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Correlation of Noise and Blade Surface Pressure in Automotive Engine-Cooling Fan

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Abstract

Automotive engine cooling fan is one of the major noise sources of automotive components, the most annoying feature of the noise being the discrete frequency noise at blade passing frequencies. These tonal components are generated by blade interactions with inflow and physical configurations such as shroud and heat exchanger. Measurements of surface pressure on the rotating blade are conducted and the results are correlated with the far field sound pressure. The result confirms a strong correlation between the surface and sound pressure at blade passing frequencies. Power spectral density of the surface pressure reveals the existence of a broad hump, which is associated with broadband noise. Finally, the surface pressure data is used as input for a time domain acoustic analogy computer code called RMN-SPA and the resulting noise prediction shows very realistic agreement with the measured spectrum.

1. Introduction

According to Lighthill's acoustic analogy, fan noise sources could be divided into three main types; monopole, dipole and quadrupole. It is well known that the dominant source of noise for low-speed fans found on automotive is dipole in nature. This dipole noise is due to the unsteady loading and the unsteady flow on the blade. It is thus important to gain knowledge of the time signal of the blade surface pressure fluctuation. A surface pressure fluctuation data gathered from experimental methods could reflect all kinds of flow phenomena such as inflow turbulence, tip vortex, vortex shedding and wake. Therefore, experimental data contain broadband fan noise components as well as discrete components. Spectral method was used to prove the fact.

2. Experimental Setup

An automotive cooling fan with a diameter of 320mm is set on the specially designed test stand as shown in fig. 1. The fan is surrounded by the shroud to guide the airflow from the upstream heat exchanger. The fan having 5 evenly spaced blades is powered by the electric motor. The test stand has a slip ring in order to handle rotating sensor wires. Pressure sensor wires rotating with the blades are connected to shielded leads from the slip ring rotor. And the wires from the signal conditioner are connected to the terminals on the slip ring stator. Four-arm wheatstone bridge type high frequency low-pressure transducers are used in this test. The size of the sensor should be small enough to be embedded on the 2 to 3 mm thick blade. Fig. 2 shows the sensor positions. The radial location of the sensor S1 is 88% (r/R=0.88) of the fan radius, while other sensors are placed at 99% (r/R=0.99) of the fan radius. Chord-wise locations are 0.3, 0.3, 0.45 and 0.6 with respect to the sectional chord length for S1, S2, S3 and S4, respectively. Only S3 is on pressure side with the others on the suction side.

3. Results and Discussion

Power spectral density <Spp> of the surface pressure signal shows peaks at shaft passing frequency (SPF) and harmonics (Fig.3). This means that energy is concentrated at SPF. These periodic pressure loadings are correlated to the discrete parts of the noise components. It is interesting that the 4^{th} SPF spectrum is higher than others, due to the interaction between the rotating blade and the rectangular shaped shroud. There's a broad hump between 8^{th} and 9^{th} SPF. These non-tonal spectra are caused by the tip vortex at the tip area and are expensed as the broadband noise at the same frequency.

Fig.4 shows the cross-spectral density between the surface pressure and the sound pressure. The microphone location for the sound pressure measurements is at 1 m upstream from the fan center. The surface pressure correlates well with the sound pressure at blade passing frequency and its harmonics as well as at the broadband hump frequency.

Another intension of this study is to combine measured surface pressure signal with a time domain acoustic analogy code called RMN-SPA. [1] For this application, the test data should be gathered with special concerns for the resolution and phase angles. With a sampling rate of 22800 data/sec at 1900rpm, the spatial resolution of the data acquired is 0.5 deg. Synchronized signals from fiber optic speed sensor is needed in order to calculate the phase difference and the retarded time. Another advantage of using the measured surface pressure data as input is that many revolutions data can be used. Fig. 5 compares the RMN-SPA predicted result (using surface pressure data averaged over 500 revolutions) and noise spectrum data measured in an anechoic room. The experimental spectrum is obtained through B&K 4550 spectral analyzer. Comparison of the results shows good agreement.

Conclusions

Surface pressure measurements on the rotating blades are conducted. Surface pressure data such as power spectral density and cross-spectral density correlate well with the far field sound pressure data. It is discovered that the tip region of the blade generates broadband noise (hump between 1^{st} and 2^{nd} BPF). The surface pressure fluctuation data was used as an input data for the acoustic analogy code. The predicted results show good agreements with a measured noise spectrum.

References

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2. F.Kameier, W.Neise, “Experimental study of tip clearance losses and noise in axial turbo machines and their reduction”, Transactions of the ASME, Vol.119, 1997.

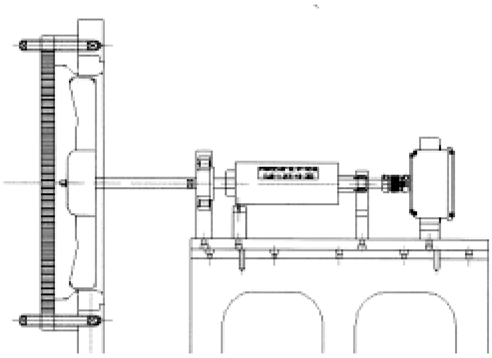

Fig. 1. Test stand for rotating blade surface pressure measurements

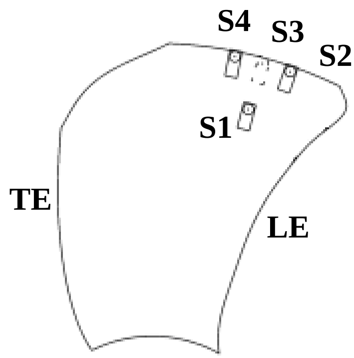

Fig. 2. Flush mounted surface pressure transducer locations on the blade

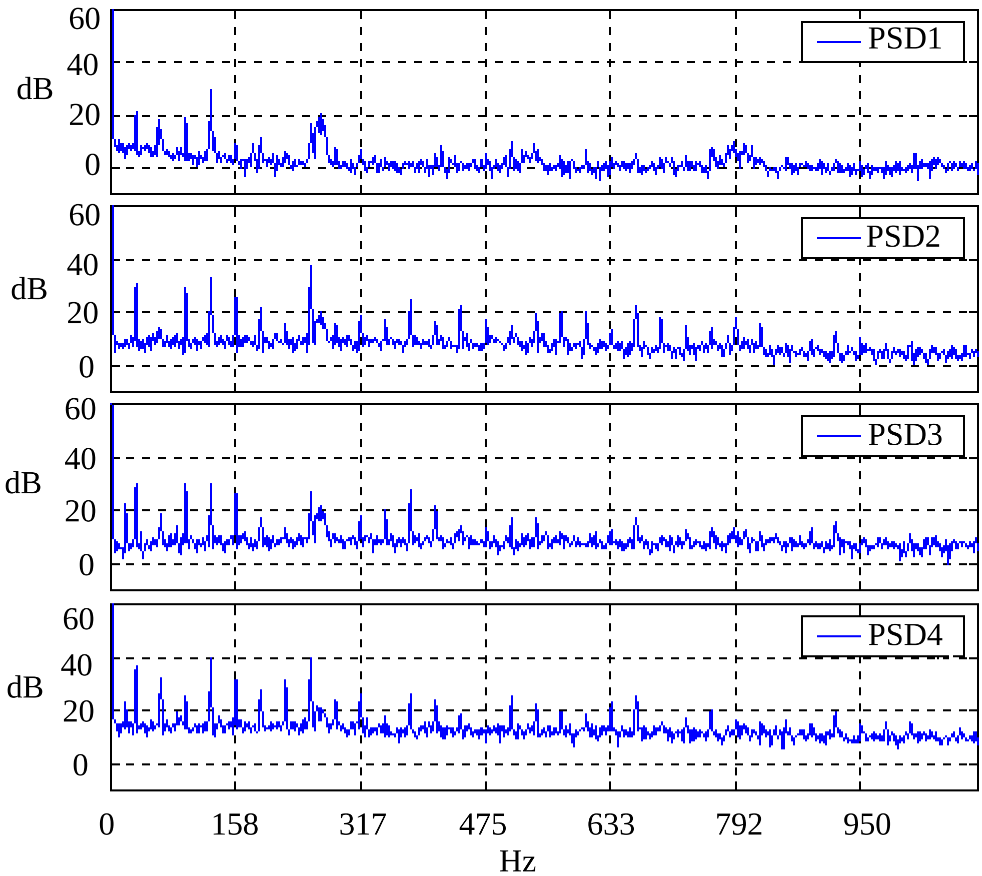

Fig. 3. Power spectral density < Spp> of the surface pressure signal at 1900 rpm

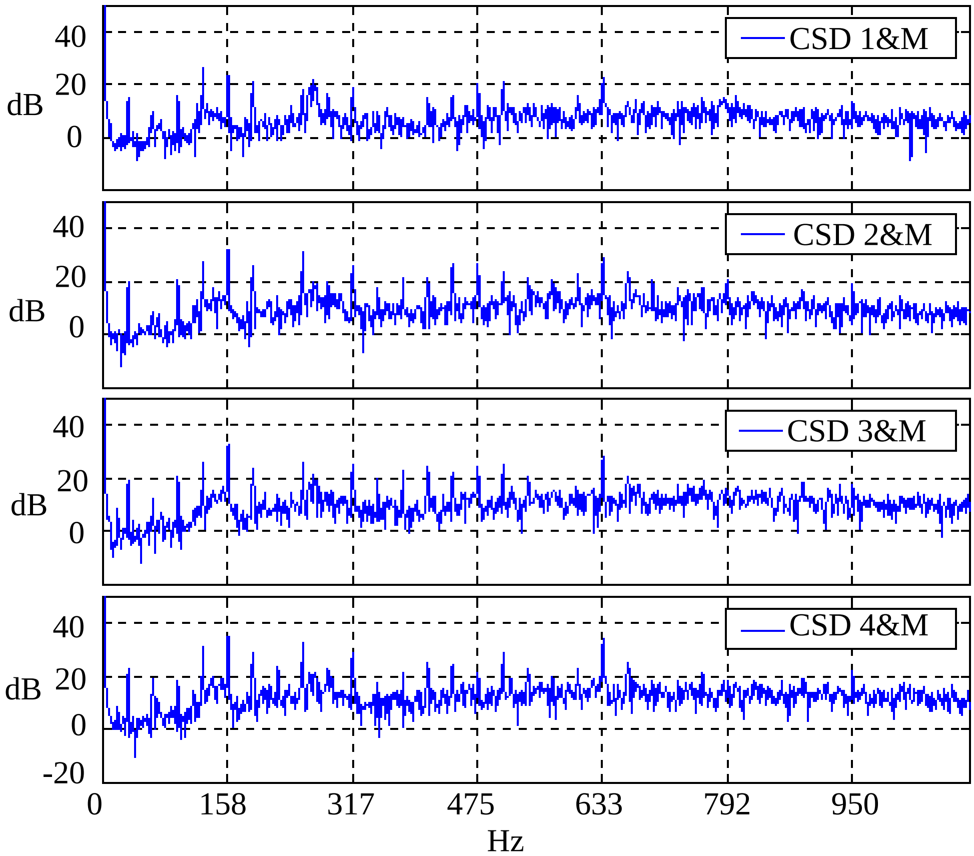

Fig. 4. Cross-spectral density of surface pressure signal and far-field sound pressure signal at 1900 rpm

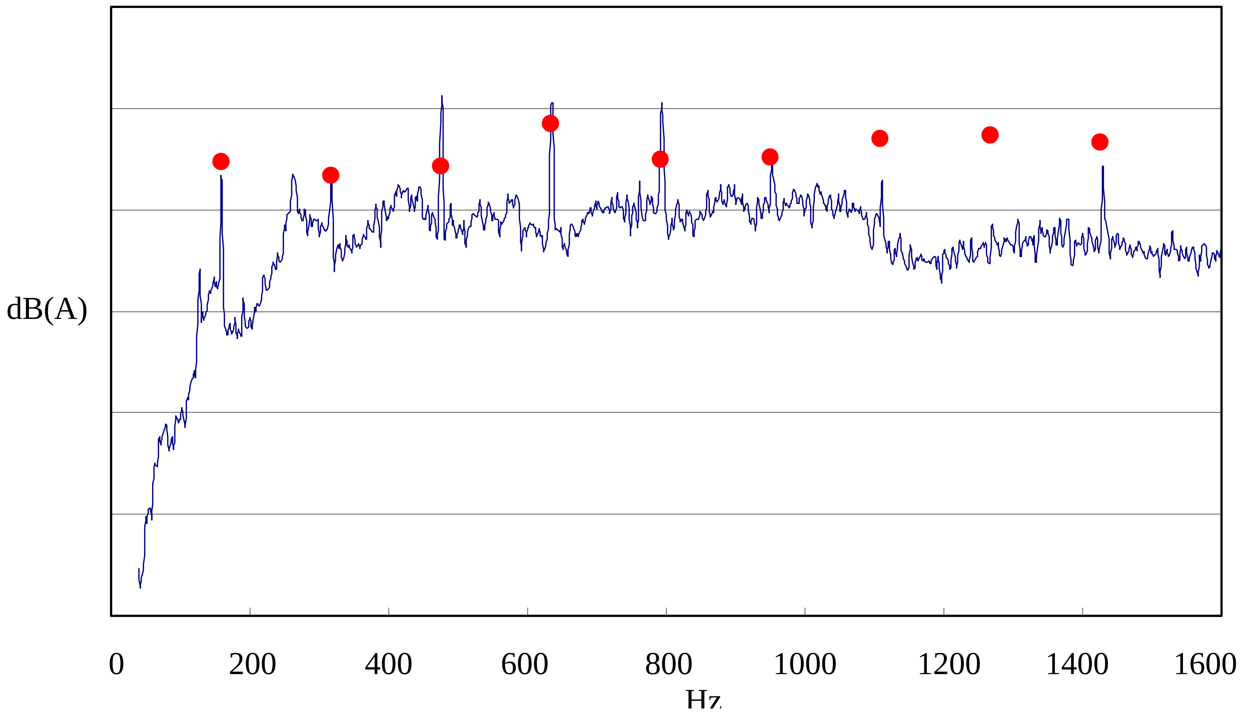

Fig. 5. Comparison of measured and RMN-SPA predicted noise spectra, at 1 m upstream from the fan centerline (Circle; RMN-SPA , Line; Measurement)