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Goals and problems in Active Noise and Vibration Control

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Abstract— Noise and vibrations have over the last two decades been regarded as important environmental health problems. Regulations regarding acoustic as well as vibration levels have therefore become more strict. High levels of sound and vibration in different means for personal transportation are often regarded as a important environmental problem. The public alertness of health risks in conjunction with sound and vibration exposure has indirectly, become an important sales argument for manufacturers. Governments and health organizations are already regulating the time and level of sound and vibration that the human body is allowed to be exposed to. These regulations are becoming more and more strict, wherefore new methods for sound and vibration attenuation always are in demand. The new directives from the European Union (EU), from 2005, regarding heavy vehicles (loaders, trucks etc.) constitute an example. Such regulations state that it is not the manufacturer of the heavy vehicle but the employer who has to ensure that the maximum sound and vibration limits, both on a daily and weekly basis, are not exceeded.

Index Terms— Active Noise.vibrations, Damping materials, traffic noise, surface pavement.

I. INTRODUCTION

Active Noise and Vibration Control: Active noise control works on the principle of destructive interference between sound fields generated by the original (primary) source and the secondary sources, which can be controlled. Conventional methods of suppressing acoustic noise using sound absorbers do not work well at low frequencies. (Wavelength >> thickness of a typical absorber, 100 Hz . 3.4m, using velocity of acoustic waves in air = 333 m/s).

Low frequency noise and vibration problems inside different types of vehicles are often difficult to solve by means of conventional passive methods. Passive methods in the low frequency area may employ some kind of resonant absorbers, which, unfortunately is a less attractive solution inside a vehicle. Other passive approaches include putting absorbtion material on the interior of the body, which actually is the most general solution, or to put an absorbent at some distance from the interior body. This is, however, also a problematic solution, since the absorbtion material needs to be approximately one quarter of a wave length. This implies that the absorbtion material needs to be approximately 425 mm thick at a frequency of 200 Hz. Consequently, the use of passive methods to attenuate low frequency noise and vibrations, below 400 − 500 Hz, is often impractical, since considerable extra bulk and weight is required. In addition, in all areas of transportation large weight and size is associated with high fuel consumption. One attractive alternative solution is to apply active noise and vibration control.

Today, active techniques are developing from research labs into actual products. In applications of active noise and vibration control, the basic principle is to generate a secondary sound or vibration field that interferes with the original, primary field. The superposition of these two fields will lead to destructive interference if the amplitudes are identical and the two fields have opposite phases. In theory, the reduction of the sound or vibration field can be total, but in practice there are several limitations.

The technique of active control has been known for almost 70 years, but it is not until the recent 20 years that the technique has become feasible, enabled by the development of the digital signal processor. Today ordinary PC-computers are fast enough to host an active controller. However, the PC needs to be equipped with a powerful sound card that can handle the number of inputs and outputs required. The Audio Streaming Input and Output standard gives scope for the processor to communicate with the sound card in such a way those small delays are maintained between input and output.

In a noisy vehicle, two main different approaches are considered, namely; to achieve global control where the noise in the entire vehicle is attenuated. This approach is often very difficult since it is the noise source that needs to be targeted directly. In real-life active noise and vibration applications local control is main . By local control we attenuate the noise only in certain areas of the vehicle, if possible around the ears of the passengers and operators. Though, local control usually creates higher sound levels outside the control area this is often adequate. As an example, in a car application passengers would benefit from a 10 dB lower sound level around the head but 10 dB higher around their feet.

II. BASIC IDEAS OF ACTIVE CONTROL

1936: Paul Lueg describes basic ideas of active control**:** He considered sound to be travelling as plane wave in duct caused by Primary source. A microphone M detects the sound wave and supplies the electronic controller which drives the loudspeaker (see Figure 1) Destructive interference. Diagrams 2, 3 and 4 show his intentions of mirror waveforms for non sinusoidal signals and signals extending in 3 dimensions.

III. ACOUSTIC OBJECTIVES

- Power output minimization
- Quiet zone
- Power absorption
- Control Strategies
- Feedback control
- Feed forward control

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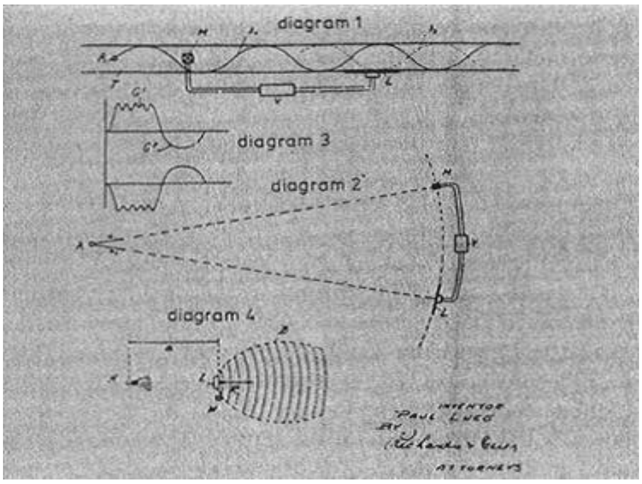


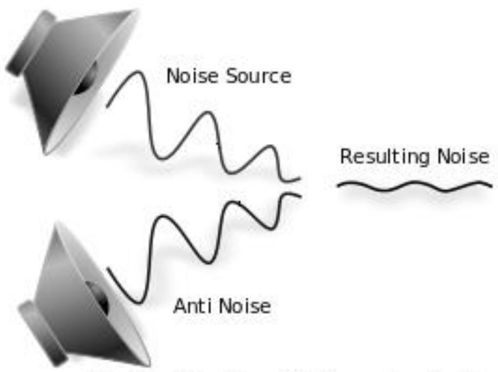
Figure 1: Diagrams from Paul Lueg's patent 1936

All of these principles rely on superposition, which applies in all linear systems. The propagation of acoustic waves is a linear process. Nonlinearity usually occurs in the loudspeakers acting as the secondary source. Destructive interference can be achieved in following way. Phase and amplitude of a signal driving one loudspeaker have to be adjusted relative to that driving another loudspeaker. Acoustic pressure at a single point can be driven to zero. On the other hand constructive interface can occur in other points.

To solve this problem, Position microphone and secondry source close together secondary source is well coupled to the microphone, and a low voltage is needed to drive the loudspeaker. Acoustic pressure at other points will not be affected by the secondary source quite zone around the microphone. 10 db reduction in a zone around the microphone within 1/10 of the wavelength is achieved. (0.34m at 100 Hz, 3.4 mm at 10 kHz)

IV. WAY TO ACHIEVE GLOBAL CANCELLATION:

Figure 2: Wave fronts from 2 acoustic sources at frequencies, where the space between the diverging wave fronts is (a) large and (b) nearly the same compared with the acoustic wavelength



Graphical depiction of active noise reduction

Figure 2

An Example: – 2 loudspeakers work at low frequency in a free field.

- If the diverging wave front are closely placed compared with the acoustic wavelength and the two sources are of the same amplitude, but out of phase, then global destructive interference can be achieved. (See figure 2(a)).
- If the frequency is increased, the interference will be destructive in some points, but constructive in others, and global control will not be achieved.(See figure 2(b))

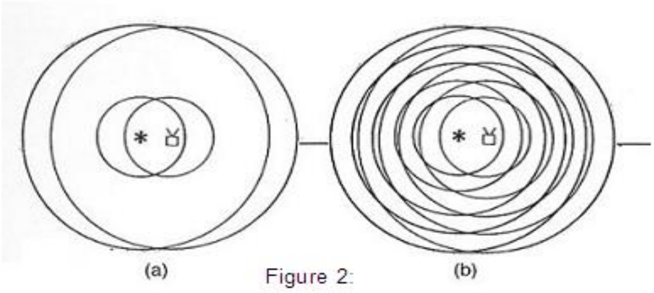


Figure 2:

Another way to describe global cancellation is to use the net acoustic power output of two equal, but out of phase acoustic sources, as shown in figure 3(c). At large separation distances compared with the wavelength, the two sources generate a total output which is twice that of only one operating alone. If the distance between the two sources is reduced, the interference becomes much stronger.

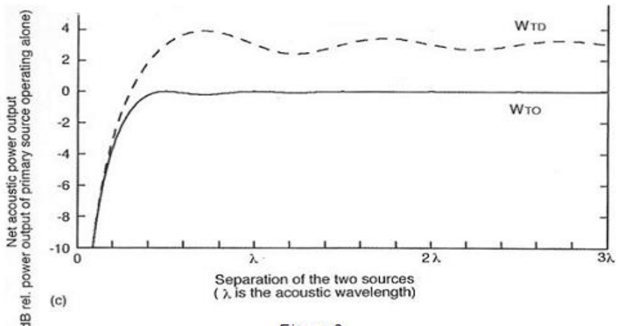


Figure 3:

Figure 3(C): WTD describes the net acoustic power (dB) of two sources of the same Amplitude, but out of phase. WTO is the net acoustic power (DB) if amplitude and phase of the secondary source are optimally adjusted to reduce the power output.

Standing Waves: In an enclosure, for example the interior of a car, the sound field is reflected and causes internal standing waves at certain frequencies. These 3-dimensional acoustic waves are the modes of the enclosure. They can be used to described the acoustic pressure efficiently.

• **Acoustic potential energy:** In enclosures, the quantity to be controlled is the acoustic potential energy. It is proportional to the sum of the mean square amplitude of each of the acoustic modes. It can be controlled similar to the Example mentioned before, by changing amplitude and phase of the secondary source. Minimising the acoustic potential energy is equivalent to minimising the net acoustic power.

Figure 4 (solid line) shows the acoustic potential energy generated in a rectangular enclosure of dimensions 1.9 m x 1.1 m x 1.0 m, which is equivalent to the interior of a small car, by a pure monopole acoustic source in one corner of the enclosure. A secondary acoustic source is placed in the opposite corner and driven at the same discrete frequency as the primary source. Its amplitude and phase are adjusted to minimise the total acoustic potential energy. The resultant acoustic potential energy is plotted as the dashed curve.

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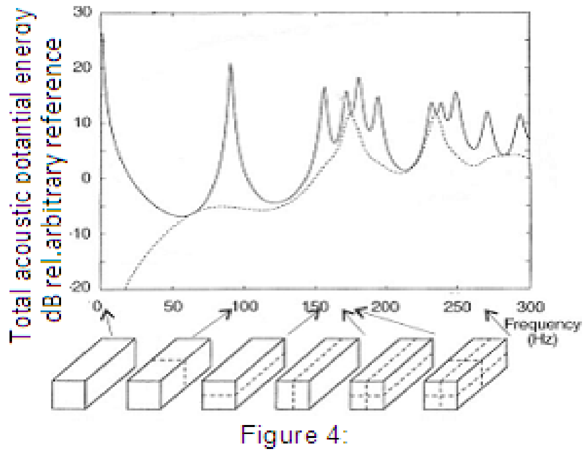

Figure 4: Total acoustic potential energy in an enclosure equivalent to a small car

V. WORKING:

The effect of the feedback group forcing e to be small compared to d, will be to cancel the acoustic pressure at the monitor microphone, as required for Active control.
Figure 5 a) shows an active noise system using feedback control. In 5 b) the electrical configurations can be seen:
d ... Disturbance
e ... microphone signal
H ... electrical filter
C ... secondary source.

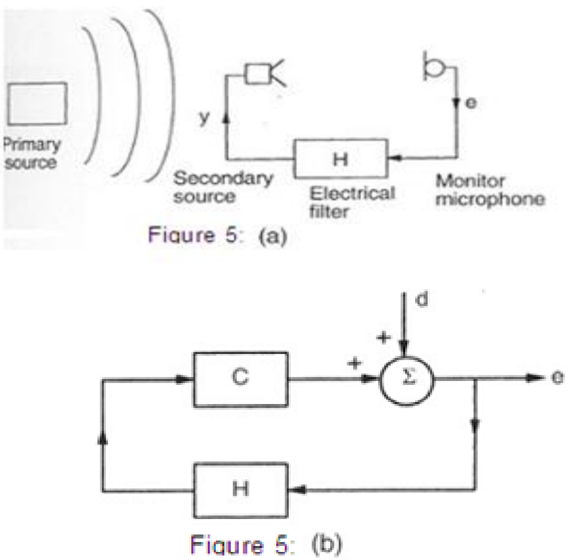

Figure 5: (a) Active noise system using feedback control. (b) Equivalent electrical configuration.

VI. APPLICATIONS:

Feedback systems have been used for broadband noise control in headset and ear defenders. Several commercial systems achieve 10-15 dB reduction of the acoustic pressure at frequencies from 30 Hz to 500 Hz.
Problems in this application are, although the microphone and secondary source are placed very close together, the high frequency limit is set by the accumulation of phase shift with frequency, causing instability unless the gain is reduced. The acoustic path between the secondary loudspeaker and the microphone changes as the headset is worn by different people, or in different positions of the same person, or even if it is lifted on and off the head.

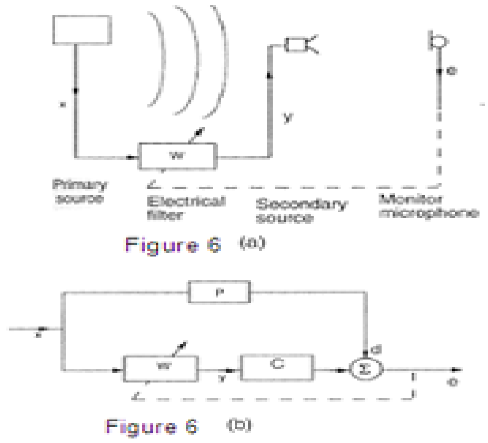

Figure 6:
(a) Active noise system using feed forward control.
(b) Equivalent electrical configuration:
P ... Primary source
W ... Electrical filter
C ... Secondary source
x ... Reference signal
d ... Disturbance
e ... Microphone signal
In the case of feed forward control, a separate reference signal is used to drive the secondary source via electrical controller. This reference signal must be well correlated with the signal from the primary source. The reference signal can often be obtained directly from the mechanical operation of the primary source, (tachometer) and is completely unaffected by secondly source. The control is purely feed forward. (See figure 6). The reference signal provides advance information about the primary noise before it reaches the microphone. This enables the controller to effect cancellation. When the noise signal is deterministic (harmonic tones,), this information has little meaning. The controller only has to implement the necessary gain and phase shift.
Because the properties of the primary noise and the characteristics of the acoustic path between the secondary source and the microphone can Change with time, the controller in active feed forward systems is often made adaptive .Therefore, digital systems are used.

VII. GOALS AND PROBLEMS IN PRACTICAL SOLUTIONS:

Active control is limited to situation in which the separation between the primary and secondary source is at most of the same order as the acoustic wave length. In enclosure, whose smallest dimensions are of the order of a few meters, the upper frequency is restricted to a few hundred hertz. At these frequencies, Active noise control is more effective than passive noise control techniques, because of the higher acoustic wavelengths. At low frequencies, passive control systems need a high amount of weight. Therefore, active systems are especially used in aircraft and light weight cars.

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VIII. ACTIVE HEADSETS

They are designed to reduce any external noise, deterministic and random.
They use a feedback system. The typical performance is shown in figure 7:
Upper curve _ Spectrum of cockpit noise in a jet aircraft
Middle curve _ Noise at the ears of the pilot when wearing a conventional headset
Bottom curve- Noise at the pilot's ear using the headset with active control

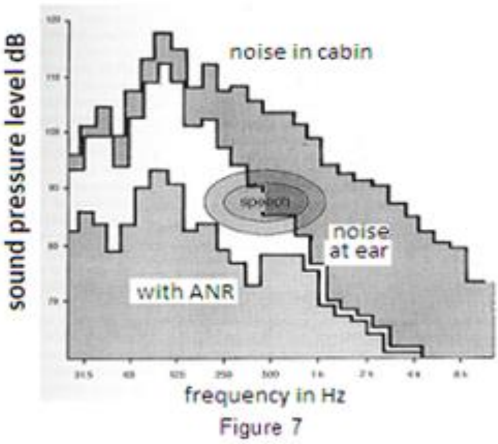

Figure 7

A. Active control in air conditions:

This system operates on the feed forward principal. Figure 8 shows the spectrum of the resulting pressure signal in an air condition duct with an airflow about 14 m/s .Below 40 hertz, the performance is limited by high levels of turbulence.

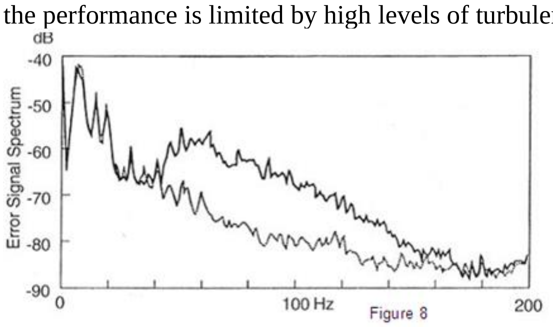

Figure 8

B. Active control in a propeller plane:

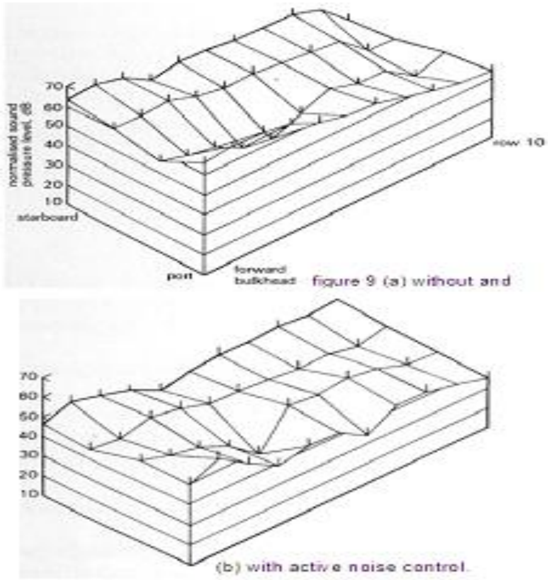

Figure 9

On a 50 seat propeller plane, an active noise control system with multiple micro phone and loud speakers was implemented. 32 micro phone and 16 loud speakers where used in a feed forward system to minimize the sum of the squared pressure of the blade passing frequency and its first two harmonics. A reduction of 10-14 dB was achieved. The sound pressure in the passenger cabin is shown in figure 9 (a) without and (b) with active noise control.

C. Active control in cars:

At higher engine speeds, many cars show some kind of boom, caused by the engine. Figure 10 shows an active noise control systems developed for reduction of engine noise in cars. A feed forward controller uses a reference signal taken from the circuit of the engine to drive 6 loudspeakers (often those already installed in the car). 8 microphones are used to provide an error signal.

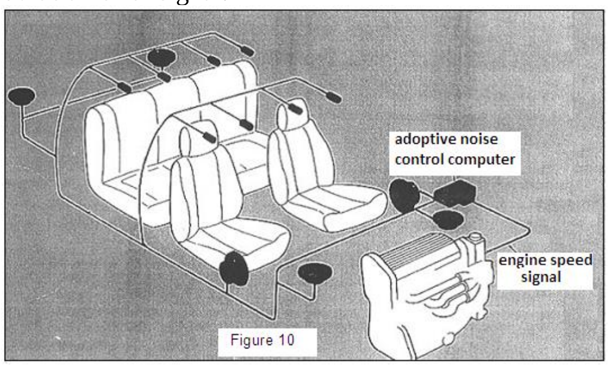

Figure 10

The result of using a 4 loudspeakers 8 microphones active control system in a Small 1.1 lit , 4 cylinder car are shown in figure 11. The car was accelerated at full load from 1500 to 6000 rpm. This corresponds to Noise frequency from 50-200 Hrtz

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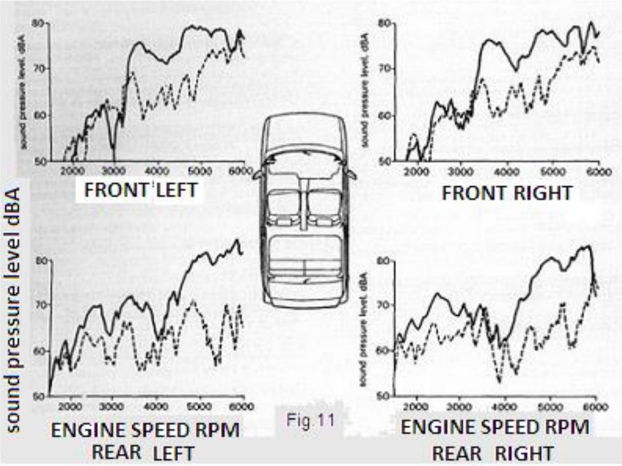

Fig.11

Solid line : Active control system off

Dashed line : Active control system on

IX. CONCLUSIONS

The secondary source cannot controls modes between those of the primary sources without increasing the excitation of other modes. Therefore the optimum secondary source strength is reduced and only little reduction at these frequencies is achieved. In practice, it is not possible to detect the total acoustic potential energy in an enclosure, because infinite numbers of microphones would be required. The microphones need to be located such that they are affected by all the foremost acoustic modes. The secondary sources need to be situated that they can stimulate these modes. In practice, using twice as many microphones as secondary source is a good compromise between complexity and performance.

X. PROSPECT APPLICATIONS OF ACTIVE CONTROL, WHICH ARE NOW DEVELOPED:

1. Active control of structural vibration
2. Adaptive sound reproduction systems
3. Active control of fluid flow
4. Active control of electromagnetic fields

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Prof. Mahajan Sharad R. completed his B.E. In Automobile Engineering, M.E. In Energy Systems, From Karnataka University and Ph.D. In Mechanical Engineering. Presented and published 15 national level papers and 9 international journals. Taught various subjects in Automobile Engineering. He is having 24 years of teaching experience .

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