelength and D the duct cross-dimension.

The active silencer that we are considering here is only able to stop the plane wave mode propagating in the duct and thus its performance is limited when the cross-dimension of the duct is larger than a wavelength. The silencer is thus only effective at low frequencies, ie $\lambda > D$ for the active silencer.

The performance of the active silencer will thus be limited at the upper end of the frequency band by this constraint and at the lower end by the size of the loudspeakers.

If the system is thus designed to operate over, say, 3 octaves then the two constraints can be linked so that

$$V \propto 8pD^3$$

The loudspeaker volume will thus be proportional to the volume of the duct system and the sound pressure level.

The cost of the active system, being proportional to the size of the installation, will broadly scale in the same way as the passive silencer. Except that the active system will give about 20 dB attenuation whereas the passive system's cost increases with performance, and that the active system's cost increases for noisier systems. These differences are important and will alter the balance between the two in different circumstances.

Additional Damping is Beneficial

The active silencer acts to reflect the sound back upstream. This reflected wave may also be further reflected and consequently may resonate. Amplification of the sound, at the resonant frequencies, will be determined by the amount of damping in the duct. It is therefore advisable to introduce some damping to reduce this effect. Damping is most easily introduced by adding passive absorbent material but an additional loudspeaker can be used to introduce the damping actively.

CONCLUSIONS

1) Where the sound propagating in the duct is low frequency (ie $f < 2c/D$) the an active silencer can be used on its own. This will have the advantages over a passive silencer that it will not introduce a pressure loss, that it will not be as bulky, and that it will be unaffected by dust in the flow.

2) When the sound extends to higher frequency then the active silencer will not be effective on its own. Here a combination of passive and active silencers will be the best alternative. This will have the advantage over a completely passive silencer that it will be smaller and will be

less expensive. There will be no significant advantage in pressure loss because the passive element will have introduced that already.

Generally, because the active silencer is relatively small it will be easier to add to an existing installation where the original equipment is not sufficiently effective. Since the loudspeakers are fitted outside the duct the installation will involve a minimum of disruption to the plant.

Despite the clear advantages of the active silencer in some circumstances there has only been one industrial application. This has probably been due to a lack of confidence in the new technology and concern over the reliability of the loudspeakers. Topexpress has been involved in the development of active silencers for the last 8 years and has demonstrated that these systems are reliable. Consequently we are confident that they represent a commercially attractive proposition and are new selling active silencers.