

A Case Study on Clean Side Duct Radiated Shell Noise Prediction

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ABSTRACT

Engine air induction shell noise is a structure borne noise that radiates from the surface of the air induction system. The noise is driven by pulsating engine induction air and is perceived as annoying by vehicle passengers. The problem is aggravated by the vehicle design demands for low weight components packaged in an increasingly tight under hood environment. Shell noise problems are often not discovered until production intent parts are available and tested on the vehicle. Part changes are often necessary which threatens program timing. Shell noise should be analyzed in the air induction system design phase and a good shell noise analytical process and targets must be defined.

Several air induction clean side ducts are selected for this study. The ducts shell noise is assessed in terms of material strength and structural stiffness. A measurement process is developed to evaluate shell noise of the air induction components. Noise levels are measured inside of the clean side ducts. The surface vibrations of the duct are measured using accelerometer and laser vibrometer. Measured noise levels drive a speaker and sound intensity measurements are made on a test bench to compute the surface radiated sound power. A simulation process is developed to predict the radiated sound power for the same air induction components. Internal acoustical pressure of the component is used to drive a frequency response finite element model. Then, two methods are utilized to predict the radiated sound power. One method is using Rayleigh Integral method to estimate radiated sound power directly from surface velocity calculation. The other method is using Boundary Element Method (BEM) to apply calculated surface velocities to a boundary element model and radiated sound power is predicted.

Results of the bench study are compared with the prediction data from the developed simulation process. Results of the correlation conclude that the simulation process is good for predicting radiated sound power of engine air induction components. The BEM method has better correlation than Rayleigh method.

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INTRODUCTION

The primary function of an Air Induction System (AIS) is to deliver fresh clean unrestricted air to the engine. Most contemporary cars have low hood lines that force air cleaners to be located remotely from the engine. In order to supply fresh air to the engine, air induction inlets are typically located in front of the engine and air ducts are needed. The induction air is a medium for plane wave sound propagation from the engine to the inlet. Air borne induction noise radiating from the inlet can be quite high during wide open throttle accelerations which is often the most significant noise that the driver hears [1, 2]. The noise that is radiated from the surfaces of these air induction components however can become noise sources as well [3, 4, 5]. Noise that radiates from the structure of the air induction system is called structure borne noise or shell noise which can be

evaluated at the driver's ear location. For example, the 2nd order driver's ear noise (DRE noise) of a vehicle with two different AIS for a I4 engine is shown in Figure 1. The only difference between the two AIS is the clean side duct (CSD). The two clean side ducts have the same length and route but with different material and shape. The noise levels inside the CSD's are not more than 4 dB apart. However, driver's ear noise varies significantly for frequencies below 150Hz. Noise levels for the circular shape duct with low modulus elasticity (CSD Design 1) are at the background noise level (~60 dBA). Noise for the polypropylene non-circular shape duct with higher modulus elasticity (CSD Design 2) is more than 10dB higher than the background level at the driver's ear for the frequency range between 120Hz and 150Hz. The main noise contribution for this higher noise is from the CSD radiated shell noise.

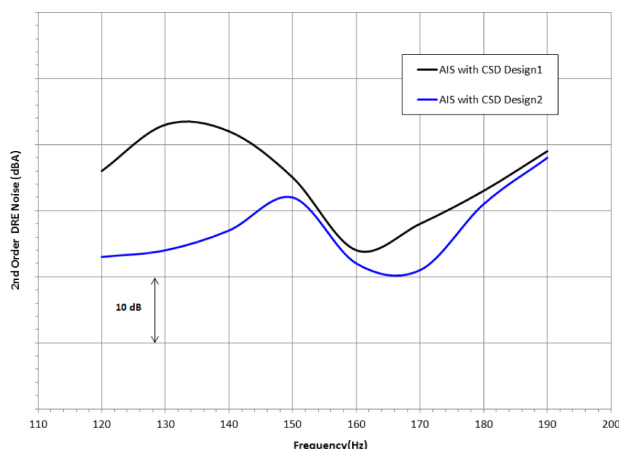


Figure 1. 2nd Order DRE Noise

The following factors need to be incorporated in order to evaluate the shell noise at the driver's ear location. First of all the vehicle has a significant impact on evaluating shell noise. The evaluation vehicle should be production intent since it will attenuate shell noise between the source and the driver's ear. Second, shell noise is also a function of the structural response of the air induction system under load. Therefore production intent air induction parts are required as well as production intent engine. Typically problems caused by shell noise are quantified in the automotive industry by using air induction structural targets, for example, the surface inertance etc. Most targets however are independent of applied acoustic load and are a result of best practices. It is assumed that these targets are applied to air induction hot spots or locations of maximum surface vibration velocity. Hot spots are a function of both acoustic load and air induction structural response. Locations of these hot spots are generally determined by experience and again best practices.

In this paper, a case study is performed to evaluate the effect of the structural rigidity of an air induction CSD on its radiated sound power under an acoustic load. The function of the CSD is to transport engine induction air from the air cleaner to the throttle body. Structural rigidity will vary with CSD material properties and CSD shape. In the first part of the study, a measurement process is developed to quantify CSD shell noise. Noise levels are measured inside of the clean side duct when the whole AIS is connected to the engine. Then, the surface vibrations of the duct are measured using accelerometers and laser vibrometer. Finally, the measured noise levels drive a speaker and sound intensity measurements are made on a test bench. A simulation method has been used to predict the air induction shell noise in the design phase [6, 7, 8]. In the second part of the study, simulation processes are developed to analysis the surface's radiated sound power. Two simulation methods which are the Rayleigh-Integral Method and the Boundary Element Method (BEM) are studied. Both methods require surface velocities calculated from FEM frequency response analysis. The correlation is also performed between simulation and test in this part.

MEASUREMENT PROCESS

Three air induction clean side ducts which are shown in Figure 2 are selected for this study. The first duct is made of a low modulus polypropylene material and the second duct is made of a high modulus glass filled Nylon material. Both ducts have the same production shape which has several flat surfaces. The Nylon duct also includes a Helmholtz resonator which affects the internal acoustic pressure of the duct. The third duct is made of a very low modulus of elasticity thermoplastic elastomer material however it has high rigidity due to its circular shape. The shell noise is evaluated in three steps. The internal acoustical pressure inside the duct is measured first, then the surface vibration of the duct is measured. Finally the sound radiated power is measured using a test bench.



Figure 2. Three Test Clean Side Ducts

1. Internal Acoustical Pressure Measurement

Engine induction air is composed of high magnitude acoustic waves. The waves are created by the periodic flow of air through the intake valves for engine combustion propagates to the AIS inlet. Generally speaking, intake volumetric flow speed increase with engine speed and cylinder size which increases the sound pressure level in the AIS. The cyclic nature of induction air flow is described with a Fourier series and components of the series are called "engine firing order." Most of the shell noise of interest is in the 2nd engine firing order of a four cylinder engine which will be the primary focus of this study. The test setup is shown in Figure 3. A pressure transducer was placed inside of the AIS clean air duct at a location close to the throttle body to measure the duct internal acoustic pressure which is indicated as "Mic 1" in Figure 3.

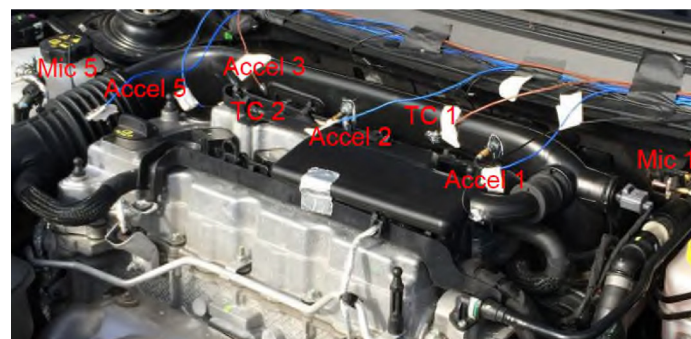


Figure 3. Test Setup with Pressure Transducers and Accelerometers