FEASIBILITY EVALUATION FOR ACTIVE CONTROL OF EXHAUST NOISE IN PASSENGER CARS

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Introduction

Active control of noise is based on the destructive interference of sound waves in opposition of phase. The possibility of application of this physical principle to control the exhaust of reciprocating engines has been demonstrated in the late seventies by the work of Prof. George B.B. Chaplin at Essex Univ., U.K.(1).

At that time, however, the limited signal processing power of the control electronics was preventing from any practical possibility of automotive application due to the rapid variations in the noise signatures that occur during normal driving conditions.

More recently, the commercial diffusion of digital signal processor chips with continuously increasing computing power and decreasing costs has opened new perspectives for the application of active control in the automotive field.

The first road demonstrations of active control of noise in the passenger cabin of a car were given by Lotus Engineering, in collaboration with the Institute of Sound and Vibration Research of the Southampton University (U.K.) since 1987 (2).

In 1989 the first experimental set-up of active muffler on a car was presented by Noise Cancellation Technologies (3).

Approximately at the same time, Active Noise and Vibration Technologies (ANVT) was developing a similar work. Both systems were based on the Chaplin principles and used loudspeaker technology for antinoise generation.

At the end of 1990, ANVT and GILARDINI joined their efforts in the development of active noise and vibrations control systems for automotive applications in Europe and formed Electronic Sound Attenuation (ELESA).

The evaluation case

The successful results of these works have risen a strong interest in the technology, which offer several substantial benefits for the vehicle design, going from lower external and internal noise levels to reduced exhaust backpressure, therefore ultimately providing for better combination of passenger comfort, vehicle performances and environmental impact.

Several concerns however remain about functional performances and reliability of the system before commercial diffusion of active exhaust noise control systems in passenger cars may effectively start.

In order to verify the main feasibility issues , an experimental analysis has been carried out with reference to a state-of-the art European front-wheel drive sedan powered by a four-cylinder, two liter, turbocharged s.i. engine with catalytic converter.

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The passive silencing system of the experimental car, consisting of an intermediate and a rear muffler, has been replaced with a simple free pipe beyond the catalytic converter and an active muffler mounted at the end.

The active muffler system used for the evaluation is based on the Chaplin principles and loudspeaker technology.

The hearth of the system is an electronic controller, based on a Motorola 56001 DSP microprocessor; the controller receives a synchronization signal from a shaft encoder installed on the engine, providing 128 pulses per engine revolution, and a residual noise signal from a sound sensor located near the exhaust tailpipe.

The control algorithms

Algorithms for active control are based on two main approaches.

Feedforward algorithms use a measure of the incoming noise upstream to compute the antinoise signal at the cancelling point (4). While this method allows the control of broadband noise and is not directly affected by transient engine conditions, the need for a measure in the exhaust pipe poses severe technological constraints for the in-pipe sensor.

Synchronized feedback algorithms, deriving from the Chaplin method (5), provide control of the engine cycle harmonics (orders), which contain most of the energy in exhaust noise. The critical in-pipe sensor is avoided in this case and replaced by a closed loop control of amplitude and phase of the noise harmonics, according to residual noise measurements.

The critical issue for this method relates to the control of exhaust noise changes during transient driving conditions.

For the evaluation of the performances of different algorithms in a controlled environment, a sequence of bench-marks have been created by recording the uncanceled exhaust noise of the experimental car on a chassis dynamometer with road load simulation, together with the engine synch, in different driving conditions.

The bench-mark signals are fed to a laboratory set-up (fig .1) consisting of a control unit, running the algorithms in real-time and an electronic emulation of the acoustic destructive interference.

In the simplest case, ideal performances of the antinoise generator is assumed in order to evaluate the limit performances of the control algorithms.

The performances of the standard synchronized feedback (Chaplin like) algorithm, executing FFT of the residual noise and recomputation of the antinoise spectrum at every engine cycle, have been evaluated in different conditions.

Fig. 2 and 3 show the effects of the algorithm on the second order (firing frequency) of noise recorded during full load accelerations respectively in first gear (lasting approximately 5 seconds) and in third gear (15 seconds).

Current research is oriented to improve the performances of the algorithm in transitory conditions by working in two main directions: faster control loops and characterization ("learning") of the exhaust noise signatures in different driving conditions.

The antinoise generation.

Although several different antinoise actuators have been proposed for exhaust silencing (6,7), loudspeakers are for the moment still the most attractive solution since are based on well developed technology and offer wide application flexibility. Several concerns however remain about the ability to comply with functional and environmental requirements of the application.

In order to evaluate the feasibility of a loudspeaker system, the spectrum of the free exhaust noise in all significant driving conditions has been determined. The envelop of these spectra defines the acoustic requirements of the canister containing the loudspeakers.

Different antinoise canister prototypes have been developed to demonstrate feasibility and evaluate performances.

Fig.4 displays sound pressure levels that should be given by the canister at a distance of 0.5 m in the frequency range 50-350 Hz in order to match free pipe exhaust noise; these values are compared to those actually emitted by a canister with a volume of 13 liters and a single conventional 200 mm loudspeaker driven at a maximum power of 100 watts.

From these data it can be derived that in the case investigated an intermediate passive element providing a 7-8 dB attenuation above 100 Hz is still necessary.

For production oriented systems an hybrid configuration should be required consisting of an intermediate passive silencer and an active rear silencer, in order to reduce sound pressure level requirements for the active system and to provide satisfactory attenuation at higher frequencies.

The tests on the vehicle

The reference vehicle has been equipped with the described active muffler and several tests have been carried out on chassis dynamometer and on the road.

Fig. 5 shows the effects, in terms of third-octave frequency bands, of the active control on the exhaust noise of the car running at 3000 rpm in steady state conditions on the chassis dynamometer.

Fig.6 displays the results obtained on second engine order during a third gear acceleration on the chassis dynamometer.

The tests carried out so far to evaluate environmental requirements for the loudspeakers have shown that the temperature inside the canister may reach values in the range of 150° C. As this is an harsh environment for commercial loudspeakers. specialized components are being developed to meet such specifications.

Conclusions

Due to intensive development activities currently ongoing at several research laboratories, it is expected that the technology will be rapidly available for commercial applications, therefore providing several benefits to passenger cars:

- lower external noise,
- easier sound quality control
- simplified design and shorter time to market
- components standardization
- lower back-pressure

The achievement of competitive costs shall be the final challenge for the future success on the market.

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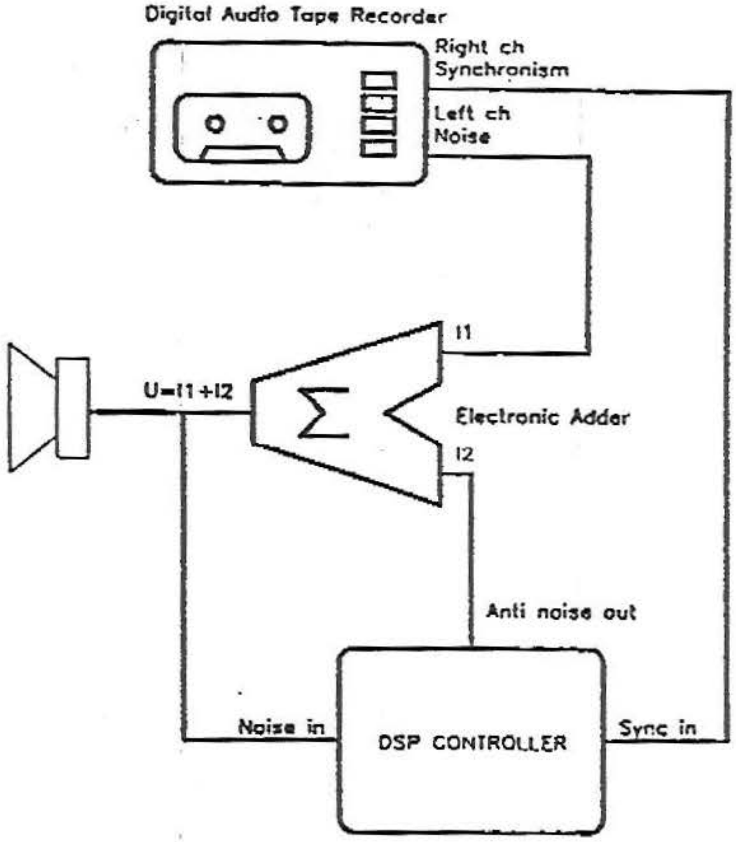

Fig. 1 Laboratory setup for hardware and software analysis

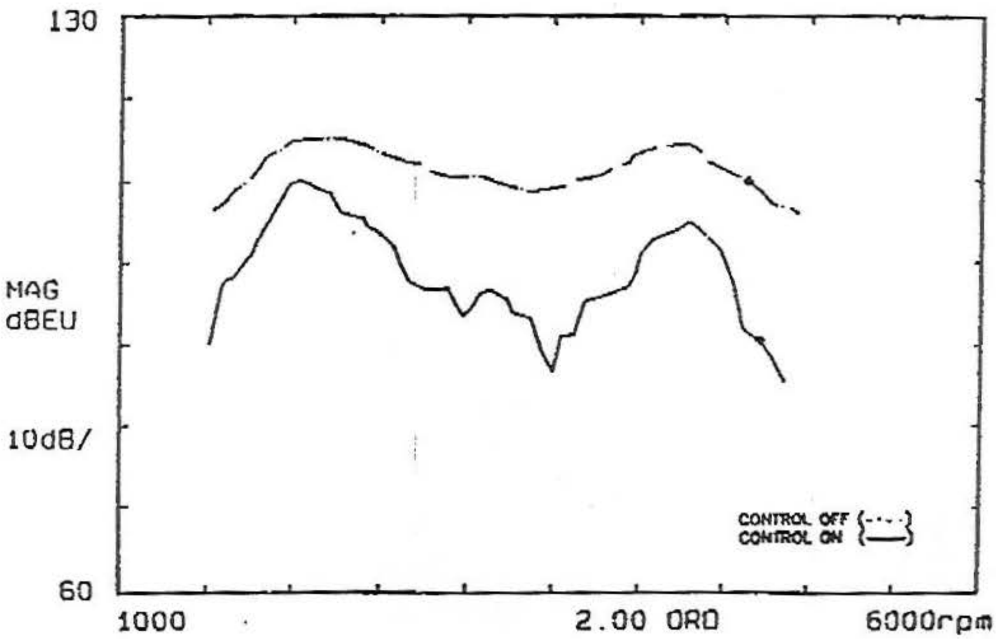

Fig. 2 Laboratory results of active attenuation on 2nd order at 1st gear.

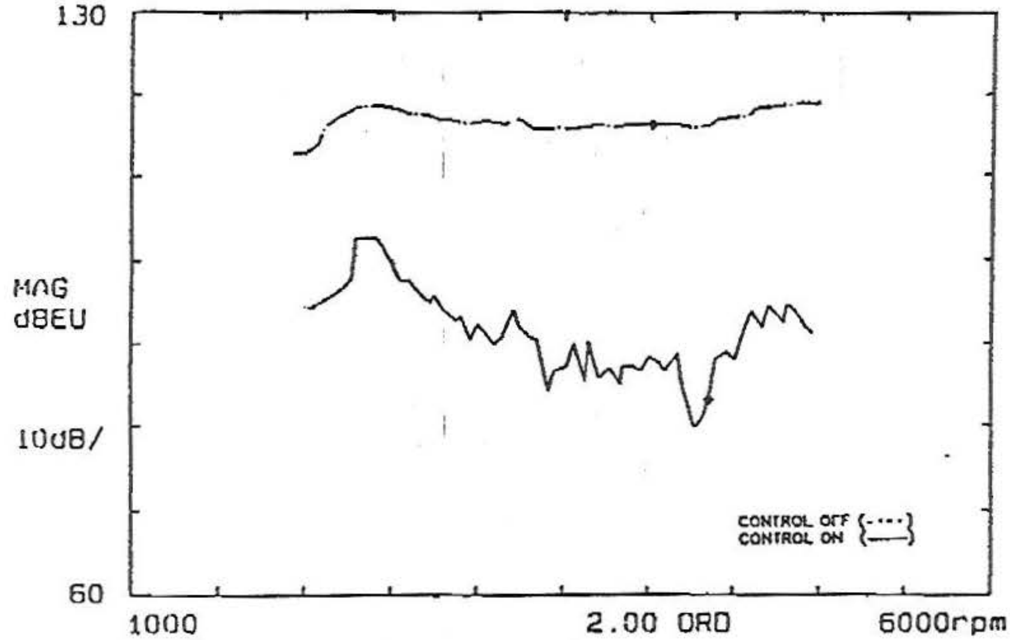

Fig. 3 Laboratory results of active attenuation on 2nd order at 3rd gear.

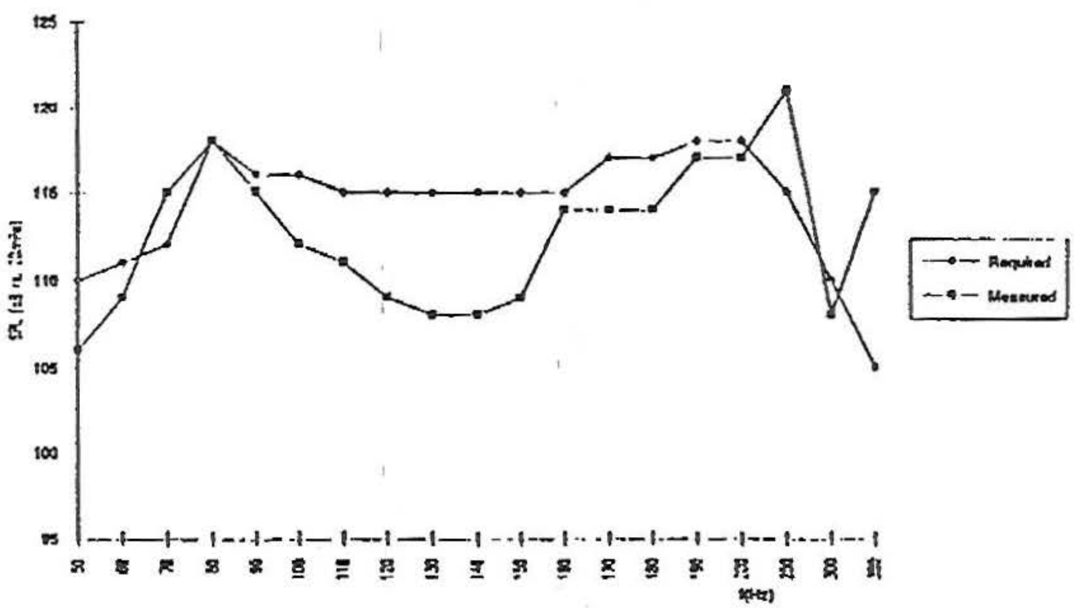

Fig. 4 Comparison between SPL required and measured at 0.5 m from canister tailpipe.

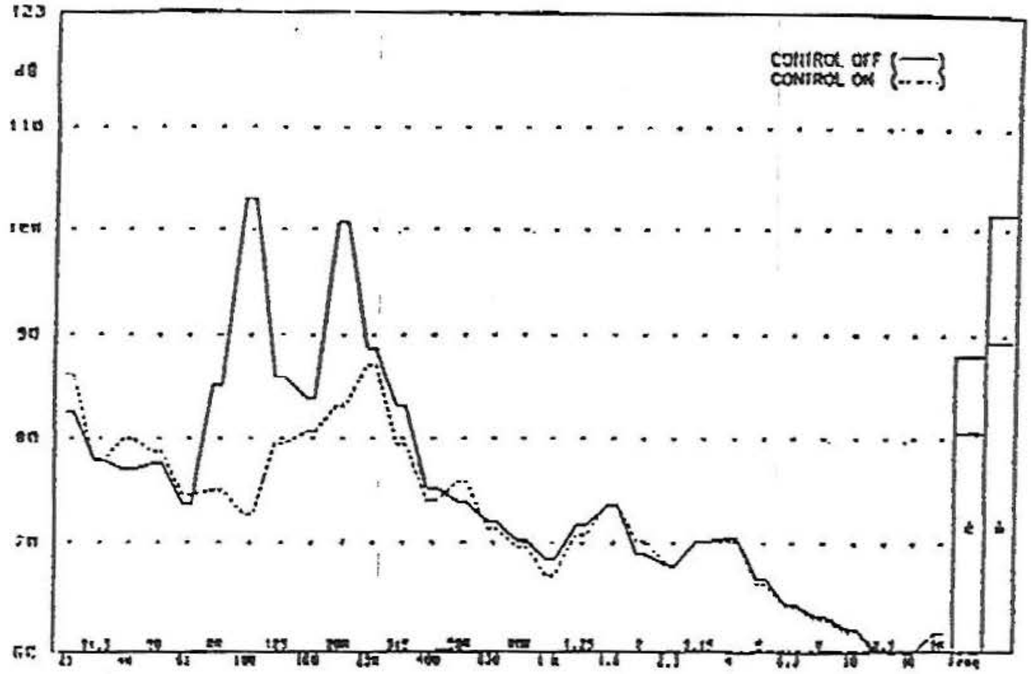

Fig. 5 Effects of active control at 3000 rpm.

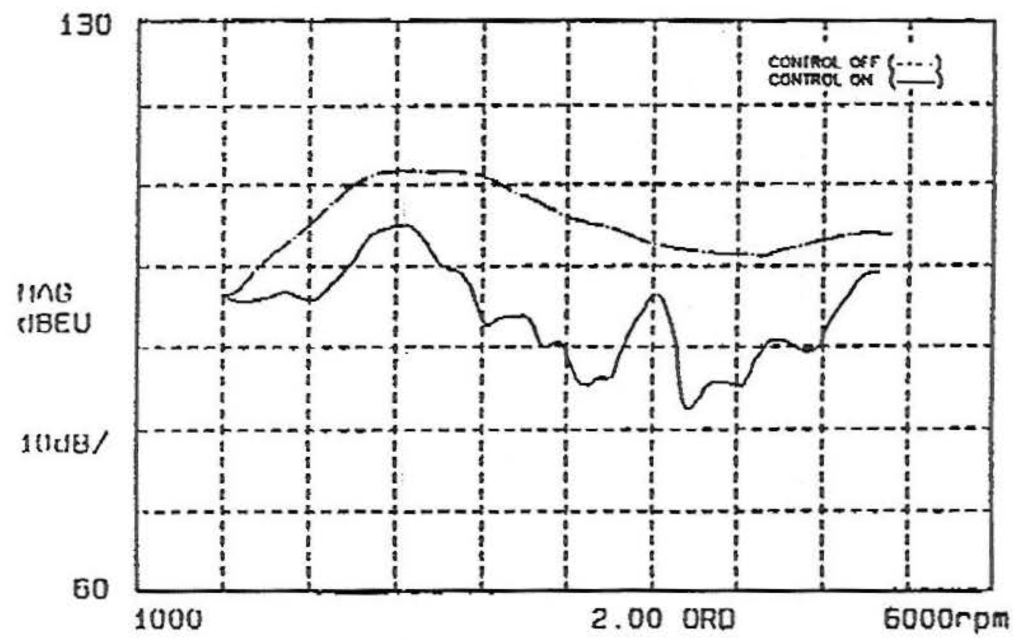

Fig. 6 Effects of active control during acceleration.