

Optimization of a Porous Ducted Air Induction System Using Taguchi's Parameter Design Method

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ABSTRACT

Taguchi method is a technology to prevent quality problems at early stages of product development and product design. Parameter design method is an important part in Taguchi method which selects the best control factor level combination for the optimization of the robustness of product function against noise factors. The air induction system (AIS) provides clean air to the engine for combustion. The noise radiated from the inlet of the AIS can be of significant importance in reducing vehicle interior noise and tuning the interior sound quality. The porous duct has been introduced into the AIS to reduce the snorkel noise. It helps with both the system layout and isolation by reducing transmitted vibration. A CAE simulation procedure has been developed and validated to predict the snorkel noise of the porous ducted AIS. In this paper, Taguchi's parameter design method was utilized to optimize a porous duct design in an AIS to achieve the best snorkel noise performance. The virtual experiments based on an orthogonal array in the parameter design method were conducted by the developed simulation procedure and the optimized design was recommended. Furthermore, the parts based on the optimized design are manufactured and tested to verify if the intended performance and other high priority requirements for the AIS are met. It was concluded that a traditional CAE analysis enhanced with robustness technique is an efficient tool to optimize the AIS design in this case study.

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INTRODUCTION

Vehicle NVH performance is an important measure of quality that relates to customer satisfaction with their vehicles. The vehicle interior noise is the net resultant of several structural and airborne noise sources, and of all the airborne sources, radiated noise from the snorkel of an air induction system ("Snorkel Noise" of AIS) can be of significant importance in defining the interior noise level and sound quality. For example, in Figure 1, the interior noise level at the driver's right ear ("DRE noise") of a mule vehicle was measured at two conditions: with and without snorkel noise source. It clearly indicated the major contribution of the snorkel noise to DRE noise.

A well-designed AIS not only delivers the right amount of cool combustion air to the engine with minimum flow restriction, but also, a low level and good quality radiated sound [1]. The design of the AIS is a challenging work since all these factors need to be addressed to meet the specified targets. More importantly, it must meet these targets in the presence of variability, such as, manufacturing variation, environmental conditions and vehicle transfer function differences, etc.

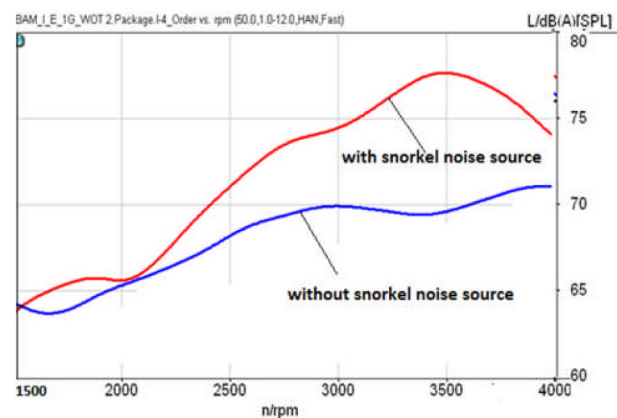


Figure 1. Measured DRE noise at two conditions

CAE analysis has been widely utilized to study the air induction noise [2, 3]. A practical CAE procedure was developed and validated in Chrysler for AIS snorkel noise prediction [4]. Taguchi Method is a robust design technology to forecast and prevent quality problems at the early stages of product development and product design [5, 6]. A traditional CAE analysis enhanced with the robustness technique can be a powerful tool to handle variability effectively in the early design stages of a new vehicle program. There are several robust design and optimization applications on Vehicle NVH

optimization [7, 8, 9, 10]. For example, a series of CAE and DFSS tools were used to improve the robustness of vehicle driveline NVH performance of RWD independent rear suspension vehicle [8].

In this paper, the authors applied Taguchi's parameter design method to optimize the snorkel noise of a porous ducted air induction system in a vehicle. First, the Taguchi's parameter design method was overviewed. Then, the simulation model which was used to perform the virtual experiment was described. Finally, a detail case study was presented following each step of the Taguchi's parameter design method and some conclusions were drawn based on the case study.

TAGUCHI'S PARAMETER DESIGN METHOD

The goal of Taguchi's robust design is to search for and obtain the state of maximum robustness in product or process design. Robustness is defined as the state of performance where the product or process is minimally sensitive to factors causing variability either in the manufacturing environment or user's environment at the lowest possible cost. The noise factors causing the product function variations are either uncontrollable or too expensive to control, such as, customer-usage condition, internal deterioration and piece-to-piece variability. Dr. Taguchi states that the most efficient measure of the robustness is the signal-to-noise ratio ("S/N ratio") which measures the quality of energy transformation that occurs within a design. Generally, the S/N ratio is expressed as:

$$\frac{S}{N} = \frac{\text{Work Done by Signal}}{\text{Work Done by Noises}} = \frac{\text{Efficiency}}{\text{Variability}} \quad (1)$$

There are several strategies and techniques can be used to increase the S/N ratio. Parameter Design method is recommended by Dr. Taguchi as an efficient and effective strategy for robust design. The main ideas associated with the Taguchi's parameter design method are [11]:

- Identifying the ideal function for a specific product or process based on its energy transformation,
- Using the noise factors systematically to induce variation in the output performance during optimization,
- Choosing the best nominal value of design parameters that optimize the performance even in the presence of noise factors at the lowest possible cost.

Typically, the parameter design includes the following eight steps: defining scope, identifying ideal function, developing signal and noise strategy, selecting control factors and levels, executing and collecting data, conducting data analysis, running the prediction / confirmation, and verifying.

DESCRIPTION OF THE SIMULATION MODEL

The GT-Power simulation tool contains comprehensive engine performance models built on one-dimensional computational fluid dynamics (CFD) code. The fluid dynamics in all engine ducts and air induction systems are approximated via finite volume solution, in which the whole system is divided into many small sub volumes. The flow from one sub-volume to another are calculated from the solution of the momentum equations solved on a staggered mesh. The GT-Model model can simulate engine breathing, combustion, emissions and thermal warm-up [12]. For AIS development, the noise radiated from the snorkel can be simultaneously predicted by GT-Power when evaluating the engine performance which makes it an ideal tool to quickly perform and compare many AIS design iterations [4]. A typical GT-Power model with engine, AIS and exhaust system is shown in Figure2.



Figure 2. A Typical GT-Power Model

The porous duct has been introduced into air induction system to reduce the snorkel noise. A case study is presented in [13] where a porous ducted air induction system was used to help achieve the interior NVH target for a new Chrysler vehicle. Good correlations were found between simulation results and test data. In this paper, the GT-Power simulation model will be used to perform the virtual experiment in the parameter design method to collect the snorkel noise data for a porous ducted AIS optimization.

APPLICATION OF PARAMETER DESIGN METHOD ON POROUS DUCT OPTIMIZATION

The eight steps of parameter design method were applied in this section to optimize a porous ducted AIS system. The objective of this case study was to optimize the porous section configuration in a dirty side duct system of the AIS.

1. Define Scope

Typically, an AIS system contains clean side duct, air box and dirty side duct. The scope of the project was defined as the dirty side duct with porous duct section since the clean side duct and air box configuration were not changed. The initial dirty side duct is shown in Figure 3.