

Analysis of Exhaust System Mounting Scheme

Vishwas Shantaram Waghmare, Vaibhav Salunkhe, Rakesh Nagrani, and Vishal Guttal
Automotive Engineering

Abstract

This paper presents a stepwise approach for exhaust system mount scheme finalization from concept to detail design phase. Finalization of exhaust hanger locations by finding Nodal points on exhaust system were considered. Various generic aspects like frequency separation, mode shapes, reaction forces, static displacement, and stress were considered. Apart from the generic aspects special aspects like peak loads and operating conditions were also considered. A combination of design of experiments (DoE) and optimization was used to finalize the mounting scheme and mounting characteristic parameters.

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INTRODUCTION

Vehicle NVH performance is an important aspect and having significant influence on overall image of a vehicle. Noise and vibration inside the passenger cabin degrade the driver's and passengers' comfort and induce stress, fatigue and feelings of insecurity. As a result the customer's needs for the quality vehicle is directly linked with the noise and vibration characteristics of the vehicle. Due to high market demand for lighter and powerful vehicles, it becomes evident that powertrain induced noise and vibration is a key component of the vehicle's interior noise [1].

Exhaust system is a vital subsystem of vehicle. It is connected with engine and vehicle body. This connectivity provides exhaust system a significance importance from NVH point of view. Due to this coupling the undesirable transfer of powertrain vibration and torque fluctuations takes place, from powertrain to passenger cabin. Therefore it is necessary to optimize exhaust mounting system in order to improve NVH performance of the passenger cabin. The exhaust hanger location and mount stiffness also influence the natural frequency of the exhaust system and hanger force transferred to the cabin [2].

In [3] simple numerical method is established for finding optimized hanger position and optimized bellows length using stiffness and position as a design variable. In [4] guideline for design & development of the exhaust system is presented along with various exhaust system attributes are described and general information about exhaust systems is provided. In [5] the importance of the systems approach from the concept design phase to the manufacture of the exhaust system to ensure minimum noise, back pressure and emissions with long term durability of total package is mentioned. In [6] optimized hanger positions are determined using DOE

optimization approach with objective of minimizing of transferred vibrations to driver cabin through the exhaust mounting. Hanger and flexible joint stiffness are used as a design variable. In [7] FE model of exhaust system along with powertrain is used for selection of hanger locations using average driving DOF displacement method (here onwards referred as ADDOFD). The influence of powertrain model on the vibration frequencies is shown. The relationship between the exhaust system model and the stiffness of the hanger is investigated. In [2] the built FEM model of the exhaust system is verified using experimental modal analysis and hanger locations are determined using ADDOFD method. The obtained locations are further checked against static consideration. In [9] the optimized hanger locations are obtained using ADDOFD method and influence of optimized hanger location on vibrations transferred from exhaust system to vehicle body is tested in vehicle vibration test. The results shows that the optimized hanger location can reduce vibrations transferred from exhaust system to vehicle body. In [10] finite element based simulation techniques for the evaluation of structural performance of an exhaust system are discussed. The different structural durability load cases and dynamic loads and their influence on the system behaviour are also discussed

In this paper the FEM model along with powertrain system is developed to find out optimized hanger locations using absolute cumulative displacement values derived from modal analysis. The DoE approach is used for optimizing hanger mount stiffness properties with the objective of minimizing transferred vibrations from exhaust system to passenger cabin. In optimization process the hanger mount stiffness is considered as a design variable. Various static and dynamic requirements are considered as a design constraint in the optimization process.

OPTIMAL HANGER LOCATION

Exhaust System FE Model

Optimizing hanger locations has capability of reducing vibrations transferred from exhaust mounting system to passenger cabin [9]. For finalizing optimized hanger locations exhaust system is built. Finite element model is as shown in [Figure 1](#).

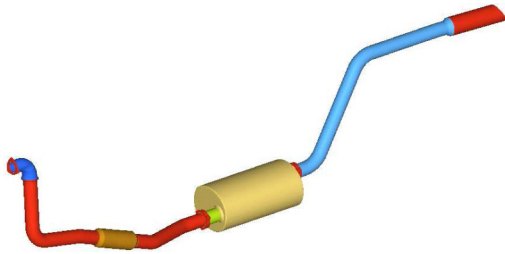


Figure 1. Finite element model of exhaust system.

Flexible Joint Position Sensitivity

Position of flexible joint has a major influence on the hanger location because of its influence on the natural frequency of the exhaust system. The standard practice to position exhaust flexible joint is below the engine roll centre or as close as possible to engine roll centre. Such positioning of flexible joint help to reduce vertical movement of the exhaust line caused by engine roll direction movement [6,8]. Few iterations are carried out to check the influence of position of flexible joint on natural frequency of exhaust system. The position iteration details are as shown in [Figure 2](#).

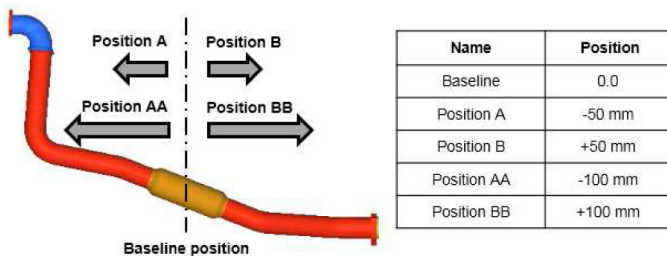


Figure 2. Consideration of exhaust flexible joint positions in exhaust system.

The comparison of exhaust system natural frequencies for different flexible joint positions is shown in [Table 1](#).

Table 1. Comparison of Eigen frequencies for different positions of flexible joint.

Baseline	Position A	Position AA	Position B	Position BB
Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)
36.0	35.0	34.1	36.9	37.8
38.1	37.5	37.0	38.6	39.3
78.7	77.9	77.1	79.4	80.0
128.4	125.8	122.3	130.3	131.8
164.1	151.9	141.7	170.3	154.6
175.7	162.2	152.0	178.3	193.4

The frequency comparison confirms the influence of flexible joint position on the exhaust system natural frequency. When flexible joint is positioned near to engine roll center system became more flexible and when it moved away from engine roll center, system became stiff. This change in frequencies and flexible joint position has further influence on the exhaust hanger mounting locations. Therefore one must finalized the flexible joint position before deciding the hanger mounting locations.

Optimized Hanger Location Layout

Nodal points are the locations on exhaust line which are showing less movement in a desired frequency band. These locations are the optimized positions for exhaust mounting system. By placing exhaust mounting system at these nodal points, the transferred vibrations from exhaust system to passenger cabin are expected to remain minimum. [6,8].

For finding nodal points on exhaust line modal analysis is carried out. With help of successive addition of normalized displacement [10] for a frequencies at each grid point, nodal points are determined on the exhaust line. The absolute cumulative displacement can be expressed as

$$f(\xi_i) = \sum_{\omega=1}^n \left(\frac{\varphi_i}{\varphi_{\max(i,k)}} \right) + \sum_{\omega=1}^n \left(\frac{\phi_i}{\phi_{\max(i,k)}} \right) + \sum_{\omega=1}^n \left(\frac{\psi_i}{\psi_{\max(i,k)}} \right) \quad (1)$$

Where φ_i , ϕ_i and ψ_i are the absolute displacement in 3 directions at location i on exhaust line at frequency ω .

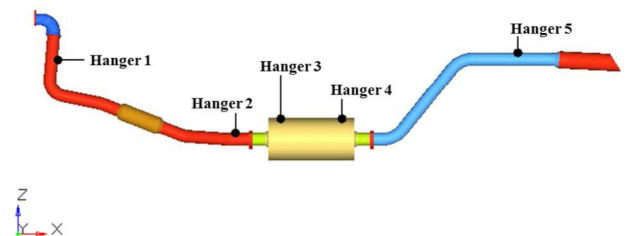
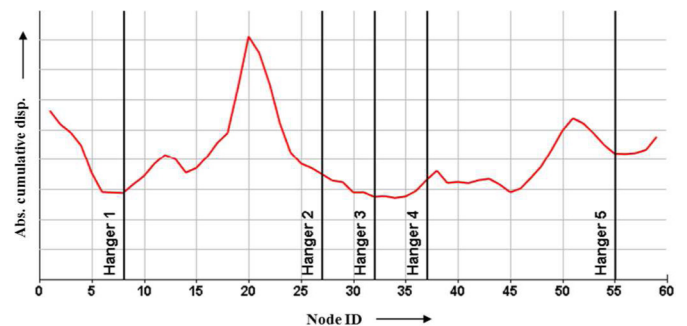


Figure 3. Result of cumulative displacement and optimized hanger mounting system locations at nodal points on exhaust line.

The locations are finalized at the determined nodal points at each zone of exhaust line and based on packaging constraints. The absolute cumulative displacement result and optimized hanger location layout is shown in [Figure 3](#).

The nodal points on exhaust line can be validated from the mode shapes of exhaust system. Natural modes of exhaust system are shown in [Figure 4](#).

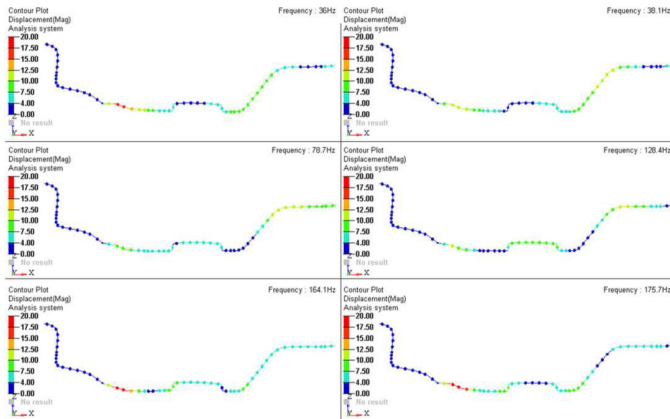


Figure 4. Normal modes of exhaust system.

The exhaust mounting systems are placed at derived optimized locations on exhaust line.

OPTIMIZATION OF HANGER MOUNT STIFFNESS

Hanger mount stiffness influence the NVH behavior of the passenger cabin, since it affects transferred vibrations from exhaust system to passenger cabin [8]. Optimizing the mount characteristic help to improve NVH behavior of the passenger cabin. The hanger mount stiffness optimizations is carried out using DoE approach. The hanger rubber mount requirements for optimization are listed below.

Dynamic Consideration

Dynamic Analysis

The dynamic consideration for selection of optimized mounting system is the minimal transferred forces from exhaust mounting system to the passenger cabin. The transferred hanger forces must be as low as possible to reduce the transferred vibrations. For 100000 N-mm excitation at powertrain centre of gravity about X axis, the hanger force must be less than 10N [2,5,7,9].

Modal Analysis

The second dynamic consideration is the natural frequencies of the exhaust system must avoid the engine excitation frequency and body frequency [2,7]. Also the exhaust system 1st Bending mode must be less than engine idle frequency [9].

Static Consideration

Static Analysis

Durability requirement is the maximum displacement of rubber hanger must be less than 3.0 mm under 1g gravity loading. This is because of the displacement limits of hanger rubber mount [2].

The other consideration is the strength requirements. The stress generated in exhaust system under 4g acceleration loading must be less than the yield stress of the material mount [2].

The flexible joint requirement is the maximum displacement of the end of flex bellow must be less than the allowable displacement limit in Y and Z direction.

FE Model with Powertrain

For the static and dynamic considerations the exhaust systems needs to be model with powertrain system. The powertrain system is modelled as lumped mass at its centre of gravity with all moment of inertia properties. The Powertrain and exhaust mounts are modelled with 1D CBUSH element. The hangers are modelled at the optimized hanger location layout based on cumulative displacement result. The exhaust line portion before flexible joint is coupled with powertrain at the determined optimized location. The complete exhaust system with powertrain FE model is shown in [Figure 5](#).

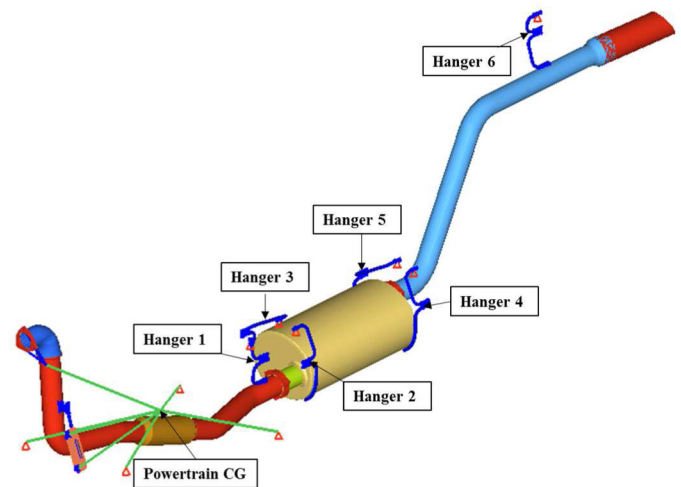


Figure 5. FE model of exhaust system with powertrain.

The powertrain mount locations and exhaust hanger mount locations are constrained in all direction for the static and dynamic analysis. This complete FE model is used for optimization process.

Optimization Process

The optimization process using DoE approach includes the defining optimization problem, carrying out design of experiment for design variables, followed by response surface approximation and optimization. The stepwise approach of optimization is shown in [Figure 6](#).