ANALYSIS OF YOUNG MODULUS AND POISSON RATIO USING I-KAZ 4D ANALYSIS METHOD THROUGH PIEZOFILM SENSOR

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Abstract: An alternative advanced statistical analysis method known as the I-kaz 4D or I-kaz 4 channels which using the sensor fusion concept by using four sensors to collect the vibration signals that excited by the impact hammer was introduced in this study. Mechanical properties of the material like Young Modulus and Poisson Ratio were obtained. The study carried for 2 types of metals i.e. copper and stainless steel. The specimens were in shape of circular, rectangular and square, where more material mechanical properties were obtained due to the variety of specimen shapes. The impact hammer used for the impact force with the range of different forces. The four piezofilm sensors have been placed on specimen surface to observe and record the vibration signal after the impact. The dynamic response technique also was used in this study and the obtained results been compared with the results obtained by I-kaz 4D method. Finally, correlation between I-kaz 4D coefficient and regression value being done to verify the result and justify the findings. The error for Young Modulus was 2.962% while Poisson Ratio was 1.000%. The study adhered to ASTM E1876 standard.

Keywords: I-kaz 4D; Impact Force; Piezofilm Sensor; Vibration Signal; Sensor Fusion

1. Introduction

The study deals with the use of the impact testing method to produce an excitation within the metallic material specimen. This method is relatively a simple technique to implement at the same time there is challenges in obtaining symmetric results. The most important features of present method are that it does not require a complex and expensive machine instead it just needs some hardware, which make this technique very attractive and convenience. The technique applies Non Destructive Test (NDT).

The implementation apparatus consists of the impact hammer, analyser and software. A piezoelectric sensor is used to monitor the vibration signal of the specimen under the impulse excitation in order to analyse and determine its characteristic frequencies [1, 6, 15-16]. Further analysis is done on the vibration
signals observed during the test impact and the possible correlation between these signals and the specific material properties were studied by digital signal analysis approach using the I-kaz 4D [12].

2. Methodology
The characterization of material properties in this study is based on the analysis of vibration signal resulting from the impact force from the impact hammer [2, 14]. With the help of Labview software 2015, DAQ NI 9234 National Instrument data collection system, and Rion-Note multi-factional measuring system platform SA-A1 device, data input from impact hammer were being processed, stored and analyzed.

Two types of signals were observed by the developed softwares, i.e., the vibration signal from the piezofilm sensor and the impact force signal. Observations were carried out using appropriate equipment to measure the signals of different type. Next, an alternative method for signal analysis and interpreting signals were used. Here, data correlation with I-kaz 4D coefficient were conducted to verify the result obtained [3-5].

The impact force were set at the range of 200-300 N, 300-400 N, 400-500 N, 500-600 N, 600-700 N and 700-800 N. Figure 1 shows the schematic diagram of the experiment while Table 1 shows the experiment components.

![Figure 1. Schematic diagram of the experiment](image)

| Component | Specifications | Quantity |
|-----------|----------------|----------|
| Impact    | D15 cm         | 1        |
I-kaz 4D is using the direct fusion where the data are collected from 4 homogeneous sensors. The formula of I-kaz 4D is as follows:

\[ Z_{4D}^* = \frac{1}{n} \sqrt{\frac{k_1s_1^4 + k_2s_2^4 + k_3s_3^4 + k_4s_4^4}{s}} \]

Where
- \( Z_{4D}^* \): I-kaz 4D coefficient
- \( n \): number of samples
- \( k \): kurtosis
- \( s \): standard deviation.

3. Result And Discussion

3.1 Type of Signals

Two types of signal data measured in the experiment simultaneously, namely the signal of the impact force and vibration signal captured by the four piezofilm sensors for each of the circular, rectangular and square shapes which will be analyzed using I-kaz 4D, beside the vibration signal captured by only one piezofilm sensor for the circular shape specimen which will be analyzed using FFT method. The two signals are generated during the process of impact between the impact hammer and the material specimens. Fig. 2 shows the vibration signal of copper. Fig. 3 shows the vibration signal of stainless steel.
The time domain signal obtained showed that fine exaggeration of impact vibration have been captured by the piezofilm sensors. The outcome proved that piezofilm sensors can act as an alternative sensor on behalf accelerometer [13].

The vibration signals obtained from the impulse excitation experiment were analysed using the new developed statistical methods known as I-kaz 4D. The I-kaz 4D method known as Integrated kurtosis-based algorithm using four sensors simultaneously to record the vibration signals.

In this method, the time domain of vibration signals that captured by the piezofilm sensors were analysed in order to extract the information contained in the signal content. The statistical analysis of I-kazTM methods is based on the concept of scattering data to a central value [3, 10].

Figure 2. Vibration signal of circular copper at 300N

Figure 3. Vibration signal of circular stainless steel at 300N
3.2 Correlation between Piezofilm Signals and Material Mechanical Properties

To study the existence of some kind of correlation between the vibration signal and any of mechanical properties of the metal materials of the three different shapes that used in the experiment, the vibration signal that recorded by the piezofilm sensor has been analysed by applying the I-kaz 4D statistical analysis method which produced the I-kaz 4D coefficient.

The pattern of changing in the magnitude of these I-kaz 4D coefficients with respect to the changing of the impact force that applied on the specimen for all shapes has been studied by plotting the I-kaz 4D coefficients of the piezofilm sensors. Fig. 4 and Fig. 5 show the graph obtained while Table 2 and Table 3 shows the data.

![Figure 4. I-kaz 4D vs impact forces for copper](image)

**Table 2.** Quadratic equations and coefficients (R²) of copper

| Shape    | Linear equations                                                                 | (R²) |
|----------|-----------------------------------------------------------------------------------|------|
| Circular | $y = 9.872 \times 10^{-12} x^2 + 8.1236 \times 10^{-9} x - 1.2412 \times 10^{-7}$ | 0.985|
| Square   | $y = 3.029 \times 10^{-8} x + 3.963 \times 10^{-7}$                              | 0.980|
| Rectangular | $y = 7.498 \times 10^{-12} x^2 + 4.202 \times 10^{-9} x - 1.737 \times 10^{-7}$    | 0.975|
3.3 Analysis of the Circular Shape Specimen
A quadratic polynomial curve fitting has been chosen to show the trend line of changing of I-kaz 4D coefficients value for each material. Quadratic polynomial trend-line is chosen because it has the best correlation coefficient (R²) that ranged between 0.971 to 0.985 as shown in Table 2 and Table 3.

3.4 Analysis of the Square Shape Specimen
A linear curve fitting has been chosen to show the trend line of changing of I-kaz 4D coefficients value for each material. Linear trend-line is chosen because it has the best correlation coefficient (R²) that ranged between 0.980 to 0.985. Based on the linear equation for each material from Table 2 and Table 3, the difference between these linear equations (y = ax + b) can be characterized clearly from its slope (a). To obtain a relationship between the vibration signal of the piezofilm sensors and the mechanical properties of the materials, the slope (a) of I-kaz 4D coefficients linear equations are analysed. Thus, the linear coefficients of I-kaz 4D curves are arranged in ascending order.

3.5 Analysis of the Rectangular Shape Specimen
A quadratic polynomial curve fitting has been chosen to show the trend line of changing of I-kaz 4D coefficients value for each material of the rectangular shape. Even though the correlation coefficient (R²) ranged between 0.975 to 0.989 as shown in Figure 4 and Figure 5, which is considered a good correlation, but the new sequence of the quadratic coefficients of I-kaz 4D (a) resulted from this curve fitting for the rectangular shape was not matching any sequence for any mechanical properties of the experiment.
specimens, Table 2 and Table 3 show the quadratic coefficients of I-kaz 4D (a) sequence of the rectangular.

3.6 Correlation between Piezofilm Signals and Young Modulus

By making a comparison between the sequence of the quadratic coefficient (a) of I-kaz 4D with the sequence arrangement of the material properties, it is found that the sequence order of the quadratic coefficient of I-kaz is similar to the sequence order of the Young Modulus of the materials. Table 4 shows the quadratic coefficient of I-kaz of vibration signal obtained from the piezofilm and Young Modulus for each type materials respectively.

Table 4: Quadratic coefficients (a) and Young Modulus of materials

| Material        | Quadratic I-kaz 4D coefficients (a) | Young Modulus (GPa) |
|-----------------|-------------------------------------|---------------------|
| Copper          | 9.87                                | 117                 |
| Stainless Steel | 13.8                                | 203                 |

From Table 4, it can be seen that there is a relationship between the vibration signal of the piezofilm sensors and the Young Modulus of the two types of the circular metal materials. The manner of the relationship is that the metal, which has highest Young Modulus, will have the highest quadratic coefficient of I-kaz 4D of vibration signal of piezofilm sensors. To obtain the expression for correlation between vibration I-kaz 4D quadratic coefficient and Young Modulus in the form of a mathematical representation, the graph of the quadratic coefficient of vibration I-kaz 4D for two types of the circular metals, which are Copper and Stainless steel versus Young Modulus been plotted as shown in Figure 6.

Figure 6. Young Modulus versus I-kaz 4D linear coefficient of vibration signal

Based on Figure 6, the linear trendline is chosen to matching the data. Linear equation for the linear trendline is \( y = ax + b \). Linear trendline is chosen because its correlation coefficient (R²) which has a good value of 1.0. The mathematical expression for correlation process is based on a resulting linear equation
(2) of Figure 6.

\[ y = 21.883x - 98.985 \]  

By using equation (2), it can be concluded that the mathematical expression for correlation process between the vibration signal of the piezofilm sensors and the Young Modulus is as the following equation (3).

\[
\text{Young Modulus,} \\
E = 21.883(\text{quadratic coefficient of I-kaz 4D}) - 98.985
\]  

(3)

To verify the accuracy and validity of the correlation equation, the value of I-kaz 4D quadratic coefficient of mild steel (that excluded from correlation process and obtained from same process) for verification purposes is substituted in equation (3) to obtain its Young Modulus such as follow:

\[
E = 21.883 (13.4) - 98.985 \\
E = (293.232 – 98.985) \text{ GPa} \\
E = 194.247
\]

The Young Modulus of mild steel obtained by correlation equation is 194.247 GPa. This value is compared with the value of Young Modulus obtained from the ASTM E1876 [8] standards which is 200 GPa. The resulting percentage error of the difference between the two values is 2.962% as computed below. These results approve that the alternative statistical analysis I-kaz 4D developed in this study can be used to characterize the Young Modulus of the metal materials.

\[
\text{Error}\% = \frac{|194.247 - 200|}{194.247} \times 100\% \\
\text{Error}\% = 2.962\%
\]

### 3.7 Correlation between Piezofilm Signals and Poisson Ratio

By using the same data obtained in Table 4, the existence of a relationship between the vibration signal that captured by the piezofilm sensors and the materials properties that used in the experiment has been investigated, the same I-kaz 4D statistical analysis method has been used.

**Table 5.** Quadratic coefficients (a) and Poisson Ratio of materials

| Material       | Quadratic I-kaz 4D coefficients (a) | Poisson Ratio |
|----------------|-------------------------------------|---------------|
| Copper         | 9.87                                | 0.355         |
| Stainless Steel| 13.8                                | 0.290         |

From Table 5, it can be seen that there is a relationship between the vibration signal of the piezofilm sensors and the Poisson Ratio of the two types of the circular metal materials. The manner of the relationship is that the metal, which has highest Poisson ratio, will have the lowest quadratic coefficient of I-kaz 4D of vibration signal of piezofilm sensors. To obtain the expression for correlation between vibration I-kaz 4D quadratic coefficient and Poisson Ratio in the form of a mathematical representation, the graph of the quadratic coefficient of vibration I-kaz 4D for two types of the circular metals, which are
copper and stainless steel versus Poisson Ratio been plotted as shown in Figure 7.

Figure 7. Poisson Ratio versus I-kaz 4D linear coefficient of vibration signal

From Figure 7, the linear trendline was chosen due to the high correlation ($R^2$) of 1.0. The mathematical expression for correlation process is based on a resulting linear equation (4) of Figure 7.

$$y = -0.0165x + 0.5182$$

(4)

By using equation (4), it can be concluded that the mathematical expression for correlation process between the vibration signal of the piezofilm sensors and the Poisson Ratio is as the following equation (5).

$$\mu = -0.0165 \text{ (quadratic coefficient of I-kaz 4D)} + 0.5182$$

(5)

To verify the accuracy and validity of the correlation equation, the value of quadratic coefficient of mild steel (that excluded from correlation process and obtained from same process) for verification purposes is substituted in equation (5) to obtain its Poisson Ratio such as follow:

$$\mu = -0.0165(13.4) + 0.5182,$$

$$= 0.297$$

The value of Poisson ratio of mild steel obtained by correlation equation is 0.297, while according to the ASTM E1876 standards it is 0.300. The resulting percentage error of the difference between the two values is 0.852% as computed below. These results approve that the alternative statistical analysis I-kaz 4D developed in this study can be used to characterize the Poisson ratio of the metal materials.

$$\text{Error}\% = \left| \frac{0.297 - 0.300}{0.300} \right| \times 100\%$$

$$\text{Error}\% = 1.000\%$$

4. Conclusion

In this study, methods of characterisation of the material properties using advance statistical analysis of
vibration signal known as I-kaz 4D has been developed. It was understood that I-kazTM method showed a significant better result [5, 10].

The I-kaz 4D coefficients for vibration signal that has been recorded in the experiment using the four piezofilm sensors simultaneously are obtained using I-kaz 4D method. It is found that the I-kaz 4D coefficient for vibration signals increased when the specimen is subjected to higher impact and forms a quadratic or linear curve [7, 9, 11]. Through the characterisation of quadratic and linear curves and the properties of tested materials, it is found that there is a relationship between I-kaz 4D coefficient of vibration signals that recorded by the piezofilm sensors and the Young Modulus and Poisson Ratio.

5 Acknowledgments
The authors wish to thank both UKM and UTeM for assisting all this while in making this research accomplished. This project is supported by Universiti Teknikal Malaysia Melaka, UTeM (grant no.: PJP/2018/FTK(5B)/S01596).

6. Appendix

7. References
[1] L. Bruno, G. Felice, L. Pagnotta, A. Poggiliani and G. Stigliano, “Elastic characterisation of plates of any shape via static testing”, International Journal of Solids and Structure, vol. 45, no. 3-4, pp. 908–920, 2008.
[2] Z. Karim, H.A.R. Izatul, S.A.S. Azuan, S. Mastura, A.Y.M. Said, A.R. Bahari, J.A. Ghani and M.Z. Nuawi, “Material mechanical property correlation study using vibration signal analysis”, Australian Journal of Basic and Applied Sciences, vol. 7, no. 4, pp. 94-99, 2013.
[3] M.Z. Nuawi, M.J.M. Nor, N. Jamaludin, S. Abdullah, F. Lamin and C.K.E. Nizwan, “Development of integrated kurtosis-based algorithm for z-filter technique”, Journal of Applied Sciences, vol. 8, pp. 1541-1547, 2008.
[4] M. Alfano and L. Pagnotta, “Determining the elastic constants of isotropic materials by modal vibration testing of rectangular thin plates”, Journal of Sound and Vibration, vol. 293, no. 1–2, pp. 426–439, 2006.
[5] M.T. Jasim, M.Z. Nuawi, S.S. Ziyad, A.R. Bahari, F.M. Nadia and M.H. Mohammad, “Characterisation of mechanical properties using I-kazTM analysis method under steel ball excitation technique”, Journal of Applied Science, vol. 14, no. 24, pp. 3595-3603, 2014.
[6] M.I. Ramli, M.Z. Nuawi, S. Abdullah, M.R.M. Rasani, M.S. Salleh and M.F. Basar, “The study of EMA effect on modal identification: a review”, Journal of Mechanical Engineering Technology, vol. 9, no. 1, pp. 103-121, 2017.

[7] T. Yoshida, K. Sakurada and M. Hoshino, “Measurement of static stress in round bar by impact sound”, Proceedings of the 14th International Conference on Experiment Mechanics, Poitiers, France, 2010.

[8] ASTM E1876, Standard test method for dynamic Young Modulus, shear modulus and Poisson ratio by impulse excitation of vibration, Philadelphia, American Society for Testing Materials, 2010.

[9] M.I. Ramli, M.Z. Nuawi, S. Abdullah, M.R.M. Rasani, K.K. Seng and M.A.F. Ahmad, “Development on simulation of small structure modal analysis method using piezoelectric film sensor”, Proceedings of the 23rd International Congress on Sound and Vibration, ICSV 2016, Athens, Greece, 2016.

[10] S.S. Ziyad, M.Z. Nuawi, M.T. Jasim, A.R. Bahari and F.M. Nadia, “Characterisation of polymer material using I-kaz™ analysis method under impact hammer excitation technique”, Journal of Applied Sciences, vol. 15, no. 1, pp. 138-145, 2015.

[11] M.I. Ramli, M.Z. Nuawi, S. Abdullah, M.R.M. Rasani, M.A.F. Ahmad and K.K. Seng, “An investigation on light structure modal parameter by using experimental modal analysis method via piezofilm sensor”, Jurnal Teknologi, vol. 79, no. 6, pp. 159-165, 2017.

[12] M.A.F. Ahmad, M.Z. Nuawi, J.A. Ghani, S. Abdullah and M.I. Ramli, “An investigation on tool wear monitoring using MFC and PVDF sensors via I-kaz™ statistical signal analysis”, Proceedings of Mechanical Engineering Research Day 2018, Universiti Teknikal Malaysia Melaka, Malaysia, pp. 301-302, 2018.

[13] J. Guo, S.K. Chee, T. Yano and T. Higuchi, “Micro-vibration stage using piezo actuators”, Sensors and Actuators A, vol. 194, pp. 119-127, 2013.

[14] M.I. Ramli, M.F. Basar and N.H.A. Razik, “Natural energy water pump: revisit the water sling pump”, International Journal of Innovative Technology and Exploring Engineering, vol. 3, no. 2, pp. 188-191, 2013.

[15] Y.F. Xu and W.D. Zhu, “Operational modal analysis of a rectangular plate using non-contact excitation and measurement”, Journal of Sound and Vibration, vol. 332, pp. 4927-4939, 2013.

[16] M.S. Ahmad, M.Z. Nuawi, A. Othman and M.A.F. Ahmad, “Metallic material characterization using acoustics signal analysis”, Jurnal Teknologi, vol. 78, no. 6-10, pp 31-37, 2016.