

Reducing Radiated Structural Noise from AIS Surfaces using Several FEM Optimization Methods

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ABSTRACT

Two finite element optimization techniques are presented for minimizing automotive engine air induction structural radiated noise and mass. Air induction systems are generally made of thin wall plastic which is exposed to high levels of pulsating engine noise. Weak air induction system walls vibrate excessively creating noise that can be heard by the driver. The conventional approach is to add ribs (many times through trial and error) which increase part weight or by adding “kiss-offs,” which restrict air flow.

The finite element optimization methods considered here are shape optimization and topometry optimization. Genesis, a fully integrated finite element analysis and optimization package by Vanderplaats Research & Development, was used to perform finite element optimization. Choice of optimization method is primarily dependent on several factors which are appearance, part interference and flow restriction requirements. “GT Power” was used to model the complete engine air flow system and calculate local acoustic pressure levels for modal frequency response analysis. Node velocity results of the structural analysis were applied to an external BEM acoustic model. “LMS Virtual Lab” was used to calculate the surface radiated sound power.

A shape optimized duct radiated significantly less noise but assembly interference requirements were increased for the duct which led to the use of topometry or part thickness optimization. Finite element structural optimization is shown here to be an effective design tool for minimizing radiated air induction shell noise. Shell noise is also shown to be significantly reduced by reducing the forcing acoustic pressure.

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INTRODUCTION

Air Induction noise is low frequency engine noise created by pulsing engine air flow that is burned for combustion. Engine cylinder combustion is a cyclic event that occurs in each cylinder during two revolutions of the crank shaft. The cyclic signature of engine air flow increases with increasing engine speed, which increases acoustic amplitudes. The driver is exposed to induction noise during accelerations, where increased engine air flow is needed for engine torque requirements. Air induction and exhaust are typically the dominant noises heard by a driver during acceleration, and are critical to the perceived quality of any vehicle. Smaller engines used to achieve better fuel economy typically generate higher levels of low frequency air induction noise.

Induction noise radiates to the driver's ear in the form of airborne and structure born noise. Airborne noise radiates from the air induction system inlet, or snorkel. Airborne Noise levels are controlled by adding Helmholtz resonators, quarter wave tubes, and/or expansion chambers to the air

induction system. However, these airborne noise attenuation devices by themselves cannot achieve demanding NVH targets if the air induction system radiates structure born noise. Structure borne noise is radiated from the surface of the air induction system and may exceed inlet noise levels at the driver's ear. Structure born noise observed experimentally often occurs late in air induction development programs when experimental or prototype parts are available. Discovery of air induction system structure born noise problems frequently delays programs and add significant development cost. It is therefore important that shell noise analysis be performed in the design phase of air induction systems.

Background

Air induction shell noise is created by acoustic waves radiating from a surface under forced vibration. Acoustic pressure excites flat panel surfaces causing the surface to bend at the frequency of the driving force. Maximum surface velocity usually occurs in the first mode or “breathing mode”



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of forced surface vibration. Acoustic waves are radiated from the surface similar to a monopole sound source (Beranek [1]). Higher panel vibration modes contain less acoustic energy and radiate significantly less noise. Several shell noise design tools were presented by White [2] in the 1990's. Plate and shell theory was used to model air cleaner flat surfaces excited by an arbitrary internal acoustic pressure. Although the acoustic loading pressure was arbitrary, vibration results closely matched experimental data. Plate and shell theory is easy and quick to use but is inadequate for modeling many complex air induction surfaces. Finite element shape optimization theory has been used by White [3] to optimize air cleaner rib design. Ribs were modeled with plate elements and the size of the ribs was optimized to reduce surface velocity. The impact of rib optimization on air cleaner shell noise was limited however due to the limited influence that rib design has on air cleaner surface stiffness. Most of the shell noise reduction by rib optimization is simply due to optimization of rib mass. Rib structural properties add little stiffness to air cleaner surfaces. Significant improvements in shell noise radiation was achieved however when the air cleaner surface was optimized. This observation leads to an important point: care must be taken to choose design variables that can significantly impact shell noise. The effectiveness of the optimization is dependent on the influence that design variables have on surface stiffness. The topic of practical applications of optimization theory for air induction systems was also discussed by White [4].

In the decade following the 1990's large advancements were made in computer aided engineering which had a significant impact on predicting and controlling air induction shell noise. The acoustic driver of shell noise is the instantaneous acoustic air induction pressure. Modern engines are designed with engine internal flow analysis programs such as GT Power that have the capacity of predicting acoustic pressure anywhere in the air induction system. Air induction systems are developed with engine models which makes air induction acoustic load information readily available. Optimization tools have also been significantly improved. FEM programs such as Genesis can easily handle large amounts of design variables to optimize surface stiffness. Air induction external surfaces with internal ribbing can be optimized for shape and thickness. The prediction of radiated sound power is also straight forward and fast. Acoustic programs such as LMS Virtual Lab can easily map structural responses from finite element frequency response analysis to a boundary element mesh for sound power analysis. These advancements have made it possible to include shell noise optimization in the design process of air induction systems. A structural optimized air induction system will save weight, support airborne acoustic performance and avoid design changes.

Acoustic Source Characterization

Shell noise is a function of the acoustic air induction forcing pressure. The air induction acoustic pressure is

dependent on the engine design, engine speed, air induction design and location in the air induction system. There are two ways to obtain the air induction pressure which are experimentally and analytically. The most accurate method of obtaining this pressure is experimentally with an internal microphone. The disadvantage to this approach is that it typically cannot be done in the air induction design phase since experimental parts are not available. Acoustic pressure could be measured within a part suspected of having shell noise, but a "fix" would require a design change and possible program delay. It would be better to obtain the forced acoustic pressure in the development stage of the air induction system. The acoustic pressures are usually available from the engine development air flow model (GT Power).

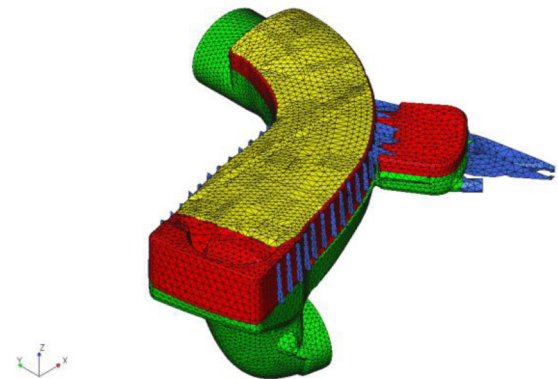


Figure 1. Flat Top Air Induction Duct

An air induction duct was being considered for production that had a flat surface (see [figure 1](#)). Since flat air induction surfaces frequently radiate noise, a study was performed to predict the radiated shell noise. Experimental parts were not available so GT Power [5] was used to predict internal acoustic forcing pressures (see [figure 2](#)). Air induction noise is typically analyzed in terms of engine firing orders or air induction noise harmonics, through a range of engine speeds. The overall noise is the sum of the harmonic noise levels at each engine speed. Air Induction noise analysis typically contains the noise levels of at least three dominant noise orders as well as the overall noise level. Structure born noise predictions are derived from a modal frequency response analysis. Modeling of each noise order requires using separate load-cases. Optimization variables would be required for each load case which makes global optimization more complex. Shell noise analysis is simplified here by creating a single load case that represents maximum exposed acoustic as a function of frequency. This is done by plotting harmonic noise levels as a function of frequency, then placing an envelope over maximum pressure values (see [figure 3](#)). It is important that air induction system standing wave maximum pressure amplitudes are captured, since they have a significant impact on shell noise. These forcing pressures are applied directly to a structural frequency response finite