

A Study on Ultrasonic Signals Processing Generated From Automobile Engine Block Using Statistical Analysis

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Abstract:- The development of statistical analysis has played an important part in studying large data that captured from engine block as apart of engine monitoring and diagnose . Within this paper the application of statistical analysis was introduced by utilizing Kurtosis, I-kaz coefficient, and Crest Factor and Skewness parameter. There is potential that these statistical parameters could serve as pattern recognition to identify engine type and characteristic. The study was performed in two stages. The first stage is an experimental process that uses two three-cylinder automobile 845 cc and 850 cc engines and two four-cylinder automobile 1468 cc and 1784 cc engines which run under idle condition. In the second stage, the plots of signal's statistical parameter based on the engine type were done accordingly. As a result, the plot of the statistical parameter against I-kaz coefficient shows an excellent classification pattern. The pattern was useful in determining engine type for signal confirmation and engine fault detection

Keyword: Statistical Analysis, Signal Processing, Ultrasonic signal

1 Introduction

Statistical methods have found extensive use in processing real-world signals, not excluding the field of condition monitoring. Demands for preventive maintenance, a severe engine and emission regulation has lead to many advances in the field. A statistical approach and reliability data fitting to estimate residual life of machineries based on its failure intensity have been developed by Vlok et al. [1]. Monitoring Q- and T2- statistics variable deviations from an acceptable reference have been used to detect faults on helical gears [2]. Osburn et al. [3] have utilized statistical techniques to classify and recognize patterns for engines misfires.

There are three main types of sound wave, categorized by its frequency value. Infrasonic wave has frequency below 20 Hz. Frequency value ranging between 20 Hz to 20 kHz is called audio wave. Whereas ultrasonic wave frequency lying between 20 kHz to 100 kHz. This paper concentrates on ultrasonic wave i.e. the study of sound propagated at frequencies beyond the audible range that is detectable by human ears. It consists of two major types of ultrasonic intensity. Firstly, is

ultrasonic wave with low-intensity and secondly, high-intensity ultrasonic wave.

2 Theoretical Background

2.1 Engine Diagnostic

In automobile engine, when the engine is running, its pistons operate by moving up and down in the cylinder block within its cycle. Therefore, interaction between the piston rings and cylinder wall will occur. These interactions will produce sound waves with frequencies within the ultrasonic range. These three piston rings, which are the two compression rings and one oil ring, is continuously touching and rubbing the cylinder wall while the pistons operate. As a result, the ultrasonic sound is continuously produced and varying with time. These ultrasonic sound patterns can be utilized as a means to identify the characteristics and condition of the piston-cylinder system in an automobile engine. Another technique was actively done by Othman et al [6] and [7] using acoustic emission as a prime monitoring parameter.

2.2 Statistical Analysis

A measured signal commonly consists of variations in amplitude, frequency, phase and energy. Signals can be divided into two main categories which are deterministic and nondeterministic. A deterministic signal can be described by a mathematical relationship between the value of the function and time. Many signals in nature exhibit random or nondeterministic characteristics which provide a challenge to analysis using signal processing techniques.

The r -th order of moment M_r for the discrete signal in the frequency band is frequently used to classify random signals. The r -th order of moment, M_r can be written as:

$$M_r = \frac{1}{N} \sum_{i=1}^n (x_i - \bar{x})^r \quad (1)$$

where N is the number of data and r is the order of moment.

The skewness, which is the signal 3rd statistical moment, is a measure of the symmetry of the distribution of the data points about the mean value. The skewness of a signal is given by

$$S = \frac{1}{n(r.m.s.)^3} \sum_{j=1}^n (x_j - \bar{x})^3 \quad (2)$$

The skewness for a symmetrical distribution such as a sinusoid or a Gaussian random signal is zero. Negative skewness values indicate probability distributions that are skewed to the left, while positive skewness values indicate probability distributions that are skewed to the right, with respect to the mean value.

Kurtosis, which is the signal 4th statistical moment, is a global signal statistic which is highly sensitive to the spikiness of the data. For discrete data sets, the kurtosis value is defined as:

$$K = \frac{1}{n\sigma^4} \sum_{i=1}^n (x_i - \bar{x})^4 \quad (3)$$

The kurtosis value is approximately 3.0 for a Gaussian distribution. Higher kurtosis values indicate the presence of more extreme values than should be found in a Gaussian distribution. Kurtosis is used in engineering for detection of fault

symptoms because of its sensitivity to high amplitude events.

The crest factor, which is commonly encountered in engineering applications, is defined as the ratio between the maximum value in the time history and the r.m.s. value:

$$CF = \frac{x_{j\max}}{r.m.s.} \quad (4)$$

The crest factor value for sinusoidal time histories is 1.41 and the value approaches 4.00 in the case of a Gaussian random signal of infinite length.

Based on kurtosis, I-kaz method [9] provides a three dimensional graphical representation of the measured signal frequency distribution. The time domain signal is decomposed into three frequency bands which are, x-axis, which is for low frequency (*LF*) range of 10-20 kHz, y-axis, which is high frequency (*HF*) range of 20-50 kHz and z-axis, which is very high frequency (*VF*) range of 50-100 kHz. In order to measure the scatter of data distribution, the I-kaz coefficient calculates the distance of each data point from signal centroid [4]. I-kaz coefficient is defined as:

$$\mathcal{Z}^o = \frac{1}{n} \sqrt{K_L s_L^4 + K_H s_H^4 + K_V s_V^4} \quad (12)$$

where n is the number of data, K_L , K_H , K_V are the kurtosis of signal in *LF*, *HF* and *VF* range and s_L , s_H and s_V are the standard deviation of signal in *LF*, *HF* and *VF* range respectively.

3 Methodology

For the experimental work, four Automobile engines were used in this study, which are Automobile engine Type 1, Type 2, Type 3 Type 4. Table 1 presents the specification of all engines. Apart from the engines, the principal components used for the data acquisition purpose include the Ultraprobe 9000 sensor and Yokogawa DL1540C digital oscilloscope. All the equipments used have been calibrated and are checked to be in good condition. The Ultraprobe 9000 is properly connected to the input channel on the digital oscilloscope using the appropriate wire connection. A sampling frequency of 200 kS/s (200 000 sampling per second) is used for this experiment, by tuning the TIME/DIV dial on the oscilloscope.

TABLE 1: Engine Specification

Make	Automobile engine Type 1	Automobile engine Type 2	Automobile engine Type 3	Automobile engine Type 4
Type	Water-cooled, 4 strokes, in-line 3-cylinder, transverse engine	Water-cooled, 4 strokes, in-line 3-cylinder, transverse engine	Water-cooled, 4 strokes, in-line 4-cylinder, transverse engine	Water-cooled, 4 strokes, in-line 4-cylinder, transverse engine
Capacity	847 cc	850 cc	1784 cc	1468 cc
Transmission System	5-speed manual	3-speed automatic	4-speed automatic	5-speed manual
Max. Power	49.2 bhp @ 5200 rpm	55 bhp @ 5200 rpm	88kW @ 5750rpm	67kW @ 6000rpm
Max. Torque	74.4 Nm @ 4000 rpm	88.3 Nm @ 3600 rpm	165Nm @ 3750rpm	126Nm @ 3000rpm

This sampling frequency setting is crucial to obtain sufficiently accurate data from the cylinder block. The engine is started and left running for a few minutes to allow the engine to stabilise, before the actual reading is captured. This stabilised RPM is shown in a screen on the control panel and is recorded.

Once stabilised, the ultrasonic reading is ready to be captured. The muzzle of the Ultraprobe 9000 is positioned directly perpendicular on one of the cylinder block without touching any engine components. In addition, the sensitivity button at the Ultraprobe 9000 is tuned to get the best and suitable frequency value detected from the operation of the cylinder block. This frequency value will set according to the maximum ultrasonic magnitude (dB). The ultrasonic signal that were captured for that cylinder, by the Ultraprobe 9000 (shown on its screen), is recorded in Table 2 below. Meanwhile, all the real-time signal data captured by the oscilloscope is stored and saved into a floppy disc for further processing. These steps are repeated for other cylinders and at other rpm speeds. All the data

in the floppy disc is then transferred to the personal computer for further statistical processing using MATLAB.

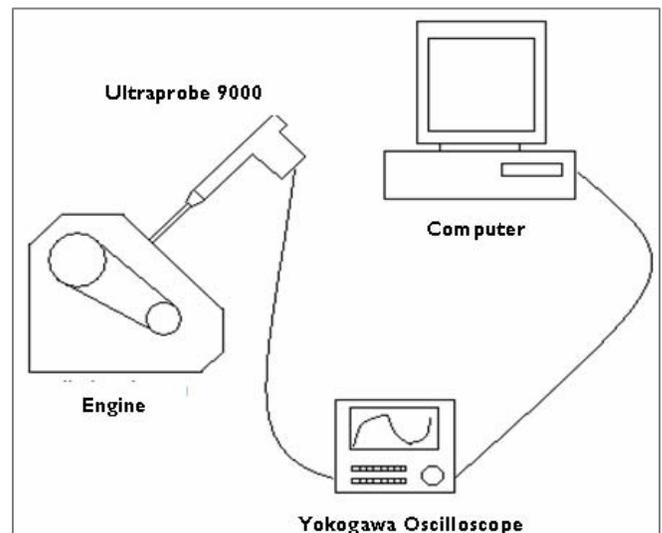


FIGURE 1: Equipments used

4 Results and Discussion

All four figures (FIGURE 2, 3, 4, 5) which shown ultrasonic signals that capture from the engines block. The figures don't indicate any significant indicator for defining the ultrasonic signals from engine block. The figures just barely showed signals amplitude that capture from the engines. The study of this ultrasonic signals will be carry on how an existence statistical analysis and recently develop method by Zaki et al [4] can be use as a tool to cluster the engine piston.

Table 2 and 3 shown statistical analysis results from each cylinder with engine type named Automobile Type 1, 2, 3, and 4. Four statistical

parameters shown in Table 3 were calculated in MATLAB environment. Both skewness and kurtosis parameters from Table 3 were calculated by existing MATLAB functions (kurtosis using KURTOSIS (data) and skewness using SKEWNESS (data)). Meanwhile I-kaz coefficient parameter which we introduce in this paper was generated by authors MATLAB codes.

Data from Table 3 were used to cluster the scattering of the data to form a cluster by engine's pistons. The clustering results showed in figure 2, 3 and 4.

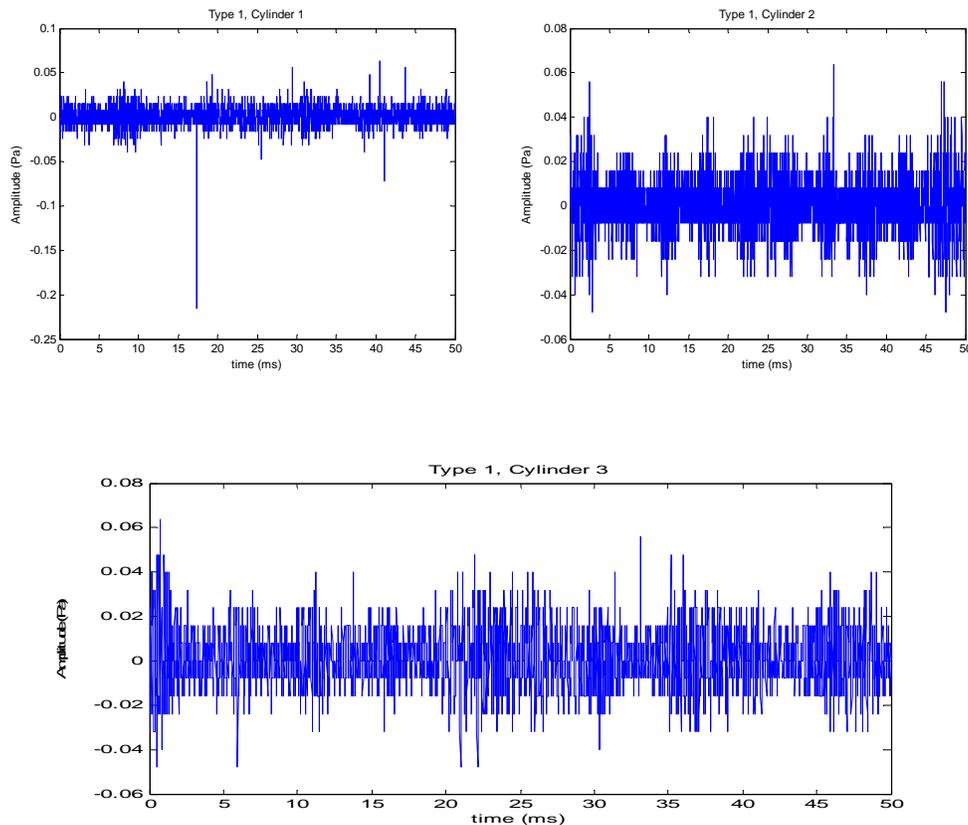


FIGURE 2: Ultrasonic signals from engine Type 1

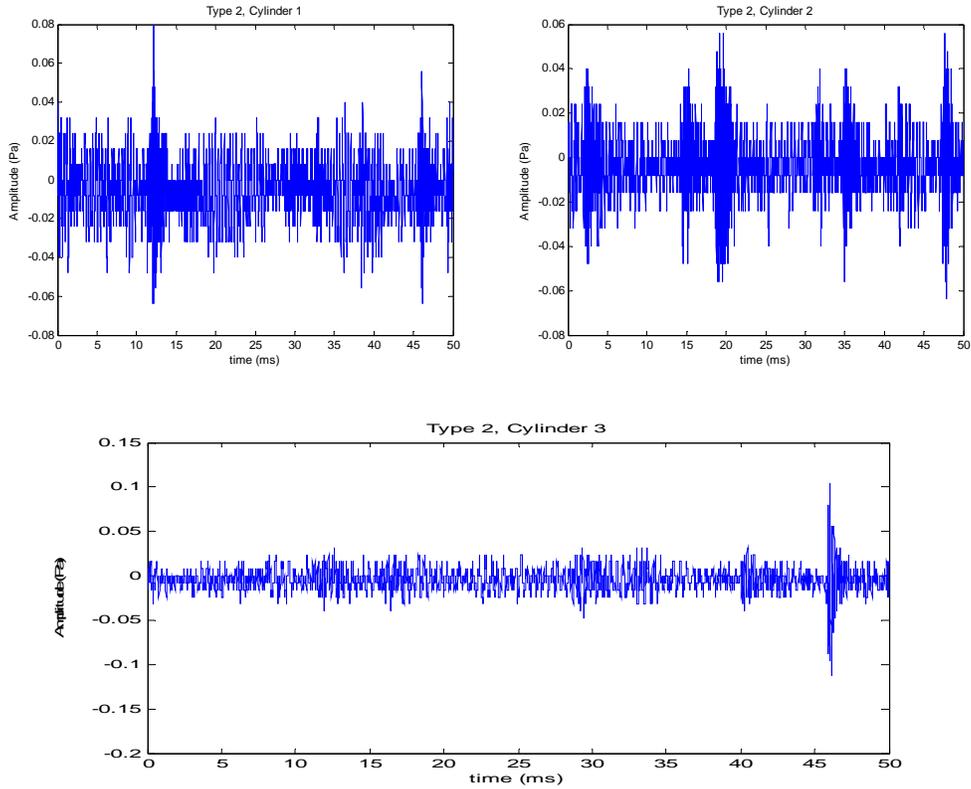


FIGURE 3: Ultrasonic signals from engine Type 2

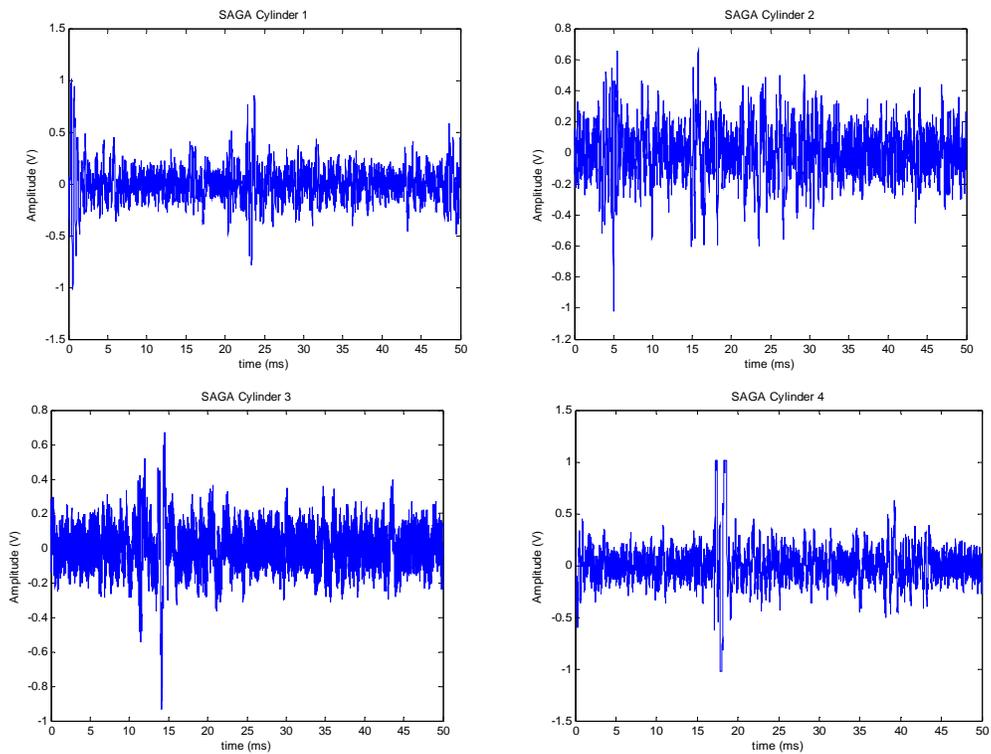


FIGURE 4: Ultrasonic signals from engine Type 3

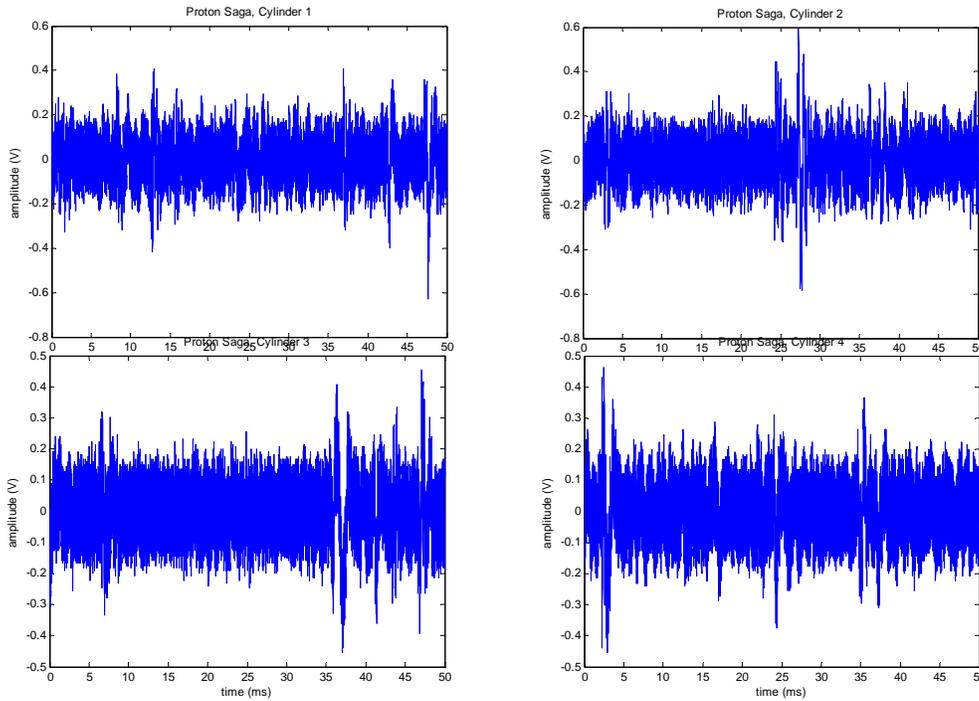


FIGURE 5: Ultrasonic signals from engine Type 4

TABLE 2: Frequency and magnitude of signal obtained from each cylinder

RPM	Automobile Type 1			Automobile Type 2		
Cylinder	1	2	3	1	2	3
Magnitude(dB)	26.94	24.00	24.44	12.83	11.56	20.32
Frequency (kHz)	48.83	48.83	48.83	2587.89	2441.41	2734.38

RPM	Automobile Type 3				Automobile Type 4			
Cylinder	1	2	3	4	1	2	3	4
Magnitude(dB)	46.05	47.51	47.35	47.05	45.97	46.59	46.40	46.87
Frequency (kHz)	18.85	18.90	18.80	18.85	18.75	18.80	18.75	18.75

TABLE 3: Statistical result of signal obtained from each cylinder for different engine.

RPM	Cylinder	I-kaz (10^{-08})	CF	Skewness	Kurtosis
Automobile Type 1	1	3.41	0.0380	0.0452	3.74
	2	3.15	0.0353	0.109	5.19
	3	4.02	0.0663	0.121	11.6

Automobile Type 2	1	1.13	0.0491	0.118	4.93
	2	1.42	0.0449	0.262	4.66
	3	1.51	0.0418	0.304	3.96
Automobile Type 3	1	246.7	0.0350	-0.050	2.531
	2	276.6	0.0330	-0.006	3.061
	3	217.3	0.0260	-0.030	2.425
	4	208.3	0.0270	-0.018	2.349
Automobile Type 4	1	178.6	0.0290	-0.018	2.368
	2	151.1	0.0200	0.003	2.000
	3	198.3	0.0270	0.005	2.470
	4	243.1	0.0310	-0.0470	2.822

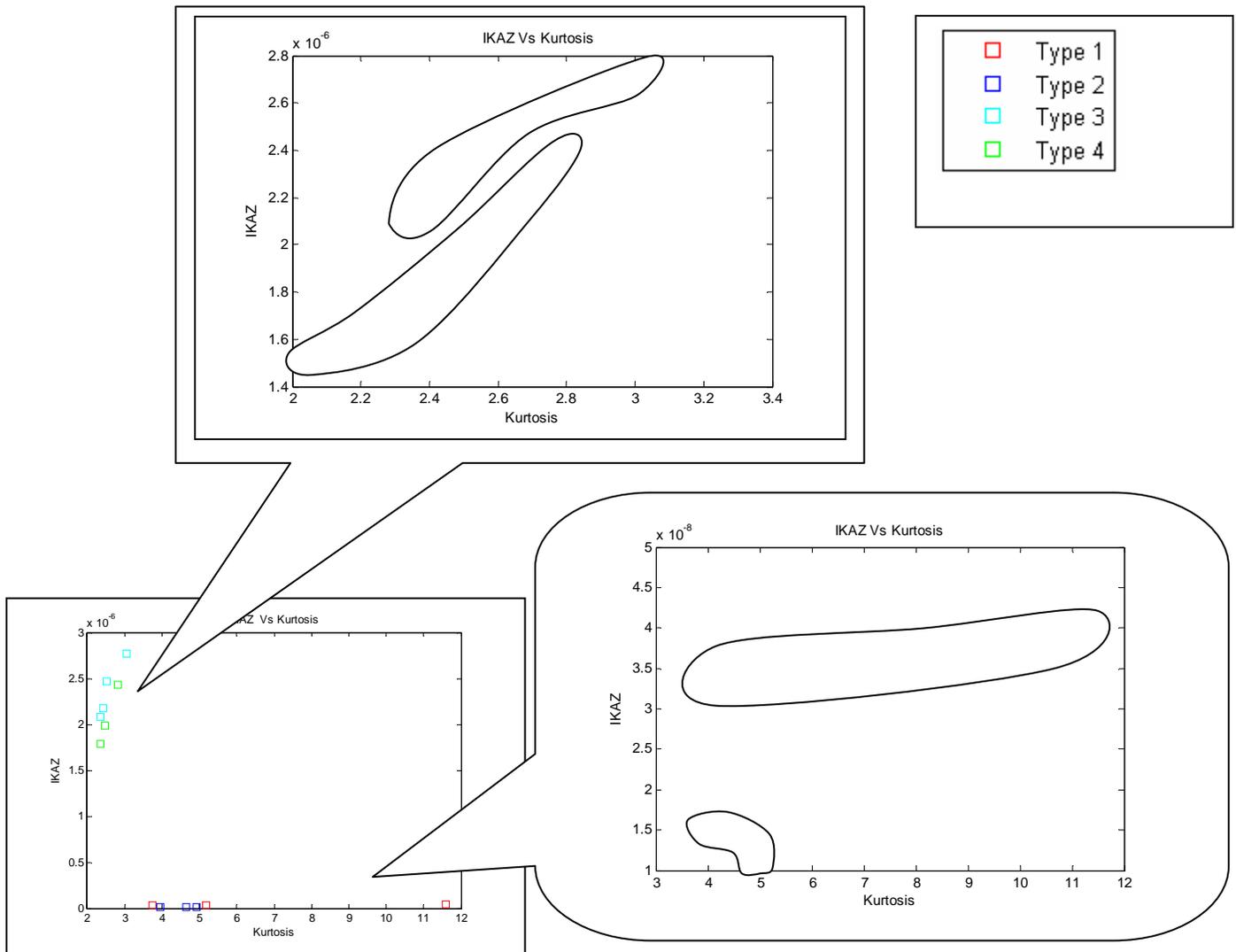


FIGURE 6: Scatter plots of IKAZ vs Kurtosis for all four engines

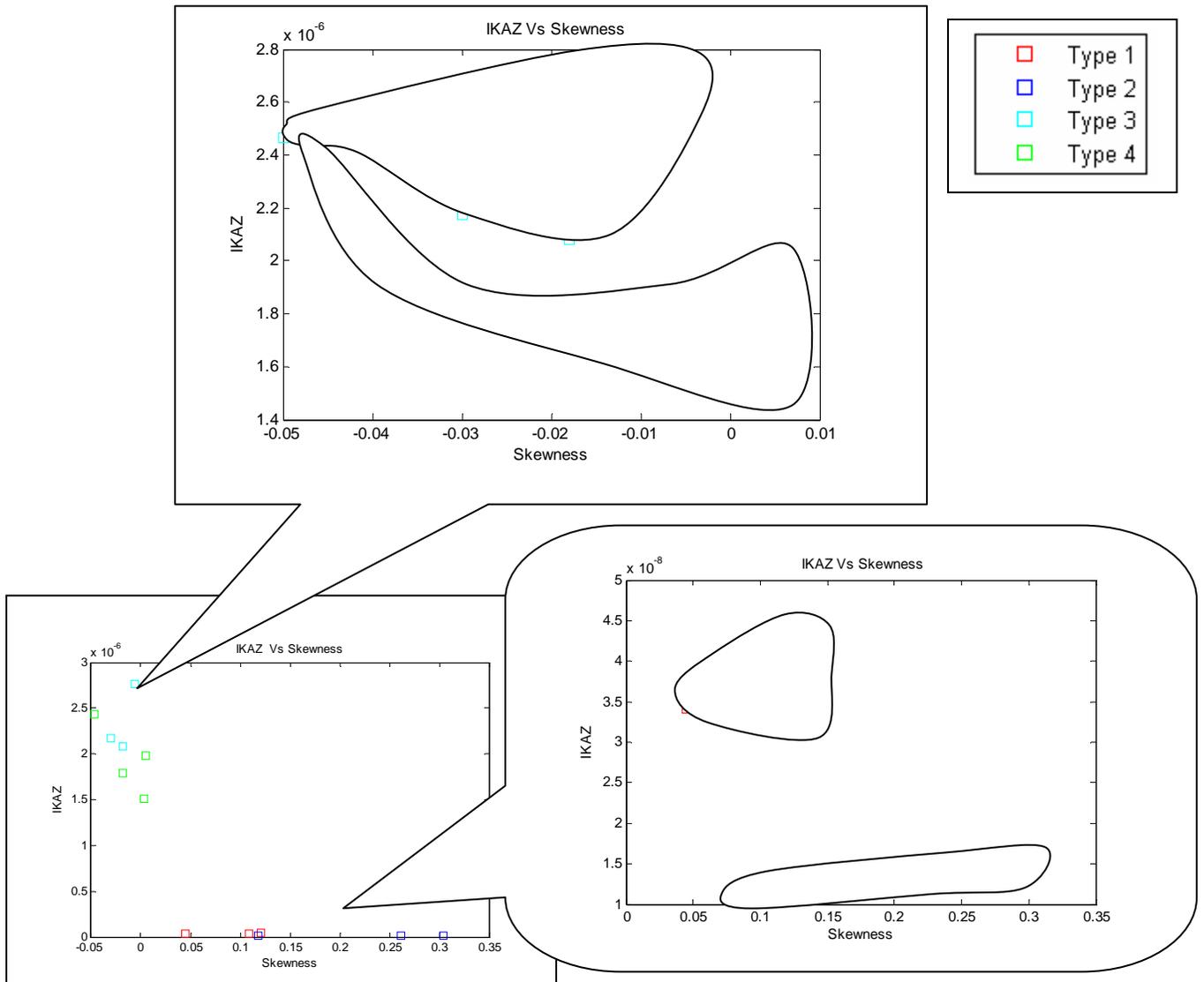


FIGURE 7: Scatter plots of IKAZ vs Skewness for all four engines

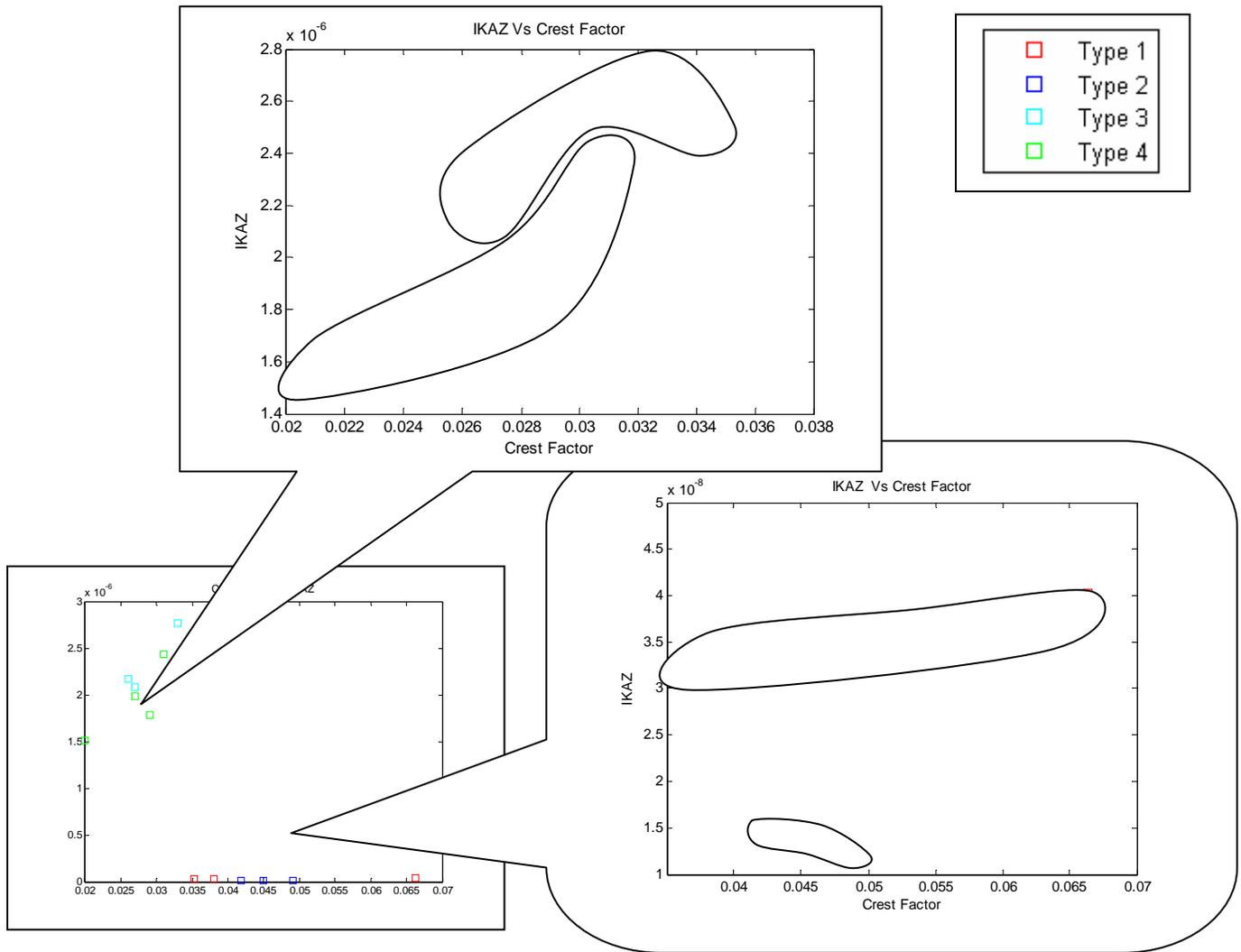


FIGURE 8: Scatter plot of IKAZ vs Crest factor for all four engines

The results indicated two major regions in clustering the pistons. One region which contains Type 1 and Type 2, another one contain Type 3 and Type 4. This applied to all three clustering method that we used to cluster the pistons. The difference of these regions due to different I-kaz coefficient value. Zooming at region with lower I-kaz coefficient as shown at the right of the figure, we had seen the pistons of engine Type 1 and Type 2 obviously locate at different region. This results contrast with region in higher I-kaz coefficient value for Type 3 and 4, where the cluster of both

engine types were separate by small gap. However the pistons still can be cluster according to their engine type. Figure 2 which plotting the I-kaz coefficient versus kurtosis was the better result of all three clustering method. The differences between each region barely observe.

An existing two major region in plotting I-kaz coefficient versus kurtosis, skewness and crest factor were due to difference in I-kaz coefficient. Result from Table 3 shown high difference of I-kaz coefficient between Type 1 and 2, however for Type 3 and 4 there were no significant difference between their I-kaz

coefficients. By comparing magnitude and I-kaz coefficient, fluctuation of I-kaz coefficient lead to changes in magnitude. This suggests the increasing of I-kaz coefficient resulted increase of magnitude.

5. Conclusions

This paper has proven that clustering can be done by the statistical parameter approach. Each engines type can be differentiate by applying this approach. Especially engines which have obvious I-kaz coefficient difference (i.e Type 1 and Type 2). To conclude, the plot of I-kaz coefficient versus skewness, kurtosis and crest factor obtained an obvious clustering of the measured signal, where the I-kaz coefficient contribute a vital role in signal clustering of engine performance.

6. References

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