CASE STUDY

Spain

Automotive

PULSE, Microphones

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Measurement of Net Sound Intensity in Flow Ducts

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This technical paper describes a procedure to estimate the flow noise generated by a rear muffler (exhaust) and the tailpipe for a plane wave motion frequency range. A comparison between it and the noise measurements carried out in a hemi-anechoic chamber is also made in order to separate the flow-noise contributions, associated with the internal generation by the muffler and tailpipe, and the generation of flow noise associated with the discharge process, i.e., the interaction between the emitted flow-noise and the outside atmosphere.

A 12-channel PULSE system with Front-end Type 3560 D was used for data acquisition and analysis together with Microphones Type 4935 and Type 4190

Introduction

Today, the study of flow-noise generation in the exhaust process is an important subject of research due to the necessity of complying with ever more restrictive automotive noise legislation. It is also interesting to know the flow-noise generation for the different elements of the exhaust system. Particularly, the flow-noise generation at the rear muffler and the tailpipe is the most important contribution to the noise emitted by the exhaust and therefore the flow noise generated in other elements of the exhaust system could be attenuated by the exhaust line. However, traditional flow-noise measurements performed in a free-field do not give enough information about the flow-noise generation for the system, as they include the contribution of the flow noise generated by the element and the flow noise generated by the discharge process.

For this reason, this paper proposes an experimental technique (an acoustic intensity measurement inside the pipe) to estimate the flow noise generated only for the exhaust element analysed.

Description of the Methodology

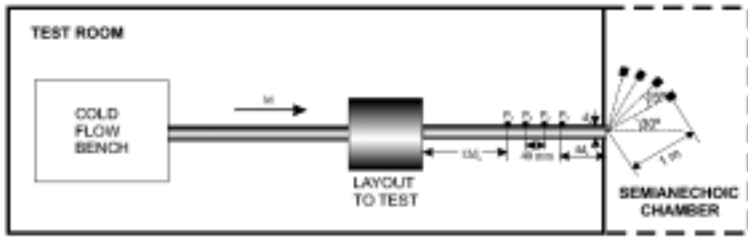

Fig. 1
Experimental settings

As shown in Fig. 1, the test system comprised a reverse expansion chamber connected to inlet and outlet pipes. The flow is provided by a cold flow bench which is supplied by a Roots compressor.

Fig. 2
Left: A Roots compressor is used as a flow generator
Right: Microphones Type 4190 measure the radiated acoustic pressure

The technique proposed to estimate the net acoustic power transmitted along the outlet pipe is based on in-duct pressure measurements using four prepolarized Brüel & Kjær Microphones Type 4935 flush-mounted in the wall.

These microphones are placed axially along the outlet pipe with the following considerations:

- the distance between the microphones is 40 mm as a compromise to low- and high-frequency errors associated with the Nyquist criterion
- the first microphone is placed at a distance of 12 diameters away from the inlet of the outlet pipe to ensure that the flow is fully turbulent at this point
- the fourth microphone is situated at a distance of four diameters from the exit of the outlet pipe in order to guarantee that the pressure measurements in the pipe are not affected by the discharge process

The pressure-time histories of the microphones were recorded for two seconds using a Brüel & Kjær PULSE™ data acquisition system. This gives excellent frequency resolution and reliable signal. Simultaneously, the radiated acoustic pressure is measured using Brüel & Kjær free-field 1/2-inch Microphones Type 4190 placed in the semi-anechoic chamber at a distance of one metre from the exhaust mouth, and for different angular positions with the tailpipe axis (from 30° to 75°, in steps of 15°). This assures free-field conditions and allows comparison between the exhaust measurements and the estimation of the net sound intensity generated by the system.

The semi-anechoic chamber is placed beside the test room as shown in Fig.1. In this configuration, the exhaust mouth is set in the wall that separates both chambers, which ensures that the noise measured in the semi-anechoic chamber is not affected by any source of noise from the test chamber, except the exhaust noise.

The measurements are carried out for mass flow rates from 300 to 700 kg/h, and in steps of 50 kg/h. The net sound intensity transmitted along the pipe, *I,* is calculated from the forward and backward pressure wave components according to:

$$I = \frac{1}{2\rho_j c}[|\hat{p}^+|^2(1+M)^2 - |\hat{p}^-|^2(1-M)^2]$$

These wave components are determined using a beamforming decomposition technique for the pressure measurements carried out in the outlet pipe mentioned above.

Experimental Results

The net acoustic sound power transmitted (W_t) is obtained through the integration of the estimated sound intensity (I) in the outlet duct section. The radiated sound power, $W_{r,}$ is obtained in a similar way using the radiated acoustic pressure measured in the semi-anechoic chamber ($p(r)$) by integrating the radiated sound intensity, $I_r(r) = p^2/\rho_o a_o$ in a hemisphere of radius $r = 1$ m.

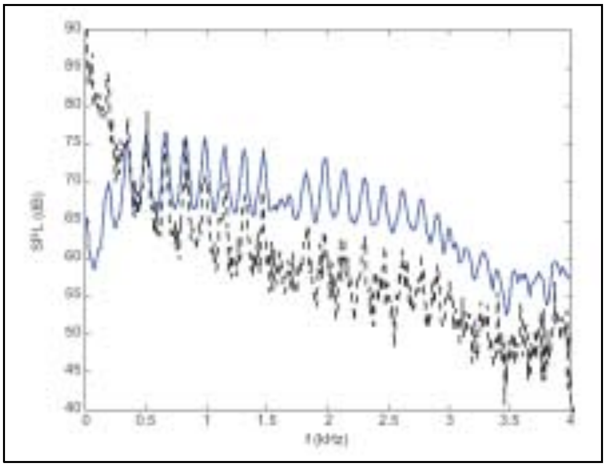

Fig. 3
Sound intensity spectra of estimated net intensity in outlet pipe (broken line) and measured radiated intensity (solid line), for a stationary flow with Mach number M = 0.16

The comparison between the sound intensity measured, I_r, and estimated I is shown in Fig.3. Note that the net intensity transmitted is corrected with the areas relation obtained from the acoustic power conservation. From this comparison, it can be concluded that:

1. Above 0.5 to 1 kHz there is a good agreement between measurements taken inside and outside the pipe. This confirms the quality of the estimation procedure
2. At low frequencies, the transmitted net intensity has a higher level than the radiated one. This is due to the fact that at this frequency range the flow energy is not radiated acoustically from the end of the pipe, but instead it is absorbed due to the interactions with the flow field.
3. The difference observed at high frequencies are associated with the discharge process because these effects are associated with an unstable layer at the outlet end. The contribution of secondary sources is important at high frequencies.

Hardware and Software

A 12-channel PULSE system with Front-end Type 3560 D was used for data acquisition and analysis together with Microphones Type 4935 and Type 4190. The microphones were calibrated using Sound Level Calibrator Type 4231 for sound pressure measurements are made, and Sound Intensity Calibrator Type 3541 for sound intensity measurments. The software used included:

- ❍ Noise and Vibration Analysis Type 7700
- ❍ Time Capture Type 7750
- ❍ PULSE Bridge to MATLAB Type 7755 B

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