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ENERGY CONSERVATION BY ACTIVE NOISE ATTENUATION IN DUCTS

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INTRODUCTION

Active noise attenuators have been suggested to be of practical use in air duct [2-6]. The subject has been well developed both in the theoretical and experimental fields.

Today, the silencer market is still cost-conscious and reluctant to accept active attenuators because of the initial cost. Energy costs and hence operating costs of electrical equipment are likely to increase, whilst low cost electronic transducers are available for use in active attenuators. Therefore, the savings on energy may favour active attenuators to tackle low frequency noise, when a combination of initial and operating costs over 20 years is considered.

NOISE CONTROL IN AIR-HANDLING SYSTEM

In most air-handling systems centrifugal fans are normally used. Fans of equal duty produce a characteristic spectrum, typically indicating high sound pressure levels in the low frequency region (below 300 Hz). This low frequency sound frequently results in noise problems in air-handling systems. In these cases, the natural attenuation available from duct bends and duct losses is not sufficient to give an acceptable noise level at the air grille, e.g. NC 35 for office areas. The conventional remedy is to insert silencers in the air duct to provide the necessary attenuation.

For an office floor supplied by a 10.5 m^3/s air-handling system, the required silencer dynamic insertion loss (DIL) is given in Table 1. To meet this requirement a 3m long conventional silencer with 30% free area is required. Its performance is shown in Table 2.

As a result of this higher attenuation, rectangular silencers are conventionally preferred to circular designs. Moreover, air-handling systems normally use rectangular ducting. In general terms, the rectangular silencer is simply a galvanised sheet steel duct section equipped with splitters which are formed from perforated metal and completed with mild steel flanges for duct connection. Splitters are filled with absorptive material such as mineral wool. The infill can be contained in woven cloth or melinex wrapping to prevent erosion of the infill by airflow.

The amount of attenuation obtainable from the splitter silencer depends mainly on the width of the airway as well as the thickness of the splitter. By decreasing the airway width and hence the percentage of free area that air can flow through, higher attenuation can be obtained from these splitter silencers.

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Absorptive silencers have a high insertion loss at frequencies above 500 Hz. However, at frequencies below 300 Hz, the insertion loss drops off dramatically. This is because towards this region the length of the wave propagating along the duct increases, giving less attenuation as the dimensions of the silencer become insignificant, relative to the wave length. High frequency noise is normally over attenuated as in the case of employing a 3m long absorptive silencer to cope with the required DIL for an office floor. This is wasteful as the high frequency requirement could easily be met by using a 900 mm long silencer with 50% free area. Its performance is shown in Table 2. The remaining low frequency requirement may be satisfied by an active noise attenuator which could provide sufficient insertion loss at low frequencies without causing a large pressure drop. There are various active noise attenuators [2] employing different control techniques which may include special loudspeaker and microphone arrangements, ingenious placement of absorptive lining, analog filters and digital adaptive filters.

TCM ACTIVE NOISE ATTENUATOR - THEORY AND EXPERIMENT

Active attenuation of noise is the cancellation of noise by destructive interference [2]. The basis of all active attenuation systems is that the sound from the secondary source must be the mirror image of the primary sound in order that the unwanted sound is completely cancelled downstream of the attenuator [2].

The simplest method of generating the anti-phase signal is to use a monopole arrangement. The TCM (Tight Coupled Monopole) active attenuator [3] comprises a single microphone, a power amplifier and a loudspeaker. Figure 1 shows the attenuator arrangement. Absorptive lining is used to reduce the effects of higher order modes, as well as to provide some attenuation at middle and higher frequencies.

The primary noise is detected by the microphone and this is then suitably amplified and inverted by the power amplifier producing a mirror image of the waveform. This mirror image signal is generated by the loudspeaker with a negligible delay throughout the microphone to loudspeaker path.

Experiments using a prototype have been carried out in an air duct with dimensions of 10m long, 450mm wide and 600mm high [5]. A 2.2 kW axial fan with a maximum of 2800 rpm was chosen as the generator of primary noise. The air velocity was 5 m/s in the duct. The secondary source was a KEF-B139 loudspeaker mounted on the wall of the duct. The microphone was fitted with a wind-screen to reduce wind noise. The performance of this system is shown in Table 2.

TCM Active Noise Attenuator - Module Design - The data provided by the prototype in Ref [5] have led to the construction of the attenuator module. The TCM attenuator proposed for use in the air-handling system has dimensions of 1200mm long, 1800mm wide and 1200mm high. This system can be formed from 6 modules bonded together in the same way that conventional silencers modules are bonded to form large silencers. The modular construction has effectively subdivided the duct and increased the first lowest cut-off frequency. Each module has dimensions of 1200mm long, 600mm wide and 500mm high. A typical module placement is shown in Figure 2.

DISCUSSION

Two alternative methods for achieving the DIL requirement shown in Table 1 have been considered: (1) a 3m long silencer and (2) a 900mm silencer combined with a 1200mm TCM system in series. While (1) fulfills the DIL requirement, at the lowest initial cost, operating costs are higher than those incurred by (2).

The operating costs for HVAC system components can be calculated from formula (1) [1].

$$kWh = \frac{\Delta P \times CFM}{8505 \times eff} \qquad (1)$$

where kWh = Kilowatt-hour
ΔP = Pressure drop in inch w.g. (1 inch w.g. = 250 Pa)
CFM = Airflow through silencer in cfm ($1\ m^3/s$ = 2117 CFM)
eff = system, fan and motor operating efficiency

Costs for the 3m silencer have been calculated based on a pressure drop of 140 Pa over an operating time of 4380 hr/yr, with 75% operating efficiency. Electricity cost is taken as 4 pence per kWh. Operating costs per floor are shown in Table 3a. Operating costs for the combined 900mm silencer and TCM are composed of (1) silencer and (2) electronic elements e.g. amplifier, microphone and loudspeaker. The pressure drop of the 900mm silencer is taken to be 20 Pa and that of the attenuator 10 Pa.

Again, formula (1) has been used to calculate pressure dependent operating costs. The results are shown in Table 3a.

To calculate the energy consumption of the electronic system the acoustic power radiation of the secondary source should be considered. The relation between electrical power requirement and acoustic power radiation has been examined by FORD [7]. The power required to drive the loudspeaker in the experiments carried out in Ref [5] was found to be consistent with the theoretical value in Ref [7]. The estimated electrical power required for the amplifier is 3 watt per module. Assuming an efficiency of 50% for the whole electronic system, the overall electrical power requirement is 6 watt per module. With six modules for each floor, a total of 36 watts would be required. Energy costs are shown in Table 3. Any cost analysis of the TCM system must include replacement costs, in order to allow for the relatively shorter service time of the electronic elements. Assuming a moderate inflation rate of 7% the analysis would indicate significant saving for the TCM system. Results are shown in Table 3b. Assuming further that the saving in power consumption per unit floor area is generalised to half of the total commercial office space within Greater London, the potential savings in energy would amount to 50 million kWh per annum. The energy conservation is shown in Table 4.

CONCLUSION

An active attenuator system could be used to provide low frequency attenuation in an air duct without resulting in costly pressure drop. The initial difference in price between the silencer systems is balanced out by reduced operating costs of the energy efficient TCM. Substantial savings in energy costs could be achieved by using a low pressure drop combination of an active attenuator and a 900mm conventional silencer to satisfy a specified DIL requirement.

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(Hz)	63	125	250	500	1K	2K	4K	8K
(dB)	13	17	24	16	20	22	18	15

Table (1). The required silencer DIL (octave band) for an office floor.

	63	125	250	500	1K	2K	4K	8K
3m	13	26	42	52	55	53	51	42
900mm	2	7	11	15	21	26	18	11
TCM	10	11	16	13	1	0	0	0

Table (2). DIL of silencers and TCM Active Attenuator.

	Passive only	Active and Passive Combination	
	3m Silencer	TCM	0.9m Silencer
Capital Investment	£1,944	£1,700	£436
Running Cost over 20 years	£6,838	£ 614	£978
Replacement Cost	-	£1,716	-
		£4,030	£1,414
TOTAL	£8,782	£5,444	
Saving over 20 years per floor		£3,338	
Saving for 20 floor building		£66,760	

Table (3a). Cost comparison (No inflation).

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	Passive only	Active and Passive Combination	
	3m Silencer	TCM	0.9m Silencer
Capital Investment	£1,944	£1,700	£436
Running Cost over 20 years	£13,231	£1,189	£1,892
Replacement Cost	-	£3,518	-
		£6,407	£2,328
TOTAL	£15,175	£8,735	
Saving over 20 years per floor		£6,440	
Saving for 20 floor building		£128,800	

Table (3b). Cost comparison (Inflation rate is 7%).

	Passive only	Active and Passive Combination	
	3m Silencer	TCM	0.9m Silencer
Annual power consumption per floor	8547 kwh	769 kwh	1221 kwh
TOTAL	8547 kwh	1990 kwh	
Saving per annum per floor		6557 kwh	
Saving per annum per m^2 office space		5.7 kwh	
Potential saving per annum of electricity in half of the commercial offices within Greater London, with available space of 17.54 million m^2		50 million kwh	

Table (4). Energy conservation.

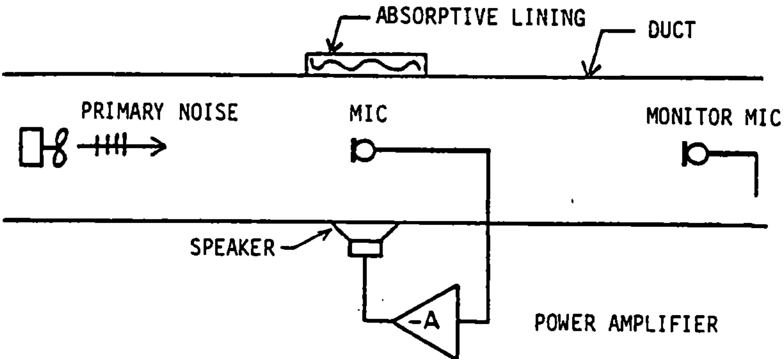

FIGURE 1 : ARRANGEMENT OF THE TCM ATTENUATOR

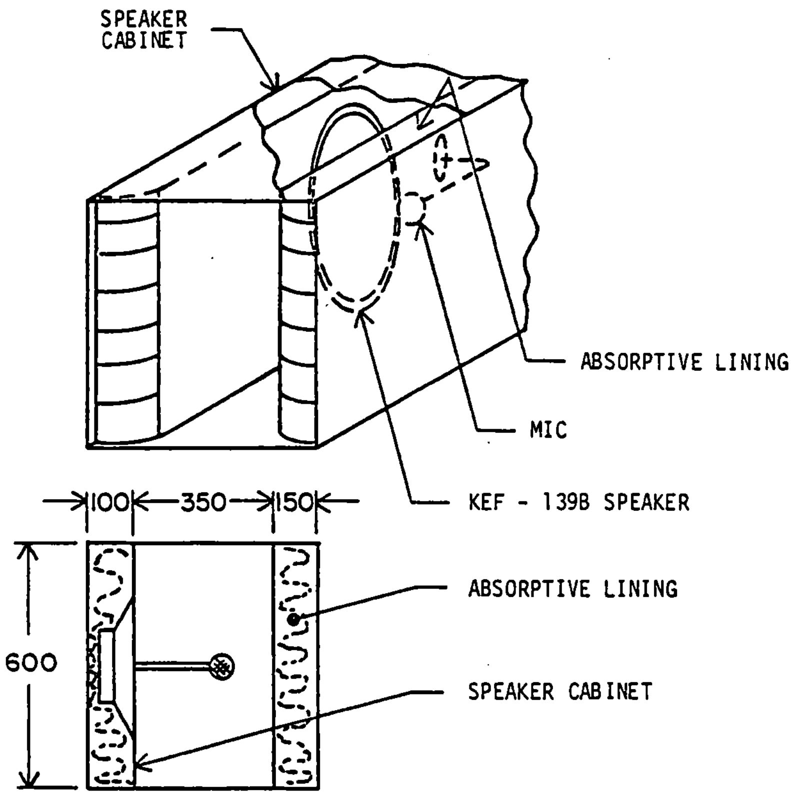

FIGURE 2 : TCM ACTIVE NOISE ATTENUATOR MODULE