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ACTIVE CONTROL IN ONE DIMENSIONAL FLOWS

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ABSTRACT
Signal processing for active noise control has developed to a high level but there are remaining limitations on applications. Transducers are the most important problem to be solved for active noise control in flows, especially flows at high temperatures containing chemicals and abrasives. The paper considers the effects of flow on the operation of active noise control and describes the flow modulation "flap" valve ExAct, which has been designed to make use of the energy in the flow, by imposing fluctuations on the flow itself, in order to cancel the noise in the system. ExAct has been applied to a wide range of gas and liquid systems and is of particular application to controlling the low frequency noise of hot exhausts.

1 - EFFECTS OF FLOW
In a two-microphone active attenuator system, where the first microphone is the signal detector and the second microphone is an error detector, the error microphone assumes that sound which it detects has also been detected by the signal microphone a short time previously. However, if the flow causes uncorrelated signals at the microphones, a measure of the maximum attenuation which might be achieved is given by $10\log\left(1-\gamma^2\right)$ dB, in which γ^2 is the coherence function between the two microphone signals. To obtain an attenuation of 10 dB or more the coherence must be greater than about 0.95. Degradation of the coherence is normally caused by local turbulence at the microphones or by turbulence due to non-streamline flow conditions, such as might occur at bends and take-offs in a poorly designed duct. These problems are reduced by anti-turbulence screens on the microphones, although coherence cannot always be recovered. A number of microphones distributed over a duct surface with their outputs added, or processed in a more complex way, may also be used. A rotational, or similar, detector for repetitive sources, removes the requirement for one of the microphones

The greater the flow velocity, the greater the turbulence at the microphones, but if the noise to be cancelled is mainly tonal, very high flow velocities can be tolerated. This is because, despite a high level of turbulence noise, the tone projects above the level of the turbulence. Microphones have been used on tonal noise from industrial fans in which the flow velocity was up to 45 m/s.

The pressure in the flow may cause a static displacement of a transducer diaphragm. Microphones normally have an equalisation hole to ensure that the same static pressure exists on both sides of the diaphragm. Although there is a tendency to seal between the front and rear of a loudspeaker, equalisation may have to be provided, especially in high pressure flows where there are substantial levels of noise to be cancelled and a high loudspeaker displacement is required.

2 - EFFECTS OF TEMPERATURE AND VIBRATION
Conventional loudspeakers are designed to operate under a restricted range of temperatures. Special high-temperature loudspeakers, giving attention to the temperature dependent properties of the cone and suspensions are available. In addition, a protective diaphragm may be required over the cone to prevent damage from chemicals and particulates. There is a limitation on how far a conventional moving coil loud speaker can be developed to enable it to operate in adverse environments.

The traditional air condenser microphone has good temperature properties, but is very expensive. Other high temperature microphones employing crystal or strain gauge units are available. Industrial systems may have inherently high vibration levels on, for example, the walls of pipes or ducts to which the active systems are to be fitted. The vibration may be in a similar frequency range to that of the noise which is to be controlled. If the microphones are sensitive to vibration, a reduction in the coherence of the microphone signals may occur. Therefore, microphones must be selected for their low sensitivity to vibration, or some means found of cancelling out that part of their signal which originates in vibration.

3 - SOUND POWER OUTPUT.

Very high levels may be required to cancel noise in, for example, an engine exhaust. It is possible to make a simple prediction of the sound power level of a single loudspeaker, acting as a point source in free field, leading to:

$$W = \frac{\rho}{c} 4\pi^3 f^4 \left(A\bar{d}\right)^2 \text{ watts}$$

or

$$\textit{Sound Power Level} = 40\log f + 20\log\left(A\bar{d}\right) + 117 \text{ dB}$$

where A is the effective source area and $\bar{d}$ is its rms displacement.
Whilst the operation in a ducted system is affected by the duct impedance, causing maxima and minima to be superimposed on the loudspeaker response, this equation does indicate some of the problems of using a loudspeaker. For constant displacement, the power output falls rapidly with reducing frequency, dropping by 1/16th for each halving of frequency. Thus, it is difficult to produce high levels at low frequencies due to the limitations on displacement, d.

4 - THE EXACT OSCILLATING VALVE

ExAct overcomes some of the problems of loudspeakers in flow The system is shown in Fig. 1. An oscillating motor-driven flap valve is on an axis across a pipe, so that the plane of the valve is at right angles to the axis of the pipe. ExAct has applications where pulsations are superimposed on a mean flow, such as an engine exhaust or fluid pump [1], [2], [3], [4]. It acts as a variable control to the flow, superimposing new pulsations upon it to cancel the original pulsations.

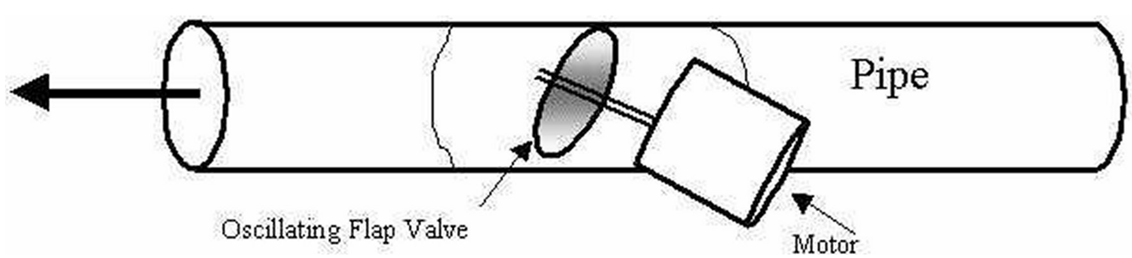

Figure 1: Oscillating motor driven valve.

Thus, ExAct cannot operate without a mean flow and becomes more efficient the greater the flow velocity, as this leads to greater dynamic pressure. The presence of the valve results in a pressure difference between upstream and downstream flows, which can be expressed as $\Delta p = 1/2\Lambda\rho U^2$, where Λ is a non dimensional head loss coefficient determined experimentally, and $1/2\rho U^2$ is a measure of the kinetic energy of a flow of mean velocity U and density ρ. Λ depends on the angle between the valve and the flow and, when the valve oscillates, Λ contains both a mean and a fluctuating component so that $\Lambda = \Lambda_0 + \lambda$, where λ is the fluctuating component of head loss. It can be shown [1] that the source strength of the oscillating valve is given by

$$Q = \lambda\rho U^2/2$$

Thus, in contrast to a loudspeaker, the source strength is not frequency dependent and also increases as the square of the flow velocity. The valve is a good choice for attenuating low frequencies in one dimensional flows. ExAct has been used to cancel levels as high 150 dB in experimental exhaust pipes.
There are two limitations on frequency response.
The inertia of the drive motor and valve limits oscillation amplitude at high frequencies.

When the time of travel of the fluid around the valve is similar to the period of the oscillating component in the flow, cancellation is not possible.
The characteristic travel time is $\tau \approx L/U$ sec, where L is the valve dimension and U is the flow velocity, so that L must be small in low speed flows. For L=0.05 m and U=10 m/s, the characteristic frequency is $F_c = 1/\tau$ is 200 Hz. Control is lost for frequencies greater than F_c.
The ExAct oscillating valve has been demonstrated in a range of one dimensional fluid flow noise control applications. These include engines, pumps and air conditioning ducts. Fig. 2 illustrates its use in a small HVAC duct, in which the fan is used to provide flow and the loudspeaker adds noise [5]. Attenuation of 15-20 dB occurs between 40 Hz and 100 Hz (Fig. 3).
The ExAct oscillating valve can be constructed of high temperature material and applied to a range of situations in which a loudspeaker will not be possible.

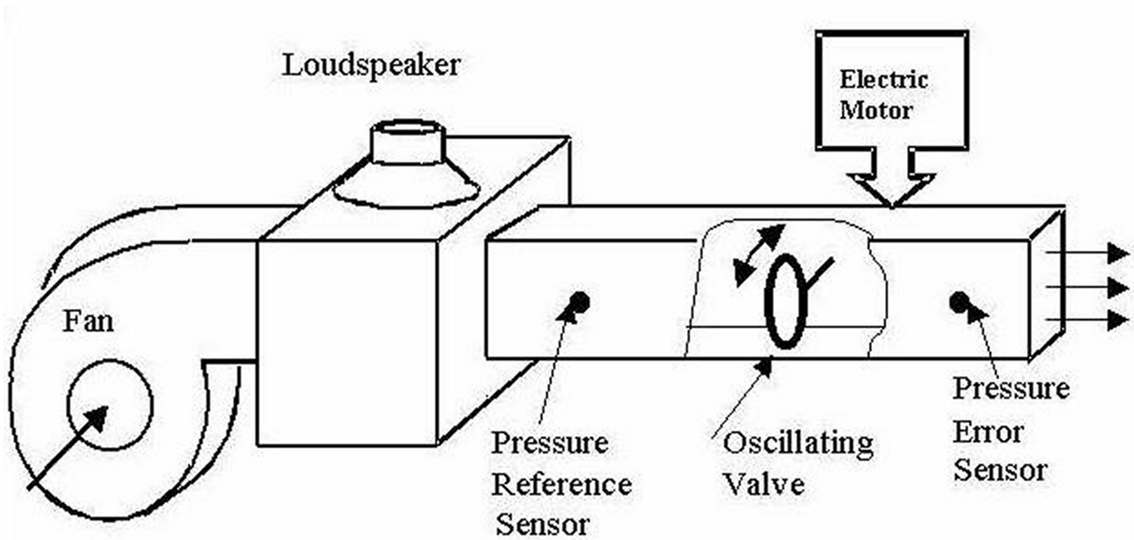

Figure 2: Flap valve in an HVAC duct.

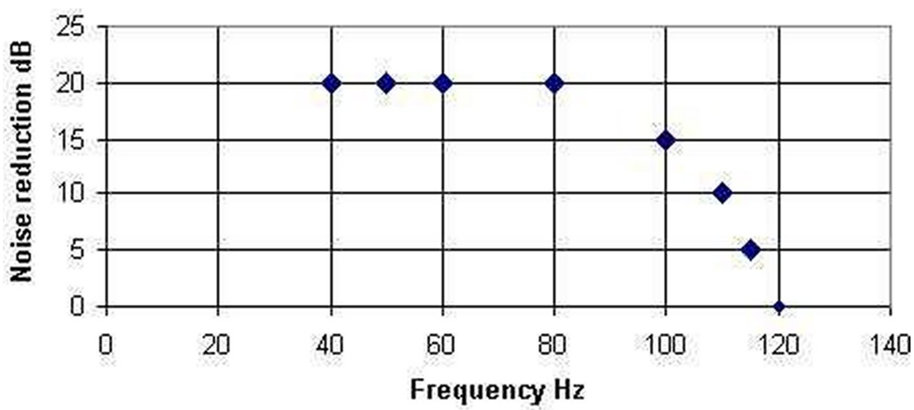

Figure 3: Active noise reduction with oscillating flap valve.

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