Active, Feedback-Controlled Noise Abatement in Air Induction Systems

of Automobile Engines

Reactive absorbers, such as Helmholtz resonators (HR) or quarter-wave tubes, are commonly used as the most effective solution for abating the low-frequency tonal noise in many applications including the quieting of air intake induction system noise in internal combustion engines. The problem with these low-frequency absorbers is their large size. In addition, reactive absorbers can only be tuned to a single frequency. When absorption at multiple frequencies is required, a number of these absorbers tuned to different frequencies should be used. Accommodating a large number of these resonators under the hood (modern vehicles use upward of 5 resonators) is a packaging challenge, not to mention expensive. Active noise control would enable automakers to eliminate the need for resonators. It allows one to deal with multiple frequencies using only a single control system.

Active noise control systems normally consist of a microphone, another sensor to identify the targeted frequencies (e.g., the engine rpm sensor), an electronic controller, and a speaker mounted at a vehicle's air induction system. The signals measured by the microphone and the 2nd sensor are processed by the controller (algorithm) creating the control signal which will drive the speaker. The active system is small and does not cause under-the-hood packaging problems. Most active control systems use feedforward, Least Mean Square (LMS) based adaptive algorithms as their controllers. These complex algorithms need fast, powerful digital signal processors to run. To ensure the convergence of the algorithm, the rate of adaptation should be made slow. This might create the loss of effectiveness of the controller during the transients, e.g., a fast run up of the engine. Although these adaptive feedforward algorithms have been around for more than 35 years, but their complexity and cost have prevented them from finding wide-spread acceptance by auto industry.

DEICON's cost-effective, feedback-based active acoustic filter can be configured as a tuned acoustic absorber, to abate the low frequency induction noise. The feedback controller is either programmed in a low-cost, high-speed micro-controller or realized by a *low-cost, adaptable, op-amp circui*t. Tuning the controller *to a single or multiple frequencies* abates the sound at that (those) frequencies.

> Air induction system noise in internal combustion engines is mostly tonal and most objectionable at low frequencies. It is the loudest under wide open throttle, hard acceleration conditions.
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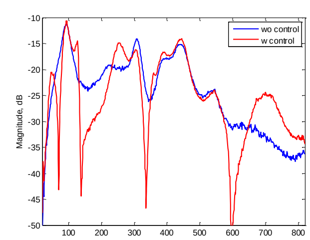
> The main source of this noise is the surge in pressure from opening and closing of intake valves as well as the air flow turbulence in the air intake manifold and around the valves, constructively adding up and generating low frequency pure tones predominantly at the firing frequency of the engine, resulting in a tonal sound radiated out of the air intake manifold inlet.

A microphone, nearly collocated with the actuator (loudspeaker), is used for sensing. *Adaptation* can be done by automatic retuning of the controller to the firing frequency of the engine.

In a laboratory set up, using the induction system of a 4 cylinder engine, the effectiveness of the active feedback controlled noise abatement system is evaluated. The set-up shown in Figure 1(a) has a loudspeaker (noise speaker resembling the engine cylinder) at one end that perturbs the induction system. A second loudspeaker installed on the system acts as the control actuator. A small microphone provides the feedback sensory information.

Figure 1(b) shows the frequency response functions mapping the voltage driving the noise speaker to the pressure measured at the inlet to the induction system, with (red line) and without (blue line) control. The active control system, which is designed to absorb tones at 4 frequencies is performing effectively. Clear from Figure 1(b), the radiation of these tones to the surrounding through the air induction system inlet is hindered.



(a) (b)

Figure 1 Laboratory test set-up (a) and frequency response functions mapping voltage driving the noise speaker to the pressure at the air induction system inlet (b)

WWW.DEICON.COM INFO@DEICON.COM PH: +1 937 885 4134