

Development of Virtual Testing of EGR Coolant Rail

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ABSTRACT

Vibration testing is carried out as part of the sign-off procedure for vehicle body and power unit mounted components to ensure that the components can survive their working life without damage. The paper describes the development of numerical techniques to replicate the vibration testing of a Diesel Engine EGR Coolant Rail. A Finite element (FE) model of the coolant rail was developed and validated. Subsequently, detailed FE models of the rubber hoses were developed and added to the coolant rail model in order to carry out a forced response analysis of the structure. Results from physical tests of the structure showed good agreement with the simulation results. A method is proposed for including the effect of the rubber hoses in the FE models of body and power unit mounted components using spring-dashpot elements. This is to avoid modelling the hoses in detail with resultant savings in computational costs.

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INTRODUCTION

Vibration testing for power unit mounted components in a vehicle is essential during product development. In this type of testing, products are tested in their real or simulated operating environment to determine their vibration response, and assess their durability performance. Specifically, a diesel engine EGR (Exhaust Gas Recirculation) coolant rail with rubber hoses shown in [Figure 1](#) is the subject of this study. The EGR technique can noticeably reduce the NOx emission of diesel engines.

With the current move to minimise design and development costs and time-scales in the development of new vehicles, the application of CAE tools such as Finite Element (FE) Analysis to validate system design through the use of virtual testing is becoming ever more important. This study aimed to develop an accurate FE model of the EGR coolant rail, including its connecting rubber hoses, to enable designs to be optimised before commitment to building prototypes. The aim was therefore to replicate the vibration testing of the coolant rail using FE simulation with a view to solving any durability problems quickly and efficiently.

The EGR coolant rail is composed of a steel tube attached to rubber hoses which connect it to the cooling system. It is mounted on the engine and exposed to engine vibrations as well as additional rotary components in all three principal directions over a wide range of excitation frequencies from 50 Hz to 800 Hz. Under such conditions, its durability performance needs to be determined particularly as there

have been reported failures in the field. Having developed appropriate modelling techniques and validated FE models of the coolant rail and rubber hoses which accurately describe the behaviour of the coolant rail, a simplified rubber model was introduced in terms of equivalent stiffness and damping characteristics as alternative to the complex rubber hose FE model.

Previous studies have reported the vibration analysis of structures mounted on rubber type materials [1], [2], and [3] in which the rubber type material was modelled using FE. Techniques were developed for determining corresponding mass, effective stiffness and equivalent damping [4] for the attached rubber type material in order to effect a considerable reduction in problem size and complexity [5]. The Kelvin-Voigt model [6], Standard Linear Solid (SLS) model [7], and Maxwell rheological model [8] are well-known models for representing the viscoelastic behaviour of elastomeric materials. However, the Prony series [9] method is one of the most commonly used methods in FE analysis and was employed in this study.

In this research, the simulations and tests have been organised in the following categories:

- I. Model #1: Coolant rail without rubber hoses
- II. Model #2: Coolant rail with rubber hoses
- III. Model #3: Coolant rail with equivalent spring and damper

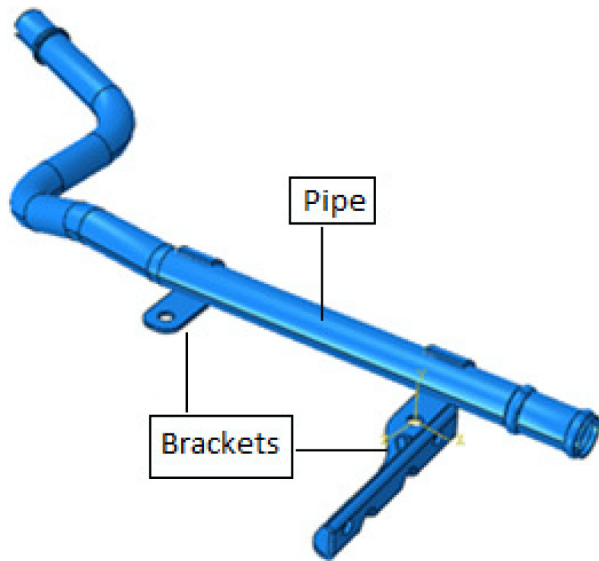


Figure 1. EGR coolant rail

TEST SET-UP

The aim of the study was to develop computer aided analysis models capable of accurately representing the vibration testing of the coolant rail, particularly when including rubber hoses and therefore provide a virtual testing platform for such components in the early stages of system design and development. In order to validate the finite element model of the coolant rail through comparison with the measured mobility, a vibration test rig was designed and developed.

Vibration testing was carried out by introducing a forcing function into a supporting structure with a shaker mechanism and using system analysis techniques to measure the ratio of the response to a measured input force.

Forced Vibration Test

During the vibration testing, the structure was connected to an electromagnetic shaker to provide a force to the structure as shown in [Figure 2](#). The first step in setting up a structure for frequency response measurements was to consider the fixture mechanism necessary to obtain the desired constraints (boundary conditions). Fixturing was a vital stage in the test facility development as it directly affects the general structural characteristics, particularly for subsequent analyses such as structural modification, finite element correlation and substructure coupling [10]. So, vibration test fixtures were designed and developed, which include a plate and brackets as shown in [Figure 2](#).

The vibration test procedure was divided into three steps: setting up the modal test, making the control/measurements by using LabVIEW package and parameter estimation by using Matlab software.

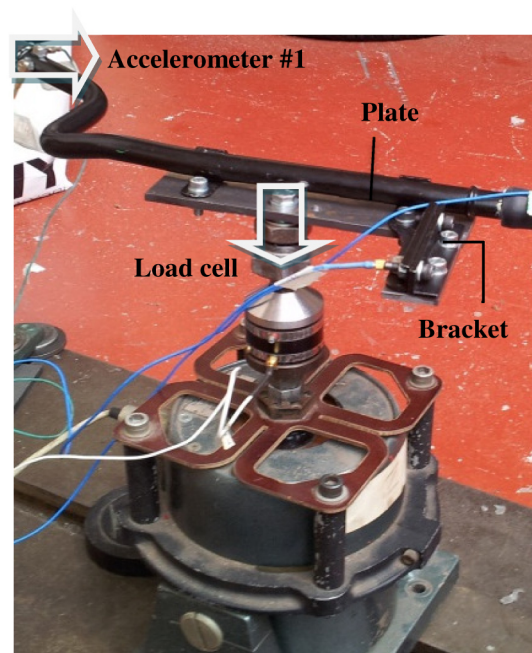


Figure 2. Vibration test rig

The final experimental setup for coolant rail without rubber hoses (model #1) and with rubber hoses (model #2) are shown in [Figure 2](#) and [Figure 3](#) respectively. The test rig for the coolant rails with rubber hoses was designed and built in order to adapt fixtures with the rubber hose additions to both ends of the tube. Each rubber hose was consequently attached to a fixture on either end of the tube.

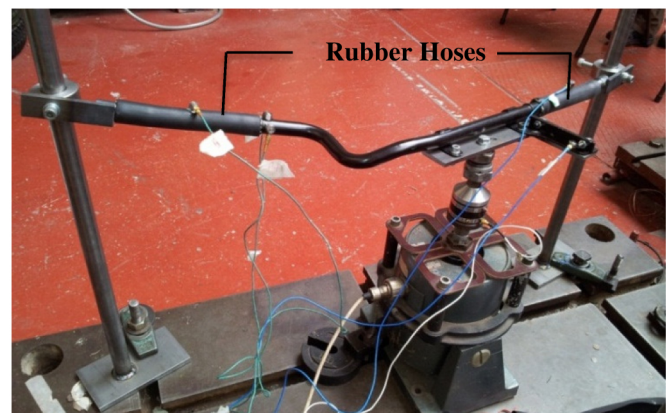


Figure 3. The experimental test setup for model #2

The test control and data acquisition software for the vibration testing of the coolant rail was developed in the LabVIEW package. The system works on the principle of measuring the mobility response of the coolant rail when excited over a range of frequencies (50 Hz –800 Hz).

The most important part of modal testing was making the mobility measurements [11], defined as equation (1)

$$Mobility = \frac{V}{F} \quad (1)$$

Mobility measures the velocity of a point (V) per unit force input applied (F). Therefore the higher the mobility, the higher the vibration amplitude generated for a given input force. Each peak of the mobility response corresponds to a resonant frequency. One method of presenting the data is to plot the mobility modulus versus frequency. At resonance, when $\omega = \omega_n$, the mobility modulus is a maximum and is limited only by the amount of damping in the system. Figure 4 demonstrates how the natural frequencies are extracted from vibration test.

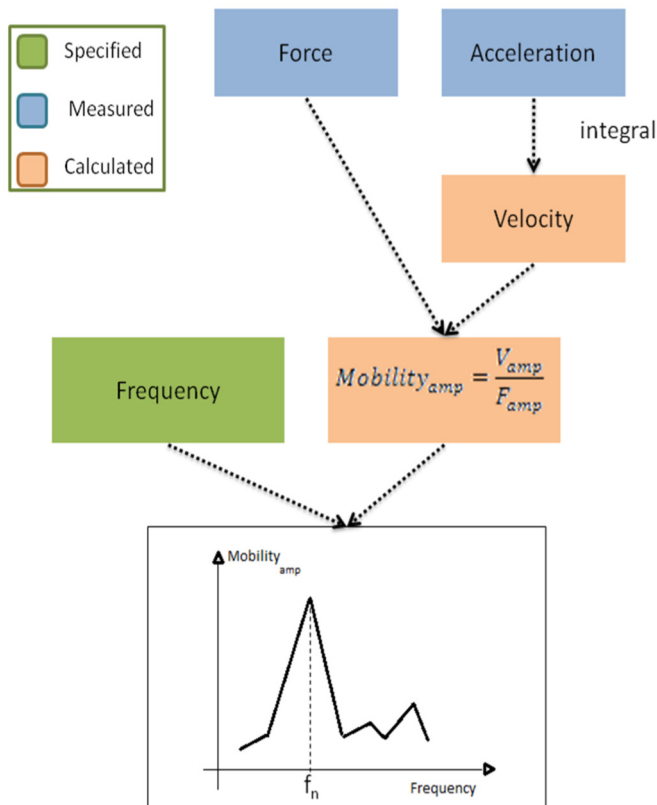


Figure 4. The schematic of data acquisition approach

FINITE ELEMENT ANALYSIS

Modelling Techniques

For checking FE model validity against test outputs, the FE model was built to correspond as closely as possible to the test condition. The rig was modelled in as much detail as possible including plates, bolts, and nut. The generated models in Abaqus can be seen in Figure 5.

The bracket and tube nodes were merged together providing a Surface-to-Surface contact with specified tolerance. The tube and bracket were joined together during manufacture of the coolant rail using resistance welding hence it was reasonable to assume that the whole inner area of bracket and outer surface of tube were welded together. Therefore assumption of merging all the contact nodes is acceptable. The fully constrained boundary condition was applied at the bolted joints between bracket and plate as illustrated in Figure 6.

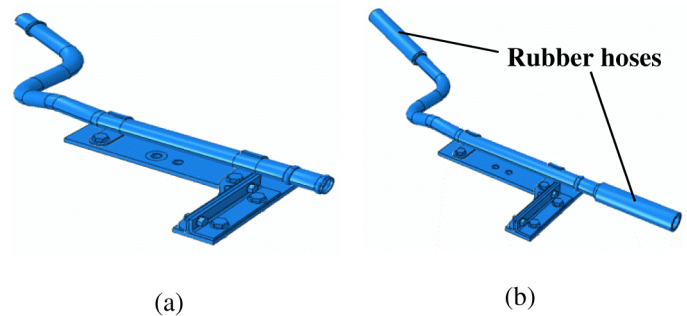


Figure 5. (a) Coolant rail without rubber hoses, model #1, (b) coolant rail with rubber hoses model #2

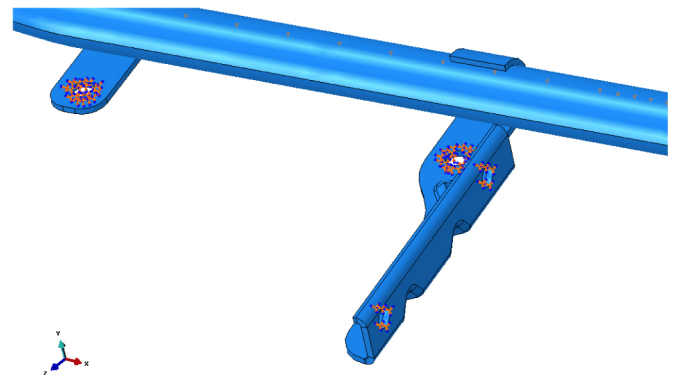


Figure 6. Boundary condition

Tetrahedral quadratic element was selected for meshing purposes due to its adaptability to complex geometries.

One major variable controlling the analysis time efficiency is the mesh quality. An investigation of natural frequency was performed at different mesh levels, and a convergence point was obtained in which all mode shapes produced consistent results as shown in Figure 7.