VIBRATION BASED HEALTH MONITORING FOR AUTOMOTIVE ENGINE

BY

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A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science (Automotive Engineering)

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JULY 2012

ABSTRACT

In this dissertation, a study of vibration signature is investigated and discuss. The vibration signature of different fault is then compared to the normal engine condition. Eleven selected faults have been selected and tested one at a time so that the outcome of the vibration signature can be predicted. The vibration levels are recorded at one point through three different axis of the engine, the axial direction along the crankshaft axis (x-axis), the transverse direction in the horizontal plane and normal to the crankshaft axis (y-axis) and the vertical direction along the cylinder axis (z-axis). In addition to that, the effect of each fault induced on the engine power and torque also is measure and discuss. All the testing is tested on two different load, no load and full load. The results have shown that every fault that applied to the engine will clearly give a higher vibration level compared to the normal condition. Thus, it can conclude that the monitoring of the engine health can be done thru vibration monitoring technique.

ملخّص البحــث

الاهــتزاز التوقيـــــع دراسـة ،الأطروحةهذه فـــي التحقيـــــق ويجــري بشـــرط مقارنـــة ثــم مختلفـــة خطأ الاهــتزاز توقيـــــع .مناقشــــة تحديـــدها تــم قـد المحـدد أخطاء عشــر أحد .العــادي المحـرك بنتــــائج التنبـــــؤ إمكانيـــة أن حيــث واحد وقـت فـــي واختبارهـــا نقطـــة عنـد الاهــتزاز مســـتويات وتسـجل .الاهــتزاز التوقيـــــع المحـوري الاتجــاه من ثلاثـــة مختلفـــة محور طـريق عن واحدة علـى عمودي واتجــاه والمحـرك (س) المــــرفقي العمـود المحـور علـى الطــائرة فـــي العرضـــي الاتجــاه (ع) محور الاسـطوانة محور طول (ص). المحـور المــــرفقي العمـود لمحـور وعادي أفقـــي المحـرك قـوة علـى فعــل كـل خطأ أثــر ،ذلـك إلــى وبالإضــــافة اختبـــار يتــم .ومناقشـــة التـــدبير هو أيضـــا الـدوران وعزم تحميـــل لا ،اثنيـــن مختلفـــة تحميـــل علــى التجـــارب جميـع خطأ كـل أن الواضـــح ومن النتــــائج أظهرت وقـد .كامل وتحميـــل بحالـــة مقارنـــة أعلـى اهـتزاز مســـتوى المشـغل إلـى تطبيــــق يمكـــن محرك صـحة رصـد أن تختتــــم أن يمكـــن ،وهكذا .طبيعيـــة الاهــتزاز تقنيـــة رصـد خـلال من بـــه القيـــام.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Automotive Engineering.

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Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Automotive Engineering.

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VIBRATION BASED HEALTH MONITORING FOR AUTOMOTIVE ENGINE

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Signature Date

In dedication to
my beloved wife and children

ACKNOWLEDGMENTS

Bismillahirrahmaanirrahim,

In the name of Allah, the most compassionate and the merciful.

First and foremost, I am thankful and grateful to Allah SWT, the Creator and Sustainer of this whole universe, the Most Beneficent and the Most Merciful, for His guidance and blessings, and for granting me knowledge, patience and perseverance to accomplish this dissertation successfully.

I take a great pride to express my sincere appreciation and gratitude to my supervisor, Assoc. Prof. Dr Waleed Fekry Faris, for his invaluable support, constant inspiration, expert guidance, encouragement and constructive criticism throughout this work. I have been fortunate to work under his guidance. I did learn a lot from his constant monitoring and his passion for perfection. It has been a wonderful experience working with him. Thank also to all engineering faculty members for support throughout the completion of my studies in IIUM

I also would like to thank and appreciate to MARA and UniKL who support my studies and also to PROTON members especially in the Noise, Vibration and Harshness (NVH) Department for their kindness and commitment throughout the completion of my studies.

Last but not least, I would like to extend my thanks to my beloved wife and children who were the source of my motivation to work hard.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Modern internal combustion (IC) engine systems have grown significantly progress in producing a better fuel consumption, emission and driveability. Its have progressed from fuel carbureted system to fuel injection system. Other innovations, including advance ignition system plus with some variables valve timing system, the combustion process have become more complicated and complex. Therefore, fault detection and diagnosis method is not easily done and need to be improved.

So, an advance engine predictive maintenance programs need to be developed. The programs or methods for monitoring the engine parts failure can detect malfunction and interruptions of normal engine operations.

An internal combustion engine will create a vibration or excitation while it is running. This source of vibration may be a free moment or a guide force moment produces by the engine or the influence on chassis frame and engine structure arising from the torsional vibration of the shaft system. A guide force moment is the transverse reaction forces that occur when the engine crossheads are acting on the engine upper structure.

According to Frank Kimmich (2005), modern vehicle on-board diagnosis system are mainly based on simple limit or plausibility check of some measured signals and on simple signal based methods like frequency analysis of the speed signal. By measuring the corresponding output signal for symptoms such as worn crankshaft, malfunction of oil pump or heavy knocking derive from abnormal combustion, etc, it's become possible to detect the problem and localized the fault.

1.2 PROBLEM STATEMENT

With the emerging of various systems on the IC engine, it is hard to figure out when the parts or the system is failing out. The method that commonly used by the user to determined the failure on the IC engine is by using a vehicle diagnostic scanner. This type of equipment only deals with the electrical voltage signals which coming from the various type of sensors attached to the system. If the failures come from the mechanical parts such as spark plug faulty, it will not be registered in the vehicle diagnostic fault.

This type of failure will create its own vibration pattern. In order to rectify and solve the problem, vibration based analysis methods need to be developed.

1.3 OBJECTIVE

i. To study a vibration monitoring system.

ii. To apply vibration monitoring system to detect engine failure.

iii. To compare the vibration signature of the normal engine condition to the abnormal engine conditions.

1.4 RESEARCH METHODOLOGY

The aim of the research is to compare the vibration signature between the faulty engine conditions to the normal engine condition at two different loads, part load and full load. Figure 1.1 showed the flowchart of the research methodology.

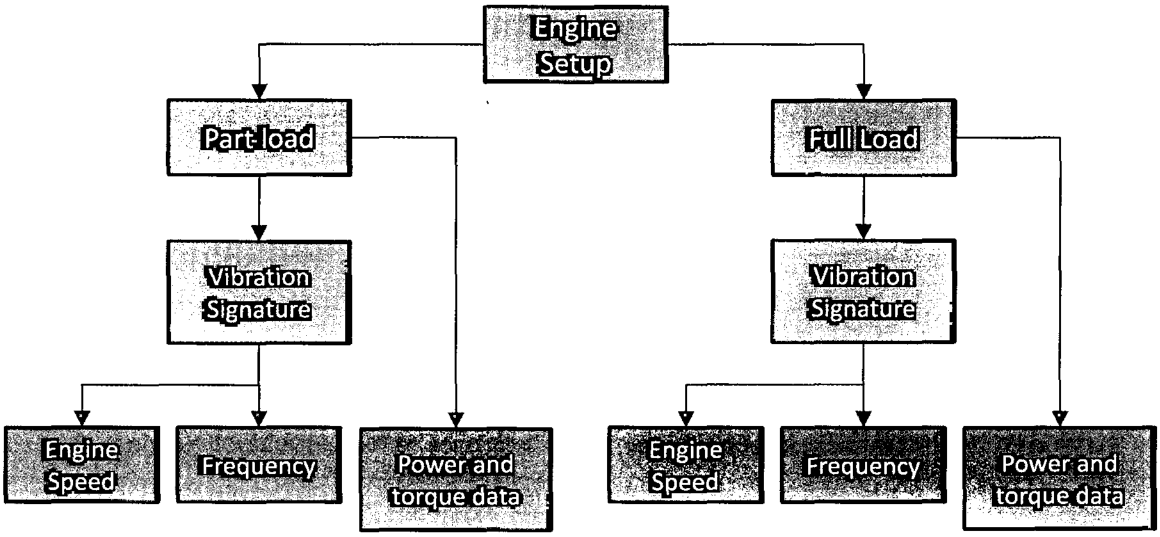

Figure 1.1: Flowchart of research methodology.

The first step is to setup the engine on the engine dynamometer and the accelerometer is attached to the engine block using industrial adhesive. The location of the accelerometer is described in the Chapter 4.

Then the engine is tested for performance result according to the engine manufacturer specification. During this test, two different loads will be applied to the engine, part load and full load. At each load test, the vibration signature will be recorded and tabled for discussion. For the vibration signature table, there are two domain will be recorded, engine speed domain and frequency domain.

The next step is to applied the engine with selected faults and test it at part load and full load. During this testing, each vibration signature from different faults will be collected and compared with the normal engine condition. Power and torque curve also will be collected for each test. Finally, all the result for the testing will discuss in the Chapter 5.

1.5 THESIS OUTLINE

This thesis is organized into five chapters.

Chapter 1 provides some essential introduction about the needs of vibration monitoring system in modern engines, the problem statement and the objective of the thesis. The research methodology also will be explained in this chapter.

In Chapter 2, the background of the vibration analysis is explained in detail such as the analysis techniques, the source of the vibration and the literature review of vibration monitoring system is given.

In Chapter 3, the theoretical background of the vibration is discussed.

Chapter 4 described the experiment setup for the CAMPRO engine on the dynamometer.

Chapter 5 focused on the vibration data. The results are tabulated, discussed and compared between two engine conditions.

Finally, conclusions and recommendations are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 VIBRATION ANALYSIS AS A PREDICTIVE MAINTENANCE

There are many predictive maintenance techniques used to monitor and predicts the mechanical condition of the equipment. The predictive maintenance that being used are:

i. Vibration monitoring. This is undoubtedly the most effective technique to detect mechanical defects in rotating machinery.

ii. Acoustic emission. This can be used to detect, locate and continuously monitor cracks in structures and pipelines.

iii. Oil debris analysis. Lubrication oil is analyzed and the occurrence of certain microscopic particles in it can be connected to the condition of bearings and gears.

iv. Particle analysis. Worn machinery components, whether in reciprocating machinery, gearboxes or hydraulic systems can release debris. Collection and analysis of this debris provides vital information on the deterioration of these components.

v. Corrosion monitoring. Ultrasonic thickness measurements are conducted on pipelines, offshore structures and process equipment to keep track of the occurrence of corrosive wear.

vi. Thermography. It is used to analyze active electrical and mechanical equipment. The method can detect thermal or mechanical defects in generators, overhead lines, boilers, misaligned couplings and many other defects. It can also detect cell damage in carbon fiber structures on aircrafts.

vii. Performance monitoring. This is a very effective technique to determine the operational problems in equipment. The efficiency of machines provides a good insight on their internal conditions.

Vibration signature analysis is used to determine the operating and mechanical condition of equipment. It can identify problems before they become too serious and cause unscheduled downtime or a poor maintenance practices, such as improper bearing installation or replacement.

Vibration measurement is an effective, non-intrusive method to monitor machine condition during start-ups, shutdowns and normal operation. It's primarily used on rotating equipment such as steam and gas turbines, pumps, motors, compressors, paper machines, rolling mills, machine tools and gearboxes.

Several studies had shown the suitability of vibration analysis for application to rotary and reciprocating machines, which can be considered to be the most widely used in general, in addition to its high capacity of diagnosis, make it the most versatile predictive technique. This technique consists of measuring the vibration levels from a certain machine and analyzing these measurements to predict any failure in the machine. The presence of a fault in industrial equipment will be accompanied by a detectable increase or modification of vibratory signal, this is the main reason behind using vibration monitoring to detect machine failure as found out by Assil Smeismeh (2008).

Some studies also has been made such as Engine Knock Detection from Vibration Signals using Pattern Recognition (Jean-Hugh Thomas, 1997), Injection Fault Detection of a Diesel Engine by Vibration Analysis (Ezzeddine Ftoutou, 2006) and Vibration Monitoring as a Predictive Maintenance Tool for Reciprocating Engines (G deBotton, 2000) have showed that the most important technique in engine health monitoring is vibration analysis as it gives clear indications regarding the condition of the machine,

Assil Smeismeh (2008) also said that in addition the level of vibrations and the frequency at which these vibrations occur can serve in determining the exact location of the defect and possibly severity of such defect.

Vibration analysis, properly applied, allows the technician to detect small developing mechanical defects long before they become a threat to the integrity of the machine and thus provides the necessary lead-time to schedule maintenance to suit the needs of the plant management. In this way, plant management has control over the machines according to Monika Godara (2008).

As stated by G O Chandroth (1999), the vibrations in a reciprocating internal combustion engine are cause by unidirectional combustion force and mechanically induced structural resonance

G deBotton (2000) also said that with a sufficient database about the machine's operating order, its components and history of malfunctions, the vibration monitoring technique can provide early information about progressing malfunctions, the sources of these malfunctions and in some cases an estimation of the time period before the problems become serious.

2.2 VIBRATION ANALYSIS

Vibration is a result a dynamic force in machine which have moving parts and in structures which are connected to machine. Difference parts of the machine will vibrate with various frequencies and amplitude. Vibrations cause wear and fatigue. It is often responsible for the ultimate breakdown of the machine as said by Bruel and Kjear (1998).

The main causes of vibration are as follows (Monika Godara, 2008):

i. Unbalanced forces in the machine. These forces are produced from within the machine itself.

ii. Dry friction between the two mating surfaces. This produces what are known as self excited vibration.

iii. External excitation. These excitations may be periodic, random, or the nature of an impact produced external to the vibrating system.

G deBotton (2000) said that the concept behind the vibration analysis method is that any machine with moving parts vibrates in response to the excitations employed on its components. Variation in the excitation forces, the machine's components or its integrity will affect the vibration pattern. Nurhadi et al. (1993) studied the correlation between the measured vibrations of an engine and its components as a source for the excitations, and concluded that the source of the vibration can be definitely be identified by employing the vibration analysis method.

It is possible to examine the same vibration signal in terms of Acceleration, Velocity or Displacement. It is seen that velocity at any frequency is proportional to the displacement times the frequency and the acceleration at any frequency is proportional to velocity times frequency, which means it is also equal to displacement times frequency squared.

Vibration displacement strongly emphasizes the lowest frequencies and acceleration strongly emphasizes the highest frequencies. When looking at the vibration spectrum of a given machine, it is desirable to display the parameter that has the most uniform level over the frequency range. This will maximize the dynamic range of the measured signal. For most rotating equipment of medium size, it will be found that vibration velocity produces the most uniform spectrum, and for this reason it is usually chosen as the default parameter for machine monitoring.

As found out by G O Chandroth (1999), trend analysis has also been established to be a reasonable technique in condition monitoring. Short time windowed Fourier analysis, Wigner-Ville distribution, time frequency analysis and wavelets analysis have also found varying degrees of success in this area (Staszewski & Worden, 1997). All these methods require complex computations as well as averaging over several waveforms. Internal combustion engines normally operate across a wide spectrum of speed and load. Time domain averaging of signals under varying speed conditions would lead to erroneous results. In an environment where fault detection has to be instant, it would be desirable to have a system with minimal computational requirements which could evaluate the machine condition on a per sample basis. The criterion for the selection of the best features for fault classification is a vital issue.

In modern fuel injection systems of IC engines, non-uniform cylinder-wise torque contribution is a common problem, causing increased torsional vibration levels of the crankshaft and also stress of mechanical components. Each moving component of an engine usually produces a vibration signature on some points of the engine body.

G deBotton (2000) also mention that the engine block side is the most sensitive location for collecting data and the direction transverse to the piston's movement plane is the most informative one.

Typically, the main sources of excitation that are likely to be observable from the vibration signal are associated with the following subjects as found out by S. S. Mohtasebi (2009) and Ezzeddine Ftoutou (2006):

i. rocking and twisting of the engine block on its supports, due to the action of internal forces
ii. impacts due to clearances at links, those at the crankshaft bearings and the so-called piston slap being extremely noisy
iii. closures and opening of valves
iv. high-pressure fuel injection in diesel engines
v. Rapid rising of gas pressure in the cylinders during the combustion, especially in diesel engines where it is compared with a hammer blow.

Ezzeddine Ftoutou (2006) also said that any point measured on the internal combustion engine structure, the vibratory signal is composed of a very complex superposition of the contributions of different vibratory sources modified by their respective transmission paths. These sources originate from several internal phenomenon's in the engine and excite the natural modes of the engine. The vibration is amplified at the natural frequencies of the engine. Therefore, the produced vibration and the noise radiated from the engine result from the combination of the excitations and the dynamic response of the structure.

As studied by G deBotton (2000), the measurements were taken at four points (see Figure 2.1), two points were on opposing side of the engine block between cylinder 2 and 3 a few centimeters above the crankcase. The other two points were in the vicinity of the rear crankshaft bearing at 70^{o} and 240^{o} relative to each cylinder axis. At each point's measurement were taken in three principal directions, the vertical along the cylinder axis, the axial direction along the crankshaft axis and the transverse direction in the horizontal plane and normal to the crankshaft axis.

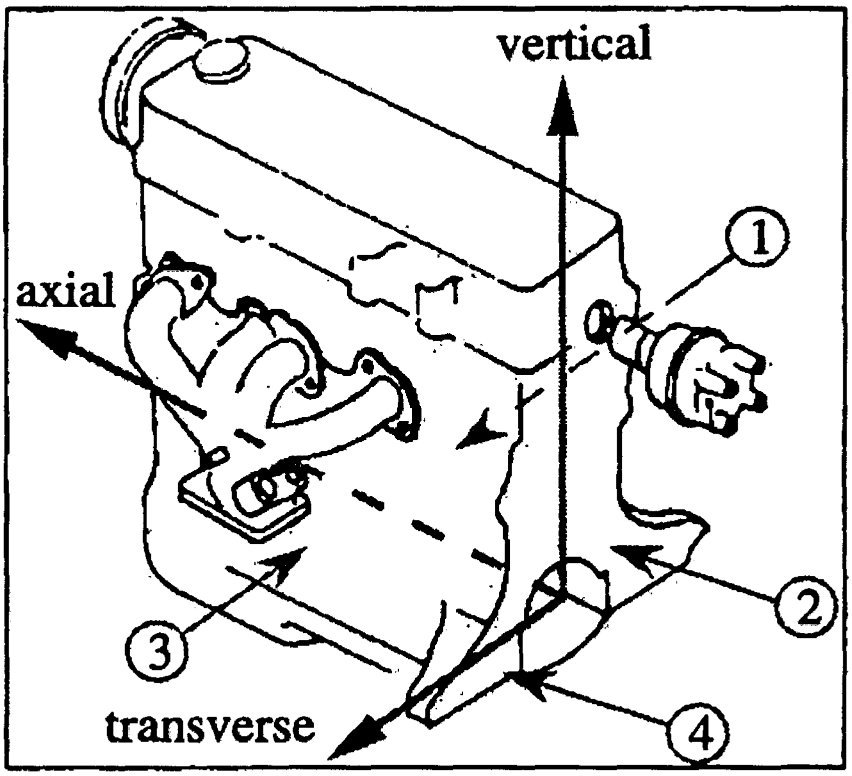

Figure 2.1: Location and direction of vibration measurement (G deBotton, 2000).

The engine is subject to complex vibration effects, which may produce six different free motions or degrees of freedom and combinations of the same. These motions can generate what are termed 'bounce' and 'yaw' about a vertical axis, fore-and-aft movement and roll about a horizontal longitudinal axis, and sideways shake and pitch about a horizontal lateral axis. The three inertia axes intersect at the centre of gravity of the engine (see figure 2.2).