

The anti-noise source may itself be a loudspeaker mounted within the duct, or may be an outlet to which the output of a loudspeaker is piped, the loudspeaker itself being external of the duct.

5 In order that the present invention may be more readily understood an embodiment thereof will now be described by way of example and with reference to the accompanying drawings, in which

10 Figure 1 is a diagrammatic view of a known active noise control system,

Figure 2 is a similar view of a system according to the present invention,

Figure 3 is a perspective view of a duct,

Figure 4 is a response graph, and

15 Figure 5 is a block diagram of a control circuit.

Referring now to the drawings, Figure 1 shows a known arrangement which is essentially that established by Paul Lueg. In this arrangement a sensing microphone 1 is positioned in the centre of a duct 2 and a loudspeaker 3 is located in the duct wall. This is the simplest form of an active attenuator for duct borne sound. The system includes a controller 4 which in turn includes an electrical signal delay to compensate for the acoustic propagation delay from the sensing microphone 1 to the antisource loudspeaker 3. If the microphone is placed directly in front of the loudspeaker piston, this acoustic delay is eliminated and the controller can be a simple inverting amplifier. Since the microphone senses both the primary noise field as well as the field from the loudspeaker, a closed loop configuration exists and there is a danger of instability. Substantial noise attenuation can be obtained provided the loop gain is high, but stability criteria limit this. In ducts, the position of sensor and loudspeaker are important for stability and maximum obtainable attenuation, as will be shown in the following paragraph.

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This can be appreciated by considering the duct shown in Figure 3. A guided propagated wave in this rectangular duct can be described by equation (1):

$$p(x,y,z,t) = \text{Re}.B e^{-j\omega t} \cdot e^{jb_n x} \cdot \psi_n(y,z) \quad (1)$$

where p is the acoustic pressure

$\psi_n B$ is the pressure amplitude

$$b_n = \sqrt{k^2 - a_n^2}$$

k = the wave number

$$a_n = \pi^2 \left[\left(\frac{n_y}{L_y} \right)^2 + \left(\frac{n_z}{L_z} \right)^2 \right] \quad (2)$$

$$\psi_n(y,z) = D(n_y, n_z) \cdot \cos \frac{n_y \cdot \pi \cdot y}{L_y} \cdot \cos \frac{n_z \cdot \pi \cdot z}{L_z} \quad (3)$$

with the constant $D(n_y, n_z)$ determined from the identity for the orthogonality of eigenfunctions:

$$1/A \iint \psi_n(y,z) \cdot \psi_{n'}(y,z) dA = \delta_{nn'}$$

where A is the duct cross-sectional area.

A microphone placed in this duct will sense the pressure as described in equation (1) and measures both plane and transverse waves. The latter cannot be cancelled with a simple monopole antisource and the contribution of these waves to the total pressure, and consequently to the overall loop gain, does not contribute to the cancellation of plane waves. The phase shift

caused by these transverse modes, especially at resonance frequencies, is also detrimental to the noise reduction which is obtainable. This is due to the reduction in the open loop gain necessary to maintain stability. It can be shown, however, that the ratio between total acoustic pressure and pressure due to plane waves is minimal when the microphone is placed in the

duct centre. If the loudspeaker is mounted in the duct wall, as in Figure 1, most transverse modes can be generated in addition to the plane wave mode, and the plane waves and even numbered (n_y and n_z are even numbers) transverse modes are sensed by the centre mounted microphone. Positioning the microphone in the centre of the duct has, however, the disadvantage that airflow in the duct causes turbulence at the microphone resulting in a locally generated noise field. This gives rise to the electrical output of the microphone no longer being directly related to the acoustic field propagating down the duct. This severely restricts the obtainable attenuation and some form of microphone wind screening is essential.

Accordingly the present invention proposes that the microphone should be located flush with the duct wall, as is shown in Figure 2 of the accompanying drawings. In this position the microphone no longer generates any flow noise because the air flow velocity at the duct surface is zero. However, there is limitation of attenuation because the microphone is no longer at a position where the contribution of transverse modes to the total acoustic pressure is minimal.

This problem can be alleviated by placing the antisource loudspeaker in the centre of the duct. In this way a minimum number of transverse modes are generated. Thus if a point source (x_0, y_0, z_0) is placed in a duct the pressure amplitude can be written as

$$p(x, y, z) = \sum_n X_n(x) \cdot \psi_n(y, z) \quad (4)$$

where $X_n(x) = \frac{-2\pi \hat{S} \cdot \psi_n(y_0, z_0)}{jAb_n} \cdot e^{jb_n|x|}$

with $\hat{S}$ the monopole pressure amplitude. It will be clear from equation (3) that only one quarter of all transverse waves will be generated.

It has been found that an active noise control system with the configuration of a wall-mounted microphone and a centre-placed antisource yields satisfactory attenuation when there is airflow in the duct.

5 It will be appreciated that an antisource placed in the duct rather than in the duct wall will generally occupy a larger volume than a microphone and will therefore provide a larger obstruction to the airflow. In most practical applications, however, the active system will
10 be integrated with a passive absorber, such as a splitter silencer. In such a case there would not be a significant increase in the overall air resistance.

Another important consideration is system stability. The active noise control system operates in a closed loop
15 configuration due to the acoustic signal path from the loudspeaker back to the sensing microphone, and consequently the system could become unstable. To prevent this, stability criteria must be met and gain and phase need to be controlled. Since the amplitude-frequency response
20 of a loudspeaker rolls off at low frequencies (i.e. a decreasing output with decreasing frequency), the open loop gain in this frequency region will decrease as well. The effect on the phase response of the total system is that it goes through zero, which could lead
25 to instability.

To meet this problem the system according to the invention incorporates an integration circuit. This is shown at 10 in Figure 5 from which figure it can be seen that the control circuitry leading from microphone 1 to
30 loudspeaker 3 comprises a microphone preamplifier 9, the integrator 10 and an inverting power amplifier 11. The inverting amplifier 11 provides the necessary phase shift to ensure that the output of loudspeaker 3 interferes destructively with the noise detected by
35 microphone 1.

The integrator circuit 10 is intended not only to improve the loop gain at low frequencies but also to secure stability by altering the phase. Thus the integrator circuit 10 has been given the amplitude-frequency response shown in the graph of Figure 4. To produce this response the circuit 10 has a transfer function $H(s) = \frac{1}{sT + 1}$

where $s = j\omega$, $j = \sqrt{-1}$, ω is the frequency in rads and T the circuit time constant. High frequency stability can be ensured by reduction of gain by means of passive absorptive material placed on the walls of the duct.

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CLAIMS

1. An active noise control system comprising a microphone located in the wall of a duct through which the noise to be controlled propagates, a source of anti-sound mounted in the centre of the duct, and means for driving the anti-sound source in response to the microphone.
 2. A system as claimed in Claim 1, wherein the anti-sound source is a loudspeaker.
 3. A system as claimed in Claim 1 or Claim 2, wherein the anti-sound source is driven from the microphone via a control circuit incorporating an integrating circuit for improving loop gain and aiding stability by altering the phase of the detected signal.
 4. A system as claimed in Claim 4, wherein the control circuit comprises a microphone preamplifier connected to the microphone, an integrator for integrating the preamplified signal and an inverting power amplifier.
 5. A system as claimed in Claim 4, wherein the integrator has a transfer function $H(S)$ which is equal to $\frac{1}{s\tau + 1}$, where $s = j\omega$
where j is $\sqrt{-1}$, ω is the frequency in rads and τ the circuit time constant.
 6. A system as claimed in Claim 5 wherein passive absorptive material is placed in the walls of the duct.
 7. An active noise control system substantially as hereinbefore described with reference to the accompanying drawings.
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