iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: V Month of publication: May 2019

DOI: https://doi.org/10.22214/ijraset.2019.5022

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue V, May 2019- Available at www.ijraset.com

Effect of Sensors Location on Measuring the Vibration of Internal Combustion Engine

Ahmed H. Osman
Assistant Professor, Mechanical Power Engineering Department, Faculty of Engineering, Zagazig University, 44519 Zagazig, Egypt

Abstract: Vibration monitoring and fault diagnosis are based on highly precise and sophisticated instrumentation and hardware-software computer systems. The knowledge behind using this technique is based on the vibration signature analysis. To diagnose the engine's faults using this technique, there should be a general guideline and spectrum for each fault. Consequently, the faulty component can be identified from its spectrum. Moreover, identifying the optimum location of the vibration sensor is essential for measurements. Building such map will assist in setting up this technique for reciprocating engines. Extracting useful information from frequency signals is especially difficult in the case of reciprocating engine because there are many vibration sources and the rotation speed is not constant. The vibration analysis of a carbureted, spark ignition, and 4 cylinders engine has been proposed. The engine block vibrations are acquired in the three basic directions at different locations on the top of the cylinder block using accelerometer. The waveform of the vibration signals has been synchronized with the crankshaft angle using a trigger signal mounted on the output pulley of the crankshaft. The data are then transformed into the frequency domain using Fast Fourier Transformation (FFT). New software is developed to measure the vibration of the cylinder block. Some known faults, such as misfire, delaying spark timing, and advancing spark timing have been analyzed. The faulty signatures have been compared with the normal signatures for these cases using different locations for sensor. According to the measurements, it is concluded that changing the location of the vibration sensor affects only the amplitude of the signal. The vertical direction contains more information than the other two direction (Traverse and Axial directions).
Keywords: Vibration analysis, internal combustion engine, predictive maintenance, vibration signature

I. INTRODUCTION

The concept behind the vibration analysis method is that any machine with moving parts vibrates in response to the excitations exerted on its components. Variations in the faulty components will affect the vibration pattern. It is a well-known fact that an experienced mechanic can detect by ear the development of many faults. The concept of "vibration signature analysis" is in principle very similar; machines in good condition generally tend to have a fairly stable vibration pattern, which can be considered as a "signature". Changes in the internal conditions are often reflected by changes in the vibration pattern which can then be detected by externally mounted pick-ups while the machine is in operation. To simplify the methodology, a simple example is given in Figure 1. The shaft rotates with 3300 RPM which means 55 Hz. If one of the blades is defected, then it will vibrates at 55*7=385 Hz and the ball bearing (with one faulty ball out of 20) has a wave with frequency 20*55=1100Hz. Adding the threesignals together represents the overall vibration signal. Converting the time domain signal into frequency domain will identify the original frequency signals. The expected maintenance cost for reciprocating engines are greater than the rotating ones due to its complexity.

The purpose of applying a predictive maintenance program is four-fold: higher productivity, higher quality, profitability, and overall effectiveness of the system (Mobley, 1990).

A. Analysis Techniques

Signal analysis of reciprocating equipment is more complex than the analysis of rotating equipment.

Vibration analysis methods have not been widely implemented as a diagnostic tool for reciprocating machines. This may be due to the complexity of the reciprocating machines, which are assembled from many moving parts. Eshleman and Lewis (1988) introduced a method for determining the crankshafts rotational vibrations. However, this research presents the design concept rather than the application of the vibration response of the crankshaft as a diagnostic tool. Report from Engineering Dynamics Incorporated (1995) introduced guidelines for vibration analysis of reciprocating compressors. Nurhadi et al. (1993) studied the correlation between the engine's components as a source of vibration and the measured vibrations, and they concluded that the source of the vibrations can definitely be identified by using the vibration analysis. Autar (1996) introduced a system to diagnose diesel engines. Macian et al. (1998) have measured the vibrations of an engine block and demonstrated that there is a relationship between the vibrations and the instantaneous crankshaft torque. deBotton et al. (1998) measured the vibration of the cylinder block under normal and abnormal conditions. They found that the vibration level of the engine reflects engine condition and demonstrated that identifying the source of the trouble can be done through the vibration analysis.

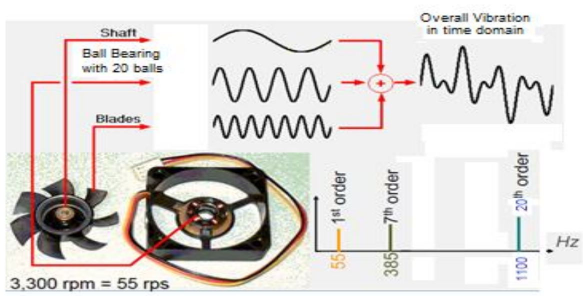


Figure 1. Relationship between time domain and frequency domain

B. Theory

Three major types of vibration analysis have been used in the early detection of machine failure, namely, frequency analysis, various techniques using the time domain analysis, and joint time-frequency analysis (Vibration Signature Analysis of a Faulted Gear Transmission System).

1) *Frequency Domain Technique:* The frequency spectrum is found by applying a discrete FFT on the time averaged signal x(t), such that the spectral components are:

$$\text{For } x[n] \text{ of length } N, \text{ set } \omega_0 = \frac{2\pi}{N}.$$
$$x[n]: \quad n = 0, 1, \ldots, N-1$$
$$X[k]: \quad k = 0, 1, \ldots, N-1$$

$$X[k] = \sum_{n=0}^{N-1} x[n]\, e^{-jk\omega_0 n} \qquad (1)$$

The frequency components are compared with the original spectrum to determine the fault.

2) *Time Domain Techniques:* All of the time domain techniques are applied to the vibration signal after it has been time synchronously averaged. The increasing trend of the vibration level indicates a serious problem as shown in Figure 2 (WWW.DLIengineerign.com).

$$FM0 = \frac{PP}{\sum_{i=1}^{n} A(f_i)} \qquad (2)$$

FM0 is a fault detection parameter that compares the maximum peak to peak amplitude to the sum of the mesh frequencies and its harmonics.

3) Joint Time-Frequency Technique: The joint time-frequency analysis approach uses the Wigner-Ville Distribution (WVD) on the vibration signal in time domain. Unlike the Fourier Transform process, the WVD provides an instantaneous frequency spectrum of the system. The spectral density of the fundamental exciting frequency and its sidebands changes as the shaft rotates through a complete revolution. If the vibration repeats itself for each revolution, a Fourier Transform will show a constant frequency spectrum, while the changing spectral density with time from the WVD provides information concerning the frequency distribution concentrated at that instant around the instantaneous frequency. Some success has been achieved in applying the WVD in gear transmission systems to recognize faults at various locations of the gear (Vibration Signature Analysis of a Faulted Gear Transmission System). The WVD will provide an interactive relationship between time and frequency during the period of the time data window. The WVD can be written as:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue V, May 2019- Available at www.ijraset.com

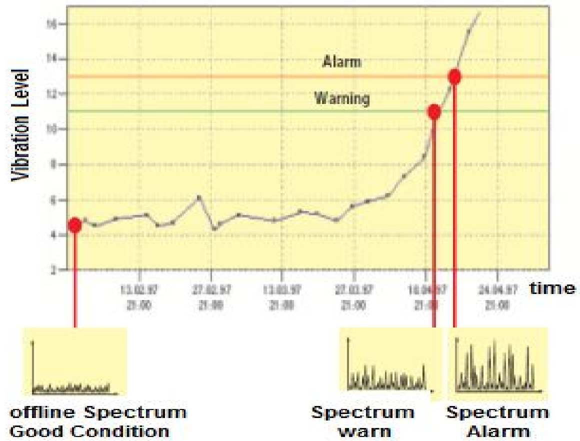


Figure 2. Increasing vibration trend indicates a serious problem

$$W(t,f) = \sum_{-\infty}^{\infty} x\left(t+\frac{\tau}{2}\right) x*\left(t-\frac{\tau}{2}\right).e^{-j2\pi f\tau}\, d\tau \qquad (4)$$

Or in discrete form

$$W_x(nT,f) = 2T\sum_{i=-L}^{L} x(nT+iT)\, x*(nT-iT).e^{-j4\pi f i\tau} \qquad (5)$$

where

W(t, f) = the Wigner-Ville distribution in both the time domain t and frequency domain f.

x(t) = signal in time domain.

T = sampling interval.

L = the length of time data used in the transform.

(Vibration Signature Analysis of a Faulted Gear Transmission System)

II. EXPERIMENTAL SET-UP

A data acquisition system is used to perform the measurements. The details of the used system are fully described in Ahmed Osman (2013). The whole test bed is shown in Figure 3.

A. Engine

The experiments were performed on carbureted, four-stroke, and four-cylinder in-line. Toyota R21 type engine is used with a total displacement volume of 2.363L.

B. Vibration Sensor

To measure the vibration, three types of sensors can be used:

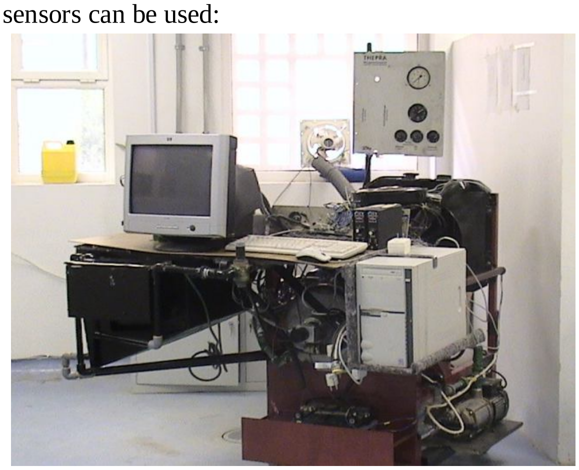


Figure 3. The whole test bed

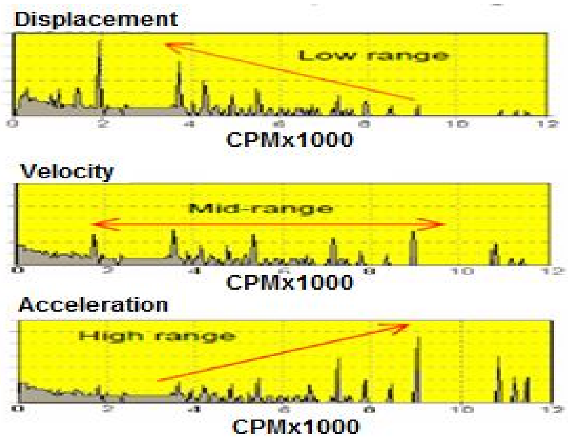


Figure 4. The best type that is suitable for certain frequency.

1) Displacement Peak to Peak in microns.
2) Velocity (Root Mean Square) RMS mm/sec.
3) Acceleration Peak g's.

Figure 4 shows the best type that is suitable for certain frequency. Depending on the frequency, one can select the suitable sensor type (Vibration Reference Guide). The vibrations were measured with a tri-axial accelerometer transducer as shown in Figure 5. The accelerometer transducer (Dytran 3093B) is mounted with an adhesive material. Measurements were taken at different locations, namely: Location 1 (Loc1), Loc2, Loc3, and Loc4. At each point, measurements were taken in three principal axes, the vertical direction along the cylinder axis (z), the axial direction along the crankshaft axis (x), and the transverse direction in the horizontal plane as shown in Figure 6. The signal from the piezoelectric pressure transducer was modulated (charge into volt) with a Dytran Charge amplifier 4112B. The AC electrical signal from the accelerometers are modulated using the a Dytran Charge amplifier 4114B1 as shown in Figure 7.

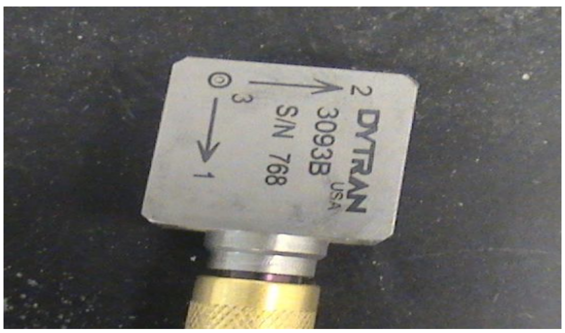


Figure 5.Triaxes accelerometer sensor

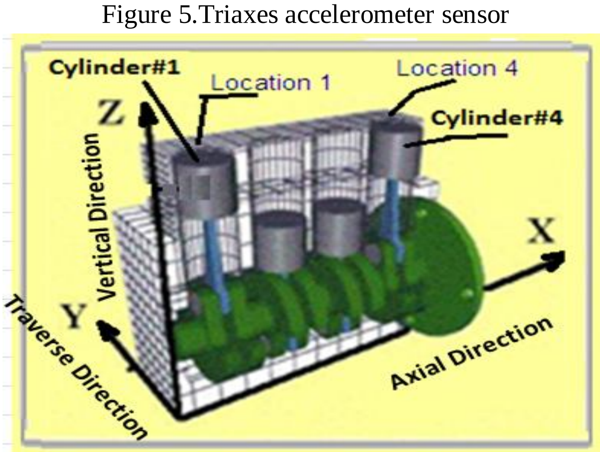


Figure 6. Principle axes & vibration sensor's locations

Figure 7. Charge amplifier for vibration sensor and cylinder pressure sensors

C. Rotary Encoder

A rotary encoder is used to measure the crank angle. The trigger synchronizes this signal with the start of the ignition cycle of cylinder #1 as shown in Figure 8. Figure 9 shows the reference point of the 1st cylinder so that the start of the ignition cycle can be identified.

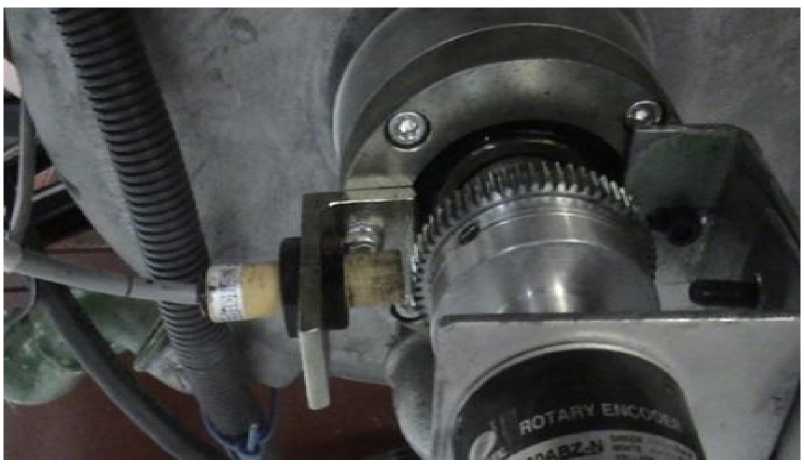


Figure 8. Installation of Rotary Encoder

Figure 9. Setting a reference & triggering signal for cylinder #1

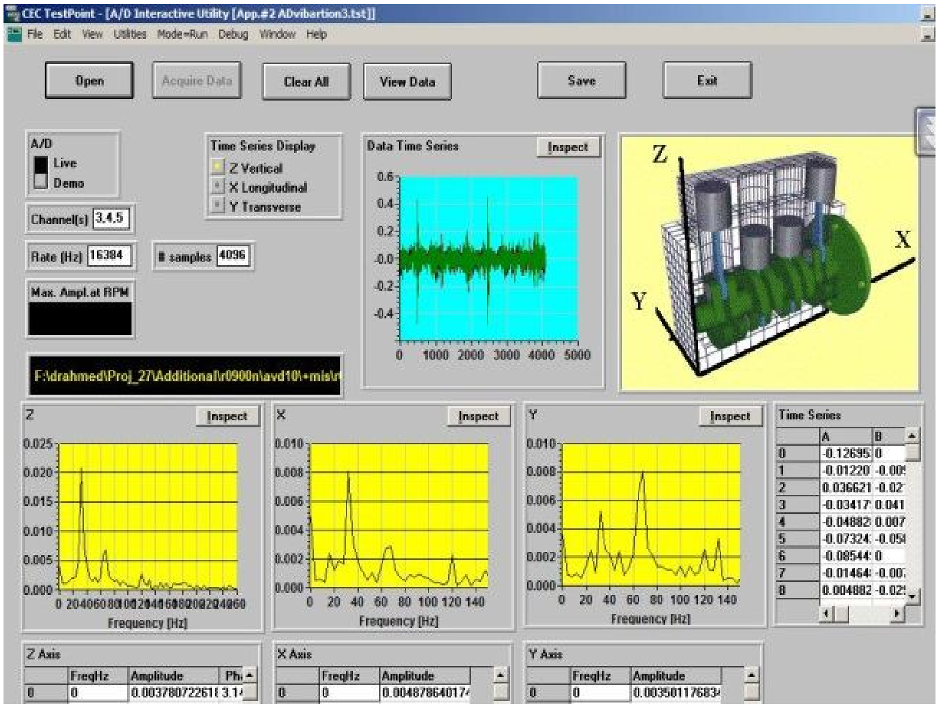


Figure 10. Main interface

D. Analog to Digital (A/D) Card

The analogue signal was then digitized with a 12 bit, 8 Differential channels. A/D card is Data Translation board DT301 with STP300 screw terminal. At the same time, the magnitude of the electric signal of a proximity switch mounted on the pulley was recorded through the second channel of the (A/D) converter as a reference phase signal for the crank angle. DT301 A/D card has a sampling rate 330 kHz.

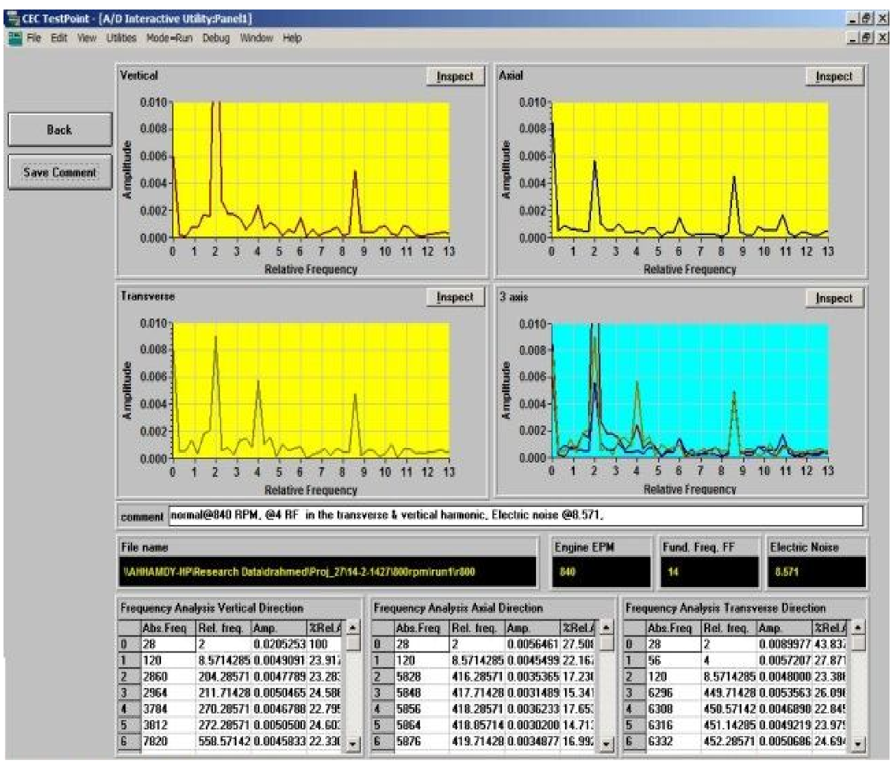


Figure 11. Analysis of output data

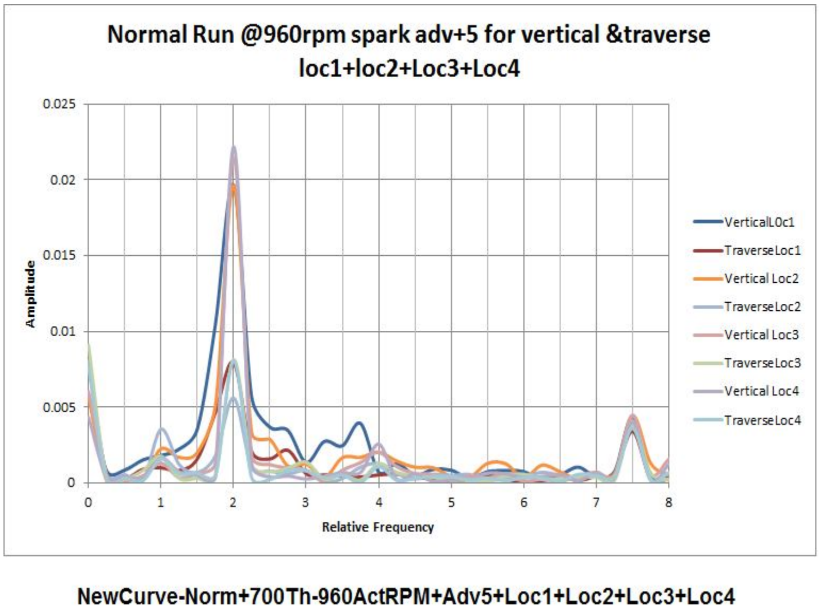


Figure 12. Vertical & Traverse Signals at different locations@ 900RPM under Normal Run

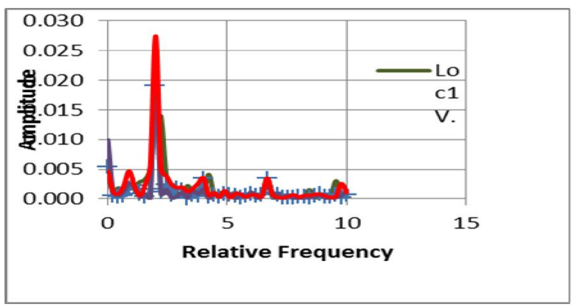


Figure 13. Vibration in Vertical Direction at different locations@ 840RPM (misfire cylinder#1)

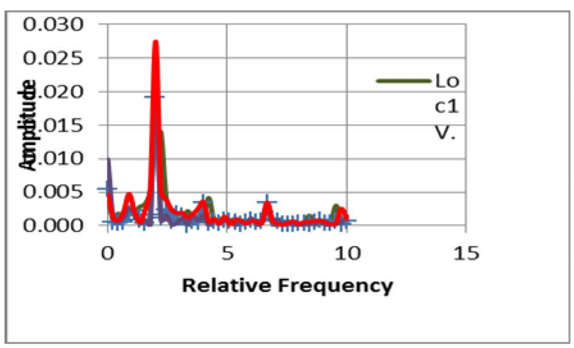


Figure 14. Vibration in Axial Direction at different locations@ 840RPM (misfire cylinder#1)

E. Software

The transformation of the measured “Time Domain” into frequency domain is calculated using Fast Fourier Transformation (FFT) as internal function in the developed software. The FFT was performed on measured data, and a new array (2^{10} = 1024 points) containing the frequency, amplitude, and phase were then calculated. Figure 10 shows the main interface of the developed software. The user can acquire the data online or process the data offline. The time domain signal is displayed and the processed frequency domain is then displayed. The user can display the frequency domain of the three axes together in one plot to compare between these signals as shown in Figure 11.

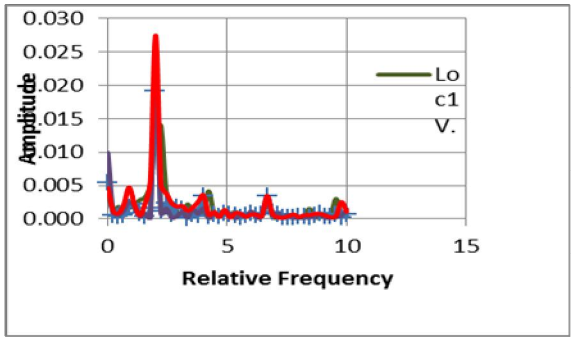


Figure 15. Vibration in Traverse Direction at different locations@ 840RPM (misfire cylinder#1)

III. RESULTS AND DISCUSSIONS

To easily read the figure, the following simple calculations need to be well understood:

1) Forcing frequency(Hz)=RPM*Engine order/60.
2) The order of the firing frequency is half the number of cylinders, i.e. a 4cylinder engine would create two order vibrations as its primary disturbance.
3) Differences in the firing process between the cylinders result in additional rythms. These ryhtms follow the 0.5^{th} and 1^{st} engine order.
4) These spectral lines will be at integer multiples of the firing rate of each piston. In a four stroke engine, the piston fires every other revolution. Therefore, the fundamental spectral line will be at 1/2 the engine RPM, often called the 1/2 order vibration. The result will be a vibration signature that has spectral lines at the 1/2 order, 1P, 1-1/2P, 2P, 2-1/2P, 3P ... etc.
5) If all of the pistons produce nearly identical combustion pulses, the difference between 1/2 order vibration will be very small.

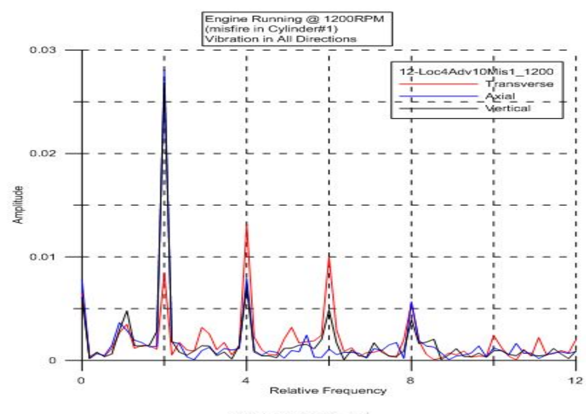


Figure 16. Comparision between the vibration signals on the three directions.

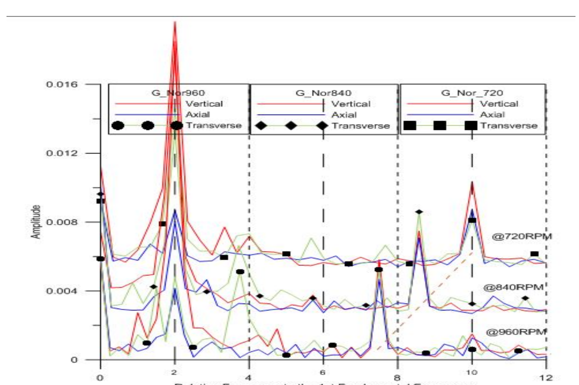


Figure 17. Comparison between vibrations signals in the 3 basic axes at different speeds

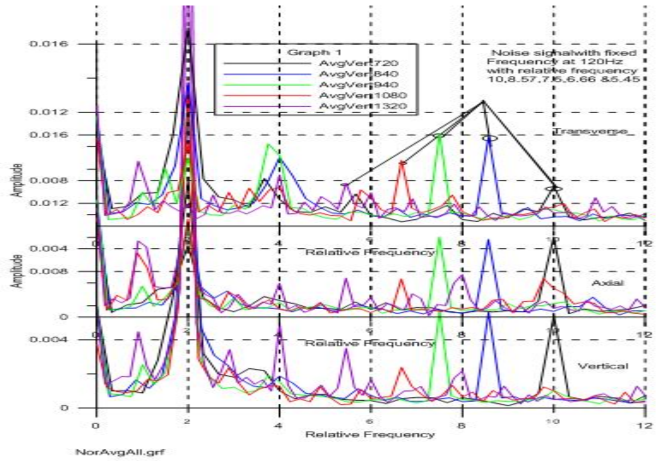


Figure 18. Four different runs of the engine from the transverse signal shows the same peaks

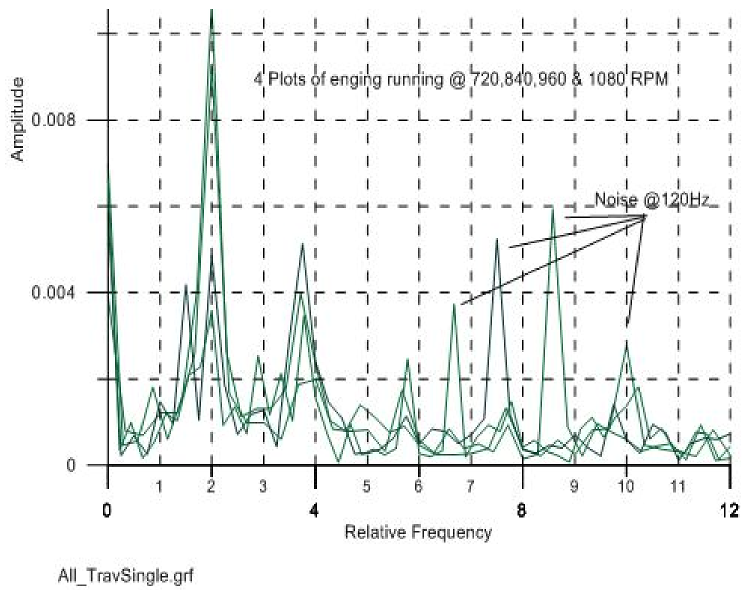


Figure 19.

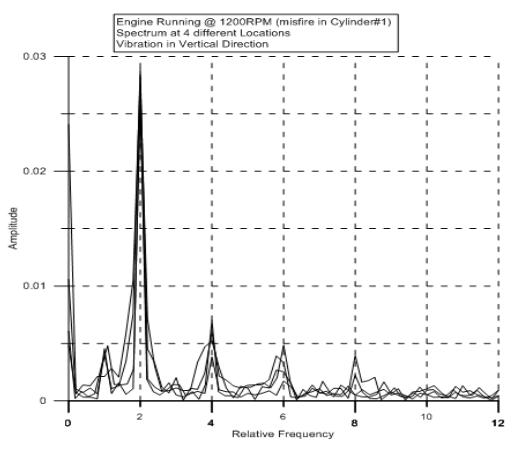


Figure 20. Vertical vibration specturm of misfire in cylinder 1 at the four different locations @1200rpm

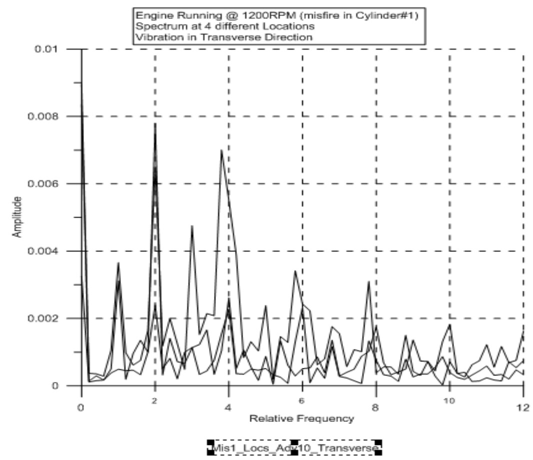


Figure 21. Traverse vibration specturm of misfire in cylinder 1 at the four different locations @1200rpm

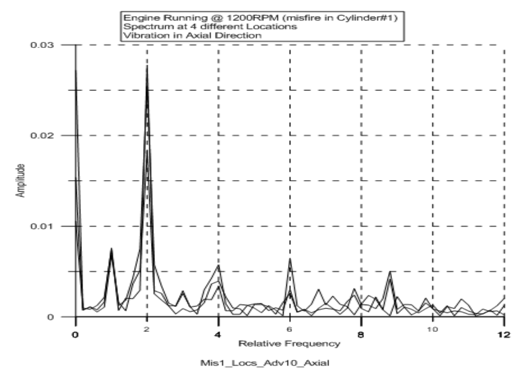


Figure 22. Axial vibration specturm of misfire in cylinder 1 at the four different locations @1200rpm

A. *Effect of Changing the Sensor's Location*

While running under the same conditions, the sensor is installed on 4 different locations on the cylinder head as shown in Figure 6. Figure 12 shows the signature at different locations at approx. 960 RPM under normal condition. This figure indicates that changing the location of the sensor does not affect the spectrum itself, but it only affects the magnitude of the amplitude. This conclusion is confirmed in Figures 13 for the vertical direction, Figure 14 for the axial direction, and Figure 15 for the traverse direction. Figures 13,14, and 15 are tested when there is a misfire in cylinder #1@840RPM. This conclusion have been tested on different speeds 700, 1100, and 1300 RPM.

B. *Senser Direction Information*

Based on the previous conclusion, all other tests are measured while the vibration sensor is installed in location 1. As shown in Figure 16, it is concluded that the maximum amplitude can be seen from the vibration signal in the vertical direction. The axial direction signal contains less information about the vibration than the other directions. This is clear because the inertia force of the piston is in the vertical direction.

A peak with fixed amplitude appears on all signals and this is due to fixed noise @120Hz (Twice the electric current frequency which is 60Hz in KSA). As the speed of the engine increases, the relative frequency of this noise will decrease. In many cases when a fault exists, the spectrum in the transverse direction will contain many peaks. In this case, it will be difficult to determine the first fundamental frequency. Using the vertical spectrum, one will be able to quickly determine it.

C. Signature due to Misfire

D. Signature due to Spark Advance

E. Signature due to Spark Retard

IV. CONCLUSION

Variations in the faulty components will affect the vibration pattern. Vibration analysis method has been performed for a reciprocating engine. The persistence of the vibration signature, under normal and abnormal conditions, was examined and verified by comparing different sets of measurements. The optimal measuring location and direction were found to be on the top of the engine block. New software is developed using (Testpoint) to acquire and process the data. The acquired data can be processed either online or offline. Due to the cycle-to-cycle variations of the engine speed, it was found that the wavelet measurements must be synchronized with the crankshaft angle in order to perform an accurate transform to the frequency domain. A straight forward mathematical procedure, however, requires an additional triggering from the proximity switch mounted on the front pulley of the engine. This procedure eliminated the need to mount a complicated and expensive encoder on the crankshaft. Using crank angle encoder is necessary when measuring the pressure inside the cylinders.

It was found that changing the location has no effect on the signature since the conversion from time domain into frequency domain have the same frequencies.

The appearance of another vibration peaks with unusual frequencies can provide an early warning that the engine has some abnormal operating conditions. The appearance of peaks at other frequencies than the fundamental frequency indicates that there is a problem in the engine.

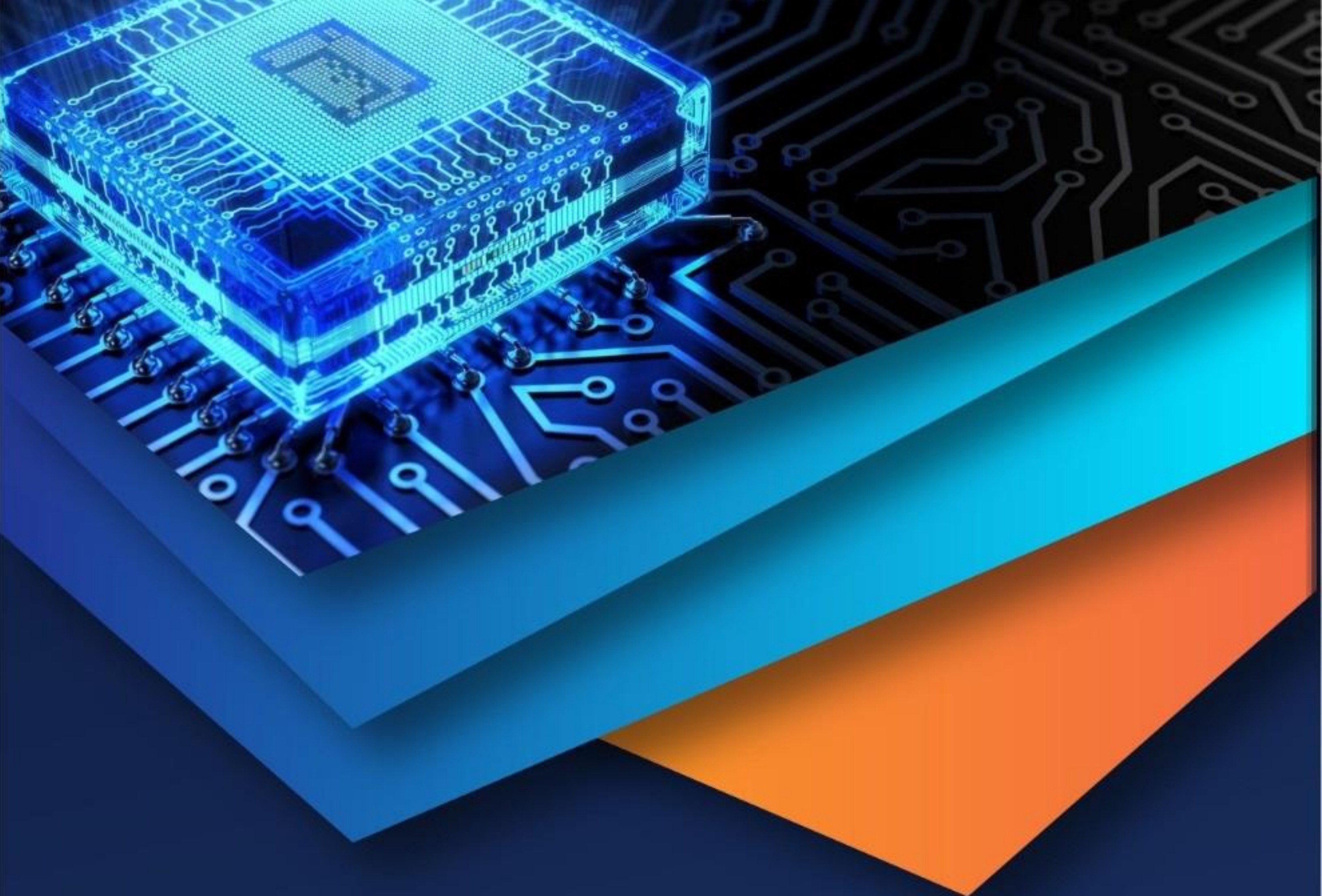
A peak with fixed amplitude appears on all signals and this is due to fixed noise @120Hz (Twice the electric line frequency which is 60Hz in KSA). As the speed of the engine increases, the relative frequency of this noise will decrease.

The engine was tested with a number of artificial malfunctions and the corresponding vibration signatures were measured. It was found that the vibration signatures are indicative and provide useful information about the corresponding malfunctions.

General evaluation criteria for the health of the engine can be established. The appearance of peaks at one-half or three-halves of the fundamental frequency, or, alternatively, dispersion of the energy at sub-harmonic frequencies or at six to eight times the fundamental frequency, clearly indicates that a severe malfunction had developed in the engine. The appearance of a peak at the fundamental frequency implies that a mechanical looseness enabled the engine to vibrate at the crankshaft frequency. In contrast with other predictive maintenance techniques, the vibration analysis method provides information about a wide variety of problems, from various process disorders to mechanical failures and degradations. The method also provides the capability for root cause analysis and diagnosis of worn units or components.

REFERENCES

[1] Ahmed Osman, H. & Magdy Masoud, M. (2013). Setting up a data acquisition system, AIIC , 24-26 April, Azores, Portugal Conference Portugal
[2] Autar, R. K. (1996). An automated diagnostic expert system for diesel engines, J. Engng Gas Turh.Pio . I IS. 673—679.
[3] Azam Ghaedi1 et al. (2015). "Fault Diagnosis of Internal Combustion Engine Using Discrete Wavlet Transform and Improved Classification System XCSR", Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345, V5, Pages 1587-1592.
[4] deBotton, G., Brn-Ari, J., Itzhki, R. & Sher, E. (1998). Vibration signature analysis as a fault detection method for SI engines, SAE Trans, J. Comm. Veh., Sec. 2, l—6; also SAE technical paper No. 980115.
[5] Engineering Dynamics Incorporated (1995). Vibrations in Reciprocating Machinery and Piping System, San Antonio, Texas.
[6] Eshleman, R.L. & Lewis, F.M. (1988). Torsional Vibration in Reciprocating and Rotating Machines, Shock and Vibration Handbook, editor Harris, C.M., McGraw-Hill, Ch. 38, 1-42.
[7] Eisenmnann, R.C. & Eisenmann, Jr. R.C. (1998). Machinery Malfunction Diagnosis and Correction, Prentice—Hall, Englewood Cliffs. New Jersey.
[8] Eshleman, R. L. (1995). Machinery Vibration Analysis I, Vibration institute, VIPress. Fault detection and diagnosis.pdf.
[9] Jafari, S.M., Mehdigholi, H. & Behzad, M. (2014). "Valve Fault Diagnosis in Internal Combustion Engines Using Acoustic Emission and Artificial Neural Network", Shock and Vibration. Volume 2014, Article ID 823514
[10] Kleiva, A. & Juzenas, E. (2014). "Analysis of Vibration of Internal Combustion Engine", Proceedings of 19th International Conference. Mechanika.
[11] Macian, N.I., Lerma, NI.J., & Barita, I. (1998). Condition monitoring of thermal reciprocating engines through analysis of rolling block oscillations, SAE paper No. 9X0116.
[12] Mitchell, S. J. (1981). Machinery Analysis and Monitoring, Penn Well. Oklahoma.
[13] Mobley, R. K. (1990). An introduction to Predictive Maintenance, Van Nostrand Reinhold, New York.
[14] Nurhadi, I., Kagiasna, k. & Edianto (1993). Signature analysis of 4-stroke I-cylinder engine. SAE paper No. 932011.
[15] Somashekar, V. et al. (2013). "Vibration Signature Analysis of IC Engine", International Journal of Innovative Research & Development,V.2 issue 213, pages 214-238.
[16] Vibration Signature Analysis of a Faulted Gear Transmission System.
[17] Vibration Reference Guide.pdf, WWW.DLIengineerign.com



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY