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ACTIVE CONTROL OF EXHAUST NOISE FROM A COMMERCIAL VEHICLE

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INTRODUCTION

The Essex Group have demonstrated on a variety of internal combustion engines that synchronized active systems can give high degrees of cancellation of the harmonically related exhaust noise components. Consequently, active noise control is now recognised as being a viable alternative to passive silencers for the reduction of high intensity low frequency noise. The active system is potentially smaller and lighter and has the added advantage of not introducing any back pressure.

To date, however, the cancellation systems have been applied only to stationary engines running at relatively constant speed where the rate of adaption to the primary waveform is slow.

This paper describes the research programme initiated by the Transport and Road Research Laboratory (TRRL) for the development of a prototype exhaust noise cancellation system for commercial vehicle applications. In order to achieve global cancellation of a heavy goods vehicle the developed active system must differ in two ways over previous installations. It must be mobile and by necessity it must respond rapidly to the changing noise field produced by the engine under the varying speed and load conditions encountered under normal driving conditions.

TRRL had already passively modified a Foden lorry in the Quiet Heavy programme (1). The Foden lorry was powered by a 350 hp Rolls Royce Eagle diesel engine. The Essex Group removed the specially developed passive silencer and replaced it with an active system and a standard passive silencer for the higher residual frequencies.

SYNCHRONOUS CANCELLATION SYSTEM

A simplified schematic of the cancelling system is shown in Figure 1. The radiated noise is reduced by driving the loud-speakers with the appropriate anti-phase signal. Synchronization (2) for the complete cancellation process is supplied by a pulsed signal taken by a magnetic pick-up located close to a toothed wheel that is fixed rigidly to the engine crankshaft. This synchronization signal locks the cancellation system to the exhaust noise produced by the engine and allows only the repeating frequency components in the noise waveform to be accurately deduced.

The chosen cancellation algorithm for synchronous active noise control is one that works in the frequency domain. However, this requires a large amount of arithmetic operations, thus the heart of the cancellation system consists of two microprocessors operating in a master-slave arrangement. The slave processor, the Texas TMS 320, is a dedicated signal processing microprocessor which under the control of the host processor, performs a Fourier transform on the microphone error signal, converting the time signal to discrete frequency components. These are then modified to give the correct anti-phase components, taking into account the system transfer function. The host processor is also used for system housekeeping, measuring the rotational frequency of the engine, error checking and diagnostics.

The only proven method of generating high intensity low frequency sound for active cancellation is based on the use of commercially available loudspeakers. Due to the limitations of space under the lorry, considerable development was required to reduce the physical size of the actuators without loss of acoustical output. A further innovation over previous implementations was the use of a quadrupole geometry (3). This entailed the splitting of the exhaust pipe into two and using two loudspeaker enclosures with single ports. This configuration gives better acoustic mixing resulting in a marked improvement in the overall cancellation.

Figure 2 shows the loudspeakers mounted on the vehicle and also the residual microphone windshield.

CANCELLATION PERFORMANCE

The final assessment test of the cancellation system is the standard drive-by. For this test the vehicle, engaged in its noisiest gear and driven at 1450 rpm is accelerated as quickly as possible past a measuring microphone. This procedure is repeated with the vehicle being driven past the measuring microphone three times in each direction. The result of this test is the worst case noise recorded. However, in this particular form of test the vehicle is unladen and only a fraction of the power available from the engine is used. For this reason more rigorous evaluation tests were performed on a dynamometer. A Rolls Royce engine of the same specification as that used in the Foden vehicle was mounted on a dynamometer test bed. The exhaust noise was isolated from other engine related noise components, such as crank case radiation, by means of a screening wall. Two (high intensity) ported loudspeakers were placed beside the exhaust outlet and the engine run under load at a fixed speed of 1000 rpm. Figure 3 shows the noise spectra taken one metre away from the exhaust outlet, for both the cancelled and uncancelled conditions. It is seen that the dominant harmonic has been attenuated by more than 25 dB.

The update time is the crucial parameter for cancellation of a variable speed engine. The cancellation module can update 28 engine related harmonics within 1.25 engine repeat cycles. Figure 4 demonstrates the rate of adaption with the engine running at a constant speed of 1000 rpm. At this speed there is approximately eight updates per second. Figure 5 shows how the cancellation system follows changes in the noise produced by both changing engine load and speed conditions in a simulated drive-by test. The engine is accelerated as rapidly as possible from 1400 rpm to full speed. During this period of rapid acceleration the degree of cancellation is less than that achieved during steady engine speed. This reduction in performance is mainly due to the inherent delay associated with the implementation of the algorithm. When the cancellation system completes an update during an acceleration it is using a signal that was derived from engine noise produced at a lower speed.

For the "type-approval" test the loudspeakers were mounted on the lorry. The necessary power to drive the cancellation module and amplifier for the loudspeakers was obtained from the lorry's own batteries via inverters. The peak noise levels of the drive-by with both cancellation on and off is shown in Figure 6. As stated, the lorry is unladen and under these conditions the engine speed is undergoing its maximum rate of change. Nevertheless, a reduction of over 6 dB (linear SPL) was recorded.

CONCLUSION

Qualitatively, the development of a prototype active noise cancellation system for a commercial vehicle was a success. Quantitatively, the use of fast signal processing techniques has shown that typical changes in engine speed can be followed and cancellation maintained under most operating conditions. Further work is needed, however, to improve the rate of adaption and to construct acoustic actuators which are designed specifically for high intensity, low frequency, noise control.

Any views expressed in the paper are not necessarily those of the Department of Transport.

REFERENCES

(1) J.W.Tyler & J.F.Collins, TRRL Quiet Heavy Vehicle Project: Development of Foden/Rolls Royce Demonstrator, TRRL LABORATORY REPORT 1067 (1983).
(2) G.B.B.Chaplin,"Cancellation of Repetitive Noise and Vibration" Proc.Inter-Noise 80, 699-702.
(3) I.Brown, "Application of Simple Source Theory to Active Noise Control", Proc. Institute of Acoustics 1985, Vol 7, Part 2, 73-78.

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FIGURE 1. Schematic of synchronous cancellation system

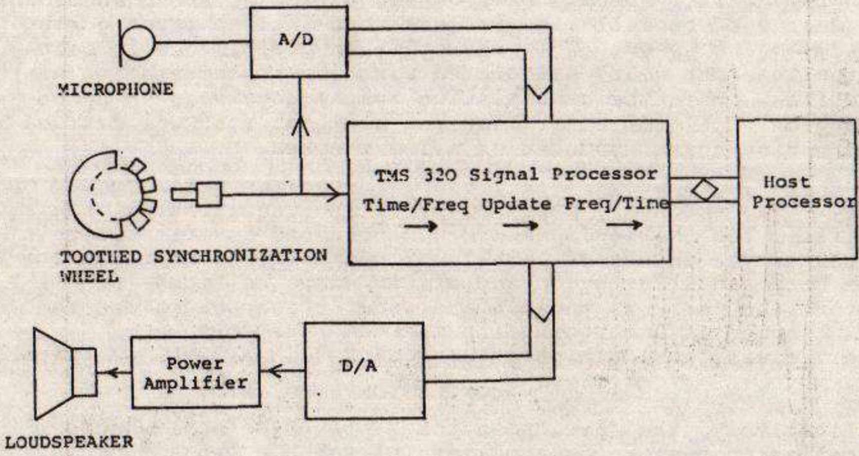

Figure 2. Ported loudspeakers and microphone mounted on the vehicle

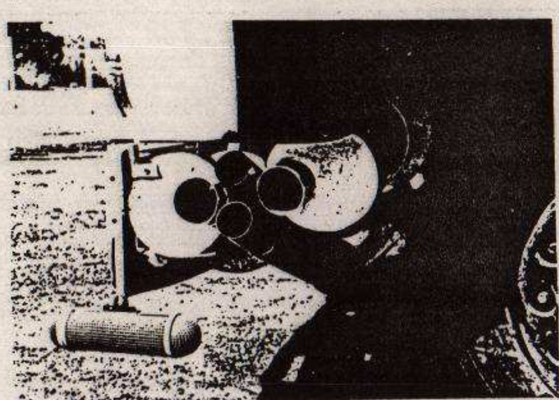

FIGURE 3. Cancellation at fixed speed on dynamometer test bed

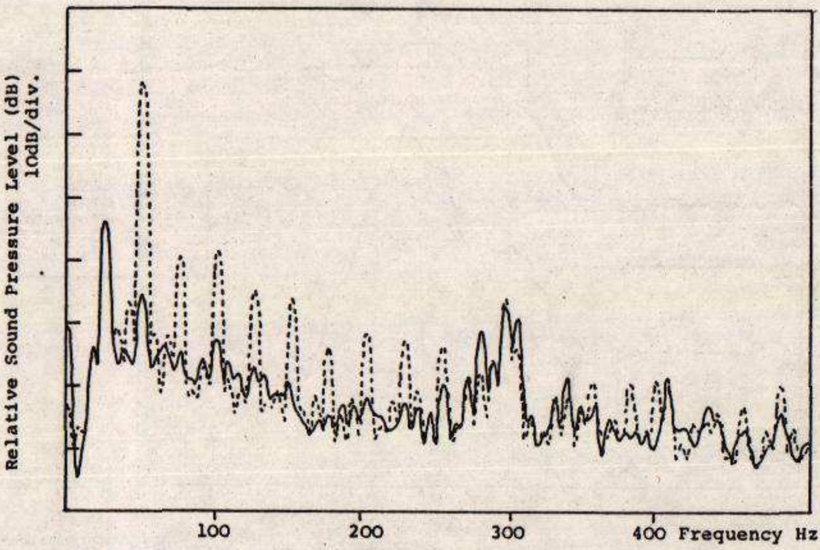

FIGURE 4. Response of cancellation immediately following switch-on

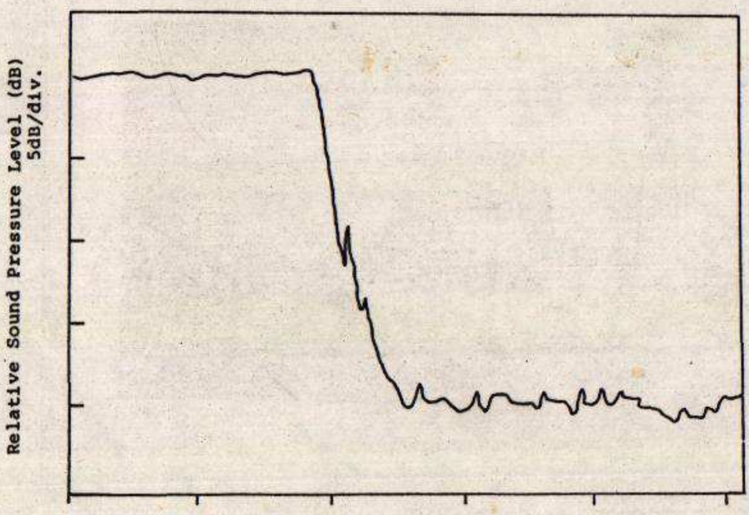

FIGURE 5. Cancellation during simulated drive-by

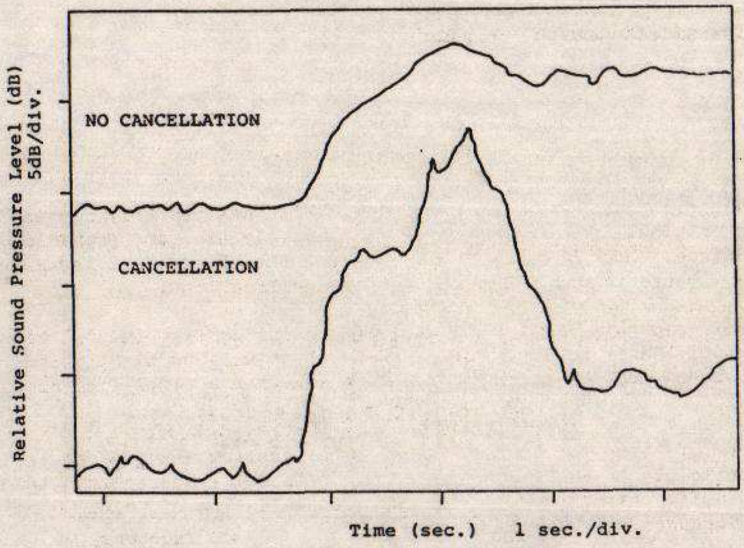

FIGURE 6. Cancellation measured during type approval test