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ACTIVE NOISE CONTROL IN THE CABIN OF A SALOON CAR

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Introduction

Active control is increasingly becoming a practical solution to noise and vibration problems, rather than being just an interesting research topic. The theory of such control has been widely published, and there is no intention to reproduce it here. This paper will describe how active sound control is being applied to noise in a car cabin and illustrate the compromises and constraints involved in bridging the gap between theory and practice.

In general terms, any active noise control system consists of four elements: sensors to measure the noise, a control algorithm to process sensor inputs in order to produce an anti-phase replica of the noise (the anti-noise), the computing power on which to run the algorithm, and anti-sources to realise the output from the algorithm. Each of these four elements must be adapted to suit the operating conditions. It is important to fully understand the problem before attempting to formulate the solution.

Noise in Car Cabins

Production cars are engineered primarily for cost efficiency and use well established technology. It can be tempting to regard them as simple. They are anything but, particularly from the acoustical point of view.

The complexity of the sound field in a car cabin arises from the number and relative importance of the noise sources which contribute to it. For instance, periodic noise comes from the gearbox and the engine (and its associated intake and exhaust noise) and broadband noise from road/tyre contact and from wind noise. The ranking of these sources in order of importance is difficult, but in very general terms engine noise and road/tyre noise could be considered of prime importance.

To further complicate matters, it is not always very easy to discover the transmission paths for each noise or to decide just how much of the noise is structure-borne and how much is airborne.

The conventional method of noise control in the car industry is the 'acoustic pack' of passive damping material. This pack carries an accompanying weight, cost and space penalty. It is not particularly difficult to design large and heavy, but quiet, cars. Unfortunately, the trend in recent years has been towards smaller and lighter vehicles. Manufacturers are using more and more sophisticated modelling and measurement techniques in order to deal with the increasing importance of noise problems.

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An Active Approach

Active sound control is an attractive method of reducing noise in a car cabin. It is most effective at frequencies below 300Hz (for reasons described later) where passive control is least effective. (A combined active/passive system to deal with low/high frequency noise would be most effective.) Active methods may well give cost, space and weight savings over passive means for the same degree of noise control. The compromises between the problem posed and the possibilities offered by the solution are the topic of this paper.

The maximum frequency which an active control system can address can be subject to a number of limitations (e.g. anti-source response). In this case, the computational time available is the limiting factor. Obviously, the faster that the calculations can be completed, the higher the maximum frequency. This is a function, amongst other things, of the type of noise that is being controlled. A periodic sound (even a varying one) will have a degree of coherence between one cycle and the next. This can be used to feed forward information about the noise so that the controller can adapt more rapidly. This is not possible with random, broadband noise and so the maximum frequency is lower. It is therefore logical for a first prototype system to tackle one of the periodic noise sources present in a car.

The system being produced is designed to reduce noise in the cabin at twice engine rotation frequency (usually called 2E noise). Such noise is one of the predominant components of overall noise in a car with a four cylinder, in line engine. This is since the 2E frequency is both the engine firing frequency and the first frequency at which out of balance forces are produced by the engine. A typical four seater saloon has a maximum engine speed of around 6000 rpm, which corresponds to 2E noise up to 200 Hz. This is an ideal frequency range for active control. Of lesser importance, but still significant, is the first harmonic of this noise at four times the engine frequency. This would be the next sensible extension of the system.

Figure 1 shows the variation of 2E noise at the driver's ear in a typical car, accelerating at full load in third gear (a standard test). Note the 'boom' which occurs at 2500-3000 rpm. Such a boom can be particularly annoying if it occurs at cruising speeds. Also note the extremely rapid variation in sound levels which can occur across very few rpm. Plots for other occupants of the car are similar, except that the boom moves to a lower frequency at the rear seats. The situation even for this simple test on one component of cabin noise is extremely complex. The following discussion is concerned with some of the points which emerged during system development.

There are two basic strategies for choosing anti-source positions:

(i) Modal Control. The sound field is described as the sum of a number of independent modes and each mode controlled separately. A minimum of one sensor and one anti-source is required for control of each mode. Analytical formulae exist for simple geometries and rigid walls (see Reference 1) which allow estimation of the modal separation. If the spacing is insufficient, then any input will excite a large number of modes due to the close coupling between them. This situation is made worse when the walls are not rigid, and significant damping is imposed. Such conditions prevail in the car, and so modal control would need large numbers of sensors/anti-sources.

(ii) Source Matching. This approach positions the anti-sources of sound as close as possible to the sound source and attempts to match the field being produced. The theoretical number of anti-sources required for source matching in a car cabin is much less than for modal control (a minimum of one anti-source per half wavelength of the maximum frequency sound). The compromises which must be made between performance and complexity are thus less severe when a realistic number of anti-sources is considered. Hence the source matching approach appears the more realistic method.

In an intuitive sense, it is obvious that the engine noise in a car comes from the front and floor. These would hence seem likely sites for the anti-sources (6" car hi-fi loudspeakers). To rationalise this, the transfer functions between control microphones mounted close to the occupants' ear positions and a large number of possible microphone positions were measured. Computer analysis then shows what benefits would accrue from a given combination of anti-source positions and numbers at a given frequency if the control were ideal (instantly adapting). The point about frequency is important. The positions of the 'best set' for a given number of anti-sources will almost certainly change with frequency. It is then necessary to select, from all the possibilities on offer, a combination which gives a balance between performance and complexity.

The number and position of the control microphones is also important. They are placed close to ear positions since this is where noise reduction is most important but if there are not enough, any noise reductions may become very localised at the microphone positions. This is obviously far from ideal: the occupants of a car are not likely to sit rigidly in one position throughout a journey. An increased number of control microphones will improve the global noise reductions. The degree of global control attained is a compromise between system complexity and performance (as it is for the number of anti-sources chosen).

One major problem is that, as was seen in Figure 1, 2E noise can change very rapidly. The active system must also adapt very rapidly, but must make sure that searching for speed of adaption does not give unwanted results. For instance, a tachometer could be used to sense the 2E frequency and a simple control configuration used to adapt very quickly with little processing of the data. This would work well at high signal (2E) to noise (other noise sources) ratios, e.g. at a boom. To reject the background noise at lower signal-to-noise-ratios, however, it is necessary to average data at a cost of time and adaption rate: another compromise between complexity and performance. This is not the only way in which increasing system complexity can adversely affect performance. Addition of additional sensors and anti-sources to a fixed control unit increases the calculation required and can thus slow down adaption.

Of course, more computational power could be employed in order to accelerate adaption. This work has used only two sets of existing hardware which have been employed in a variety of other active control problems. The effort has been concentrated on establishing the other constraints of the situation.

Conclusions

The production of a practical active noise control system is an iterative process. Changing any particular element of the system will have repercussions for every other element. The problem is to balance the importance of each, so that the whole is as effective as possible. Of course, the balance depends entirely on how "effective" is defined. In the final analysis of a car manufacturer "reduction in dB per pound spent" is likely to be the criterion.

The work described here is still proceeding. Before it is complete, many more compromises will have to be made in order to produce a working system. This paper has attempted to give an overview of how such compromises can bring together a relatively new solution and an old problem.

References

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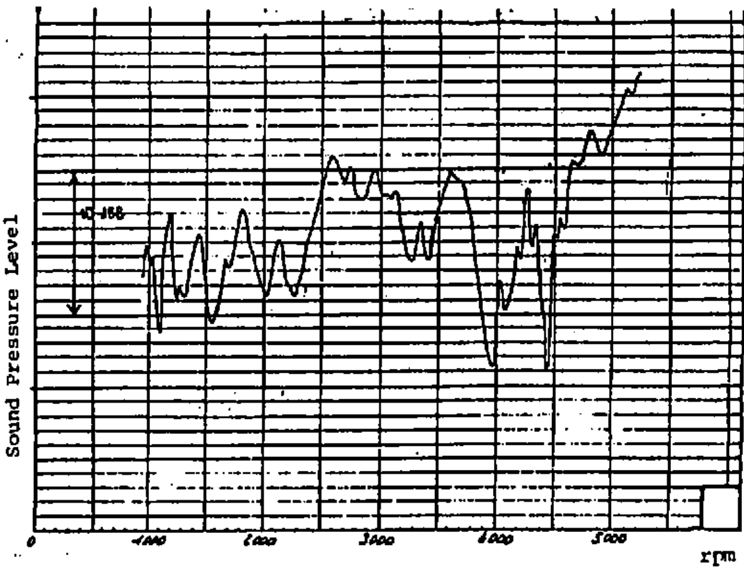

Figure 1. 2E noise at the driver's ear at full engine load in third gear