Condition Monitoring of Piston in an IC Engine Using Vibration Analysis

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Abstract- In this paper, fault has been diagnosed of piston using online condition monitoring technique. In industry, two types of fault diagnosis technique are used namely, online condition monitoring technique and offline condition monitoring technique. In offline condition monitoring technique piston has checked using visual inspection or microscopic examination but in online condition monitoring technique use different signal like acoustic signal, vibration signal, strain signal etc. to check the condition of piston.

In this paper vibration signal has utilized to monitor the condition of the piston. The vibration signals were analyzed in time-domain, frequency-domain and time–frequency domain. The vibration signal has analyzed using wavelet transformation method. Continuous wavelet transform (CWT) was used to obtain time–frequency representations. ‘‘dmey” wavelet was selected as the optimum wavelet type for this research among different wavelet types using the three criteria of energy. The results also demonstrated the possibility of using engine vibrations in piston fault identification.

Keywords: **vibration analysis, Continuous wavelet transform (CWT), frequency-domain signal**

I. INTRODUCTION

Scuffing is gross damage in which local welds are formed between the sliding surfaces [1]. When two sliding metallic surfaces contact and rub to each other, the friction and temperature of the area between these surfaces increase dramatically. High temperature in contact area and also the existence of structural weakness which could happen during production process cause the deterioration of the material strength [2]. Due to contact stresses acted to the sliding surfaces, plastic deformation occurs in materials, plastic flows are activated in layer and sub-layers, and materials go into liquid–solid phase [2]. As the result of reciprocating sliding and generation of adhesion forces, softened materials detach from the surface and stick to the opposite surface, means mutual material transfer occurs. In this situation, some chemical interactions take place between the stuck materials in the presence of lubricant [2,3]. The result of this process is formation of harder and rougher layers on the two sliding surfaces. If the contact between the sliding surfaces continues, the described process will progress with an increasing rate. Scuffing fault could occur in all sliding mechanisms such as gears and piston/cylinder.

Condition Monitoring Techniques:
Generally, Condition monitoring is dividing into two categories, namely, Offline (direct) and Online (Indirect) method.

Direct (Offline) method:
This method measures the actual quantity of measured variable such as volume of lost material for piston wear by visual inspection, optical microscope, machine/camera vision, radioactive technique. The used or worn-out piston will be taken to metrology or inspection session of the tool room or shop floor where they will be examined one of direct method. Offline methods are time consuming and difficult to employed during the course of actual machining operation at the shop floor.

Indirect (Online) method:
This method is measures auxiliary quantities and obtains the actual quantity through empirical correlation. The indirect method uses different sensor like force sensor, acceleration sensor, strain sensor, proximity sensor, acoustic sensor. These sensor data detect the machine condition. This method is more practical to implement in the industry because it enables monitoring the process online without the necessity to stop the process. Many methods have developed for tool monitoring in the machining process

For piston condition monitoring, some literatures use tonnage and/or strain signal. These signals provide information about changes in process variables and are widely use for piston protection from overload, controlling part quality and detecting forming faults, some literatures use force sensors with different mounting locations for controlling the process. The results show that the die sensor provides information that more detailed.

II. LITERATURE REVIEW

Ashkan Moosavian et.al.In this paper , the effects of piston scuffing fault type three-body abrasion on the engine performance and vibration were investigated. By obtaining some vibration characteristics due to this fault, a procedure was proposed for its detection in SI engine. The experimental results showed the significant undesirable effects of piston scuffing fault on the engine performance. In this research with the purpose of piston scuffing detection, the engine vibrations were analyzed by CWT method.

M. GE et.al.The vibration (acceleration) signals contain important information about the system dynamics. However, owing to the transients of the stamping operation, the vibration signals are nonstationary transient signals with random noise disturbance. Therefore, it is necessary to apply advanced signal processing techniques such as time–frequency distribution and wavelet transform.

W. Klingenberga, et al In this paper, it proposed to monitor the force–displacement graph during blanking in order to detect tool wear and, possibly other key aspects of the process. Therefore, the need for an alternative system, which could use in real time, became apparent. It demonstrated here that the onset of tool wear, causing product quality to deteriorate, could recognize from significant changes in the force–displacement graph. It found that in the current configuration, reliance on the blanking force was insufficient, given the natural scatter in materials properties and other parameters

K.F.Martin et al. In this paper, the paper initially discusses the necessity for planned maintenance, the extension of this into condition-based maintenance and the necessity for condition monitoring. It then discusses some definitions relating to this field of activity and in particular differentiates between hard and soft faults and the reason the latter can used for prediction, whereas the former is easier to diagnose.

2.1 Objective of Present Study:

1) Inspection of piston wears combustion process by using vibration signal.
2) Inspect the vibration signal using wavelet transformation method.
3) Find out the condition of piston at working condition.

III. WAVELET TRANSFORMATION METHOD:

3.1 Empirical Mode Decomposition :

The information, depends on intricacy, may has a lot of dissimilar coexisting mode of oscillations at the similar times. Intrinsic Mode Function (IMF) by the following definition represent every of those oscillatory mode. (a) In the entire information's sets, the amount of extrema and amounts of zero-crossing might either equivalents or contrast at the majority with one, and b at any points, the mean values of the envelopes define with the local maxima and the envelopes define by the local minima has zero. Extract the IMF's of a given data's set, the sifting process implement as follow. Firstly, recognize every local maxima, and it connected with all of the local maxima with the cubic spline line as the upper envelopes. After that, do again the procedures for the local minima producing the lower envelopes. The upper and lower envelope should wrap every data between them. Their mean has designate m_1 and the difference in all the data and m_1(t) is h_1(t), i.e.

$$x(t) - m_1(t) = h_1(t) \qquad (3.1)$$

The sifting procedure repeated, as a lot of times as it is require reducing the extract signals to an IMF's. In the successive sifting process step h1 (t) treat as the data

$$h_1(t) - m_{11}(t) = h_{11}(t) \qquad (3.2)$$

Wherever the mean of the upper and lower envelop of h1 (t) is m11 (t) . This procedure can be frequent up to k time; h1k (t) is then specified by

$$h_{1(k-1)}(t) - m_{1k}(t) = h_{1k}(t) \qquad (3.3)$$

After every processing's step, examination completed on whether the numbers of zero crossing equal the numbers of extrema. The resulting period series is the first IMF's, and then it is designate as c1 (t) = h1k (t). The first IMF's components from the data holds the most elevate oscillation frequency occurred in the original information x (t) .
This first IMF's has subtracted from the original information, and this differences, is called as residue r1 (t) :

$$x(t) - c_1(t) = r_1(t) \quad (3.4)$$

The residue r1 (t) has used as if it was the original information and we applied it once more the sifting procedure. The procedure of finding additional intrinsic mode ci (t) continues up to the final mode occurred. The final residues will be a steady or monotonic functions.

$$x(t) = \sum_{j=1}^{n} c_j(t) + r_n(t) \quad (3.5)$$

Therefore, one achieve a decompositions of the information into n empirical IMF's mode, plus residue, rn(t), which can either the a constant or mean trend.

The most commonly utilized tool for illuminating the energy utilization pattern is the power spectrum. Given a signal(t) , t € z, the power spectrum density (PSD) is defined as follows

$$y(t) = \frac{P}{\pi} \int_{-\infty}^{+\infty} \frac{x(t)}{t-\tau} dt \quad (3.6)$$

This works for the immobile process. For no stationary transient signals, a short time window is usually applied to filter the signals resulting in the so-called spectrogram. However, for highly time-variant signals even the spectrogram may not work very well. It is noted that the window used for the spectrogram is fixed once its type has been confirmed, so that the accuracy for extracting frequency information is limited by the length of the window. For the transient signal, we want to know more details about the time information in high frequency bands and more details about the frequency information in low frequency bands. The spectrogram cannot be flexible enough to meet these requirements

IV. Experimental work

In this investigation, the experiments were performs on an inline four-cylinder spark-ignition (SI) engine. The engine specifications are 180 kW Horiba-WT190 eddy-current dynamometer was coupled with the engine to control the engine speed and load. More than thirty equipments in conjunction with different sensors were used to run and control the engine such as engine speed, torque, throttle position, water temperature, oil

Table 4.1: Engine Specification

Engine type	SI engine
Combustion order	1–2–4–3
Cylinder bore _ stroke (mm)	72 _ 83
Swept volume (L)	1.560
Max. power (kW/rpm)	81/5000

pressure, ambient temperature, crankcase pressure and exhaust manifold temperature sensors. Four engine parameters, namely rotational speed, torque, power and blow-by flow rate were captured during the experiments. The engine speed and torque were measured with the accuracy of ±1.1% and ±0.6%, respectively. An AVL 442 blow-by meter with the measuring range of 3–160 L/ min and accuracy of 1.5% was employed to measure the blow-by flow rate of the engine.

V. Experimental results:

Fig. illustrates the graphs of four engine parameters namely speed, torque, and power and blow-by flow rate during the two experiments. As mentioned previous, the terms of ''Healthy" and ''Faulty" denote the first and second experiment, respectively. It is observed from Fig. (b) and (c) that the engine torque and power decreased by about 5.5 Nm and 3.5 kW respectively due to piston scuffing fault. Moreover, it is seen from Fig.(d) that piston scuffing fault caused the blow-by flow rate to increase highly so that the amount of this parameter reached 128.7 L/min at the occurrence time, whereas its maximum value was 33 L/min in healthy condition. This is because of increased clearance between piston and cylinder due to scuffing fault which caused blow-by gases to pass easier through this area and arrived the crankcase. This event can destructively affect engine parts such as crankshaft. Moreover, engine emissions may be more and more dangerous because blow-by gases mix with oil vapors and so more toxic substances are produced. In general, it is seen that piston scuffing fault can negatively affect engine performance:

Fig.5.1 Experimental Setup

VI. RESULT AND DISCUSSION:

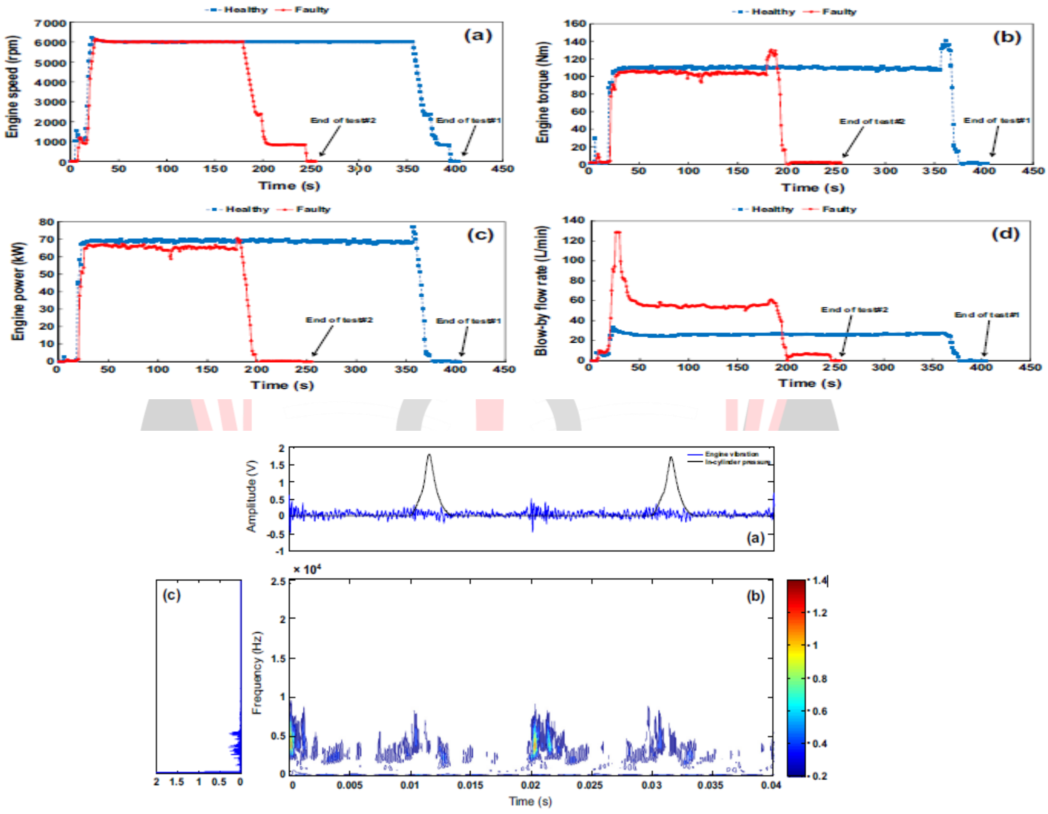

Fig. 7. (a) Waveform, (b) frequency spectrum and (c) time–frequency representation of the engine vibration in healthy condition.

Fig.5.2 Experimental result of healthy condition

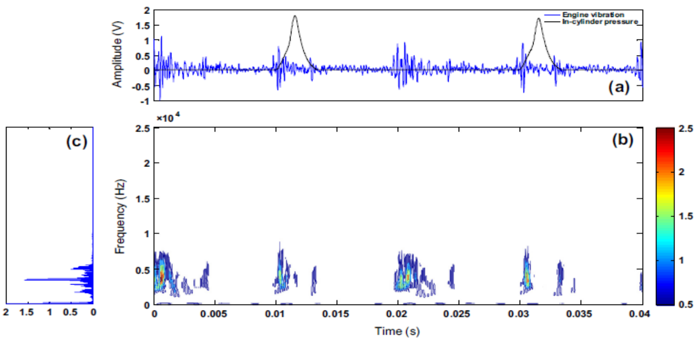

Fig 5.3 Experimental result of Faulty condition

VII. CONCLUSION

In the this study, the effects of piston deteriorations blunder type three-body rub on the engine performances and vibrations were examine. By get some vibration characteristics due to this fault, a procedure were estimated for its discovery in SI engine. The investigational outcome showed the important detrimental things of piston deterioration faults on the engine performances. In this investigation with the purpose of piston deterioration uncovering, the engine vibrations were examined by CWT method. The results show that ‘‘demy” wavelet was a valuable case for piston deterioration fault detection.

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