NORMAL MODE ANALYSIS OF AN EXHAUST PIPE

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May 2008

“I hereby verify that I have read this report and I find it sufficient in term of quality and scope to be awarded with the Bachelor Degree in Mechanical Engineering “

Signature : …………………………………

Supervisor Name : …………………………………

Date : …………………………………

“I hereby to declare that the work is my own except for summaries and quotations which have been duly acknowledge”

Signature : ………………………………….

Author : MOHAMMAD QAYYUM B. A.SHUKOR

Date : 8th may 2008

DEDICATION

To him who is our source of grace, our source of commitment, and our source of knowledge,
And,
To her, whose love is a source of joy.

ACKNOWLEDGEMENT

All praises to the Almighty Allah, for giving me the strength, patience and guidance throughout the process of completing this investigation. I am grateful to have the morally and physically support from many people throughout completing this study. For this opportunity, I would love to thank whose are either directly or indirectly involved during the process of this research is conducted.

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ABSTRACT

This project paper is basically to study the normal mode analysis on Proton Wira 1.6L exhaust pipe. From the research, the normal mode analysis at the vehicle's exhaust pipe system can be obtained. This research is also done to search an appropriate mounting point at exhaust pipe. Other than that is to study and make improvement to the design of the exhaust pipe mounting. In order to fulfill the research, there are several methodologies that have been used to obtain the normal mode of an exhaust pipe. In this research, impact hammer test is used as experimental method and MSC Nastran Software is used as simulation based method. The correlation between two different methods is achieved to locate an appropriate mounting point. The natural frequencies that have been obtained either using experimental method or simulation based method are almost similar. From both methods, the appropriate mounting point can be located at points or nodes which have minimal deformation during their natural frequencies.

ABSTRAK

Kertas kerja ini secara umumnya menerangkan kajian analisis normal terhadap terhadap sistem ekzos kereta Proton Wira 1.6L. Berpandukan kajian ini, analisis normal terhadap sistem paip ekzos kenderaan dapat diperolehi. Kajian ini juga dilakukan bertujuan untuk mencari titik lekatan yang sesuai pada sistem paip ekzos tersebut. Selain itu, kajian ini juga dilakukan bertujuan untuk mempelajari semula dan membuat pembaikan terhadap rekabentuk titik lekatan yang ada pada sistem paip ekzos. Untuk memenuhi kehendak kajian ini, terdapat pelbagai cara kerja yang dilakukan untuk mendapatkan bentuk normal terhadap ekzos paip. Di dalam kajian ini, ujian tukul berimpak digunakan sebagai cara kerja berasaskan eksperimen manakala perisian MSC Nastran pula digunakan sebagai cara kerja berasaskan simulasi. Perbandingan terhadap kedua-dua kajian ini akan diperolehi bertujuan untuk menetukan titik lekatan yang sesuai pada paip ekzos. Frekensi asli yang diperolehi hasil daripada kedua-dua cara kerja iaitu secara eksperimen dan juga simulasi yang telah dilakukan ini menunjukkan nilai yang hampir sama. Daripada kedua-dua cara kerja ini, titik lekat yang sesuai dapat ditentukan pada titik atau noda yang mempunyai perubahan yang minima pada frekuensi aslinya.

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NOMENCLATURE

UTeM	–	Universiti Teknikal Kebangsaan Malaysia, Melaka
PSM	–	Projek Sarjana Muda
FFT	–	Fast Fourier Transform
FRF	–	Frequency Response Function
CMM	–	Coordinate Measuring Machine
dB	–	Decibel (units)
DAQ	–	Data Acquisition System

CHAPTER I

INTRODUCTION

1.1 Project Overview

The improvement of simulations tools has been helping the automotive industry and other areas over the last few years. The solution of some design issues, when done with the help of simulation software, can be achieved with significant time and cost savings.

In order to figure out the modes of the exhaust pipe, there are several experiments that can be used to determine it. One of them is an impact hammer test. Impact testing is a simple and fast technique for obtaining good approximations of a systems modal properties and frequency response information.

Unfortunately, the experiment tests are time consuming. The most convenient way to improve design is the simulation-based methods using the software. There is a lot of software that can be used to determine normal mode frequencies which cause vibration. One of the software that is currently used to define the mode shape is by using MSC Nastran. However, difficulties still exist in FEA based methods in simulating the exact vibration response of exhaust systems.

This study is more to get the correlation between experimental results and simulation analysis. Comparison between these two methods of analyzing hopefully can be used as a reference or guideline to others.

1.2 Problem Statement

The problem which always came up from the driver of the passenger car is the vibration at the car body. This vibration is usually come from many sources such as from wheels and tires, suspensions, engine's mounting, air-conditioning compressor and also exhaust pipe. Thus, to reduce the vibration at the car's body, we can reduce it by preventing the vibration at exhaust pipe itself as one of the solution.

To reduce the vibration that occurs to the exhaust pipe system, the characteristic of an exhaust pipe system must be studied first. One of the characteristic that influence the vibration is natural frequencies of an exhaust pipe system. As a solution, the normal modes analysis by using several methods must be done to study the relation of it to the vibration that occurs to the exhaust pipe system.

1.3 Objective

The objectives of this project are:

- To do normal mode analysis at vehicle's exhaust pipe.
- To search an appropriate mounting point at exhaust pipe.
- To study and improve the design of exhaust pipe mounting.

1.4 Scope of Study

The scopes of this project are:

- Study the vibration of exhaust pipe for Proton Wira 1.6L variant.
- Obtain the normal mode or frequency of exhaust pipe using the MSC Nastran software for the simulation.
- Obtain the normal mode or frequency of exhaust pipe using the impact hammer experiment.

1.5 Expected Outcome

At the end of the research as expected, the natural frequencies of an exhaust pipe can be known by using the Impact Hammer Test and normal modes analysis of an exhaust pipe can be obtained by using MSC Nastran Software simulation. From this experimental and simulation results, the correlation between it can be achieved.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The literature review is based on the physics of the project undertaken here, concentrating on the introduction on the exhaust system, normal mode analysis and vibration theory. The literature review continues with the discussion on the information related with how to conduct the experiment and software simulation for this research.

2.2 Exhaust System

2.2.1 Exhaust System Overview

The parts of an exhaust system are shown in Figure 2.1. The main parts are the engine pipe, resonator, intermediate pipe, muffler and the tailpipe. The engine pipe is attached to the exhaust manifold outlet by the flange. Brackets and mountings on the various parts support the system in relation to the engine and the body of the vehicle.

The exhaust system has flexible mountings that prevent exhaust vibration from being transmitted to the body. They also allow for thermal expansion of the system.

The exhaust pipes are design with various shapes to suit the location of the engine and the type and design of the bodywork of the particular vehicle. An example of an exhaust installation is shown in Figure 2.2. The system shown has an exhaust manifold with separate branches joined to a flange. Twin engine pipes are used between the manifold and the intermediate pipe. Two mufflers are fitted, one in the middle and the other at the rear end of the system.

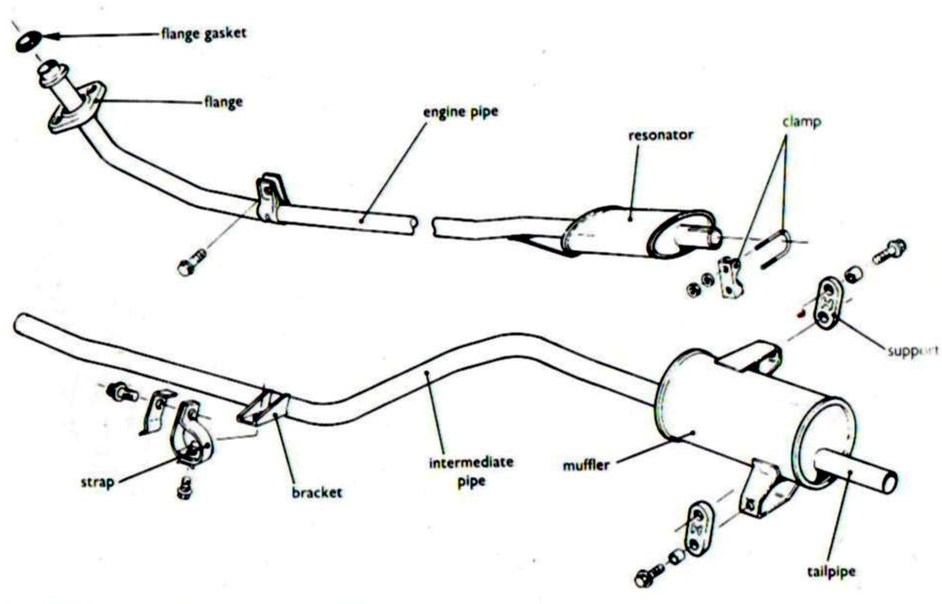

Figure 2.1 : Exhaust system components

Source : [1]

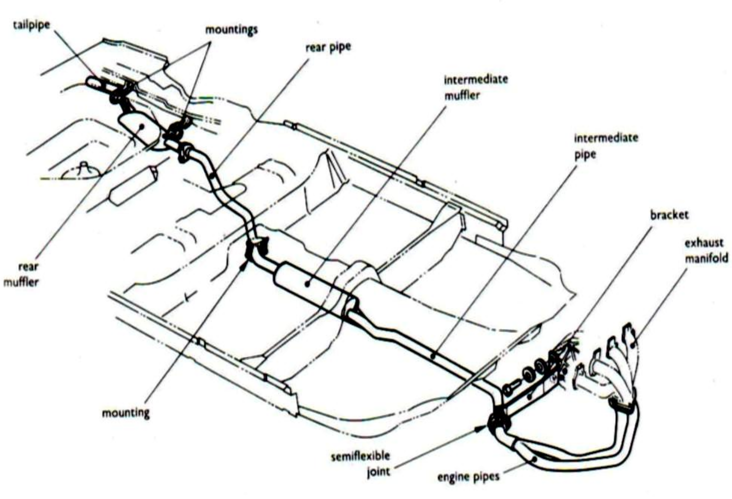

Figure 2.2 : Components of an exhaust system

Source : [1]

2.2.2 Exhaust Connections

In some cases, the exhaust pipes and mufflers are joined by fitting the end of one pipe into another which shown in Figure 2.3. A clamp is then used to hold the parts firmly together. In other cases, connections between the parts of the system are made with flanged joints.

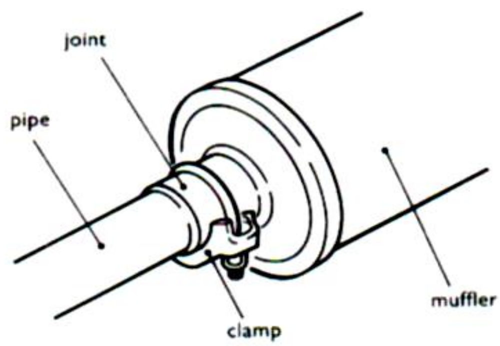

Figure 2.3 : Joint on mufflers and exhaust pipe

Source : [1]

Figure 2.4 shows a joint between the exhaust manifold flange and the engine pipe flange. Two holes in the manifold flange align with the two corresponding holes in the engine pipes. The exhaust gas from two of the engine's cylinders is fed into each engine pipe. A gasket of heat-resistant material is fitted between the two flanges.

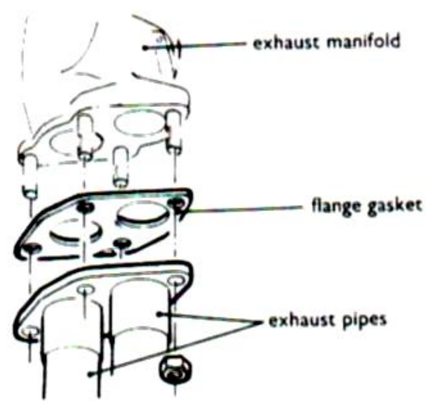

Figure 2.4 : Exhaust manifold to engine pipe connection

Source : [1]

Figure 2.5 shows one type of connection that is used between the engine pipe and the intermediate pipe. This is semi flexible designs that assist with alignments of the pipes and also helps to reduce vibrations. In this joint, the sealing ring (3) between the two pipes has a spherical end, which fits into a similarly shaped end of the exhaust pipe (4). The two bolts (7) that hold the flanges (2) and (5) of the two pipes together are fitted with springs (6), so that the sealing ring is held firmly onto its seat. This provides a joint that is firm, but not rigid.

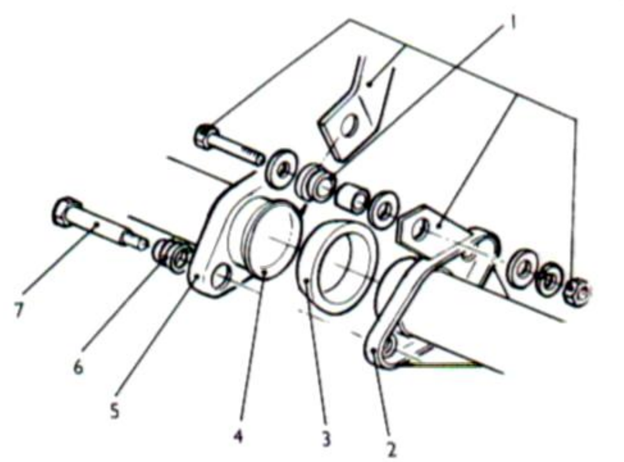

Figure 2.5 : Semiflexible connection in exhaust system
1 mounting-bracket assembly, 2 flange on engine pipe, 3 sealing ring, 4 conical seat, 5 flange on intermediate pipe, 6 spring, 7 flange bolt

Source: [1]

2.2.3 Exhaust with Extractors

An exhaust system which includes extractor pipes is shown in Figure 2.6. The system provides one pipe for each exhaust port. The pipes are designed with sweeps that prevent back pressure. They also provide a scavenging effect, which assist in extracting the exhaust gasses from the cylinders, thereby increasing engine performance.

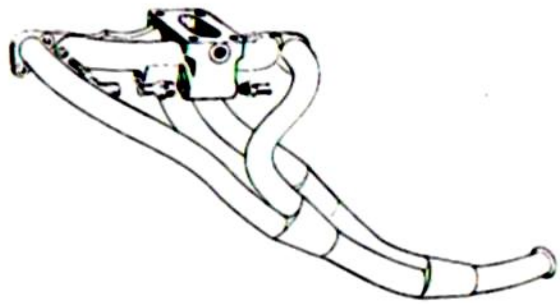

Figure 2.6 : Exhaust manifold with extractor pipes; the inlet manifold has water heating
Source : [1]

2.3 Vibration

2.3.1 Vibration Overview

Vibration is a study of the repetitive motion of objects relative to a stationary frame of reference or nominal position (usually equilibrium). The vibrational properties of engineering devices are often limiting factors in their performance. Vibration can either be harmful and should be avoided, or it can be extremely useful and desired.

Typical examples of vibration familiar to most are the motion of a guitar string, the quality of ride of an automobile and motorcycle, the motion of an airplane’s wings, and the swaying of a large building due to wind or earthquake. Vibration is modeled mathematically based on fundamental principles such as Newton’s laws, and analyzed using mathematical methods.

The physical explanation of the phenomena of vibrations concerns the interplay between potential energy and kinetic energy. A vibrating system must have a component that stores potential energy and releases it as kinetic energy in the form of motion (vibration) of a mass. The motion of the mass then gives up kinetic energy to the potential-energy storing device. Vibration can occur in many directions and can be the result of the interaction of many objects.

Vibration refers to mechanical oscillations about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road. Vibration is occasionally desirable. For example the motion of a tuning fork, the reed in a woodwind instrument or harmonica, or the cone of a loudspeaker is desirable vibration, necessary for the correct functioning of the various devices.

More often, vibration is undesirable, wasting energy and creating unwanted sound-noise. For example, the motions of engines, electric motors, or any mechanical device in operation are usually unwanted vibrations. Such vibrations can be caused by imbalances in the rotating parts, uneven friction, the meshing of gear teeth, and etcetra. Careful designs usually minimise unwanted vibrations. The study of sound and vibration are closely related. Sound, pressure waves are generated by vibrating structures and pressure waves can generate vibration of structures. Hence, when trying to reduce noise it is often a problem in trying to reduce vibration.

2.3.2 Types of Vibration

Free vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and then letting go or hitting a tuning fork and letting it ring. The mechanical system will then vibrate at one or more of its natural frequencies and damp down to zero.

Forced vibration is when an alternating force or motion is applied to a mechanical system. Examples of this type of vibration include a shaking washing machining due to an imbalance, transportation vibration (caused by truck engine, springs, road, etc), or the vibration of a building during an earthquake. In forced vibration the frequency of the vibration is the frequency of the force or motion applied, but the magnitude of the vibration is strongly dependent on the mechanical system itself.

2.3.3 Free Vibration without Damping

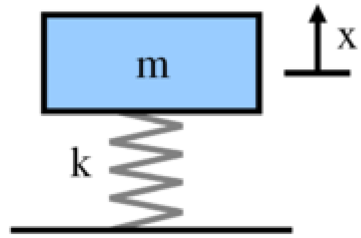

Figure 2.7 : Free body diagram of free vibration without damping

Source :[3]

To start the investigation of the mass-spring-damper, the damping is negligible and that there is no external force applied to the mass (free vibration) will be assumed. The force applied to the mass by the spring is proportional to the amount the spring is stretched "x" (the spring is already compressed due to the weight of the mass will be assumed). The proportionality constant, k, is the stiffness of the spring and has units of force/distance (e.g. lbf/in or N/m).

$$F_s = -kx$$

The force generated by the mass is proportional to the acceleration of the mass as given by Newton's second law of motion.

$$\Sigma\ F = ma = m\ddot{x} = m\frac{d^2x}{dt^2}$$

The sum of the forces on the mass then generates this ordinary differential equation:

$$m\ddot{x} + kx = 0.$$

If the system starts to vibrate by stretching the spring by the distance of "A" and letting go, the solution to the above equation that describes the motion of the mass is:

$$x(t) = A\cos(2\pi f_n t)$$