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COMPARISON STUDY ON LIGHT STRUCTURE MODAL PARAMETER USING EXPERIMENTAL MODAL ANALYSIS METHOD VIA PIEZOFILM SENSOR

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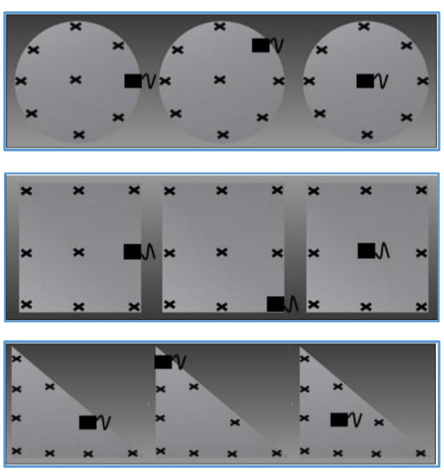
Graphical abstract



Abstract

This study determines the effect of modal parameters namely natural frequencies and mode shapes of aluminum 6061 (Al6061)through free dynamic vibration analysis and testing. The simulation procedures was conducted via ANSYS software while the experimental work was performed through impact hammer testing. Three types of specimens in the form of circular, square and triangular-shapes were used to determine the vibration parameters. Two sensors i.e. piezoelectric film and accelerometer were used. The results for circular shape were $y_a = 270.55x - 134.82$ (accelerometer) and $y_p = 280.89x - 215.05$ (piezofilm); for square shape were $y_a = 316.42x - 104.13$ (accelerometer) and $y_p = 309.63x - 43.20$ (piezofilm); and for triangular shape were $y_a = 329.77x - 142.87$ (accelerometer) and $y_p = 305x + 15$ (piezofilm). The y_a (accelerometer) and y_p (piezofilm) are represented as a linear equation of which the data were plotted in mode shape versus natural frequency graph accordingly. By applying the simultaneous equation, the regression ratio can be obtained. The relation between natural frequency and mode shape of accelerometer and piezofilm for the circular-shaped specimen was $y_a = 0.96y_p + 72.3$; square-shaped specimen was $y_a = 1.02y_p - 59.98$; and triangle-shaped specimen was $y_a = 1.08y_p - 159.08$ respectively. The results for the natural frequency from the experimental test were used to compare with the results from the simulation. It was understood that the regression ratios of 0.96, 1.02 and 1.08 of circular-shaped, square-shaped and triangular-shaped were closed to 1.0. The outcome showed that the piezoelectric film sensor is a potential candidate to be used as an alternative sensor for the accelerometer.

Keywords: Modal parameters, natural frequency, mode shape, modal analysis, piezoelectric film, accelerometer

Abstrak

Kajian ini dilakukan untuk mengenalpasti parameter modal terdiri daripada frekuensi jati dan bentuk ragam bagi aluminum 6061 (Al6061). Kajian untuk mengenalpasti parameter dilakukan dengan analisis getaran dinamik bebas. Simulasi dijalankan menggunakan perisisan ANSYS manakala ujikaji makmal menggunakan tukul hentaman ke atas specimen bentuk bulatan, segiempat sama dan segitiga bagi mengenalpasti parameter getaran. Dua sensor iaitu filem piezoelektrik dan meter pecutan digunakan. Keputusan diperolehi adalah $y_a = 270.55x - 134.82$ (meter pecutan) and $y_p = 280.89x - 215.05$ (filem piezo) untuk bulatan; $y_a = 316.42x - 104.13$ (meter pecutan) and $y_p = 309.63x - 43.20$ (filem piezo) untuk segiempat sama; $y_a = 329.77x - 142.87$ (meter pecutan) and $y_p = 305x + 15$ (filem piezo) untuk segitiga. y_a (meter pecutan) and y_p (filem piezo) merupakan persamaan garis lurus terhasil dari data diperolehi daripada graf bentuk ragam melawan frekuensi jati. Seterusnya, menggunakan persamaan serentak, nisbah regresi dapat ditentukan. Hubungan antara frekuensi jati dan bentuk ragam untuk meter pecutan dan filem piezoelektrik bagi spesimen bulatan adalah $y_a = 0.96y_p + 72.3$; segiempat sama $y_a = 1.02y_p - 59.98$; segitiga $y_a = 1.08y_p - 159.08$. Selanjutnya, keputusan frekuensi jati dari ujikaji makmal digunakan untuk perbandingan dengan keputusan simulasi. Dapat disimpulkan nisbah regresi 0.96, 1.02 dan 1.08 mendekati 1.0 dan mematuhi status penderia piezoelektrik yang boleh digunakan sebagai alternatif kepada penderia meter pecutan. Satu keputusan yang jitu diperolehi menerusi perbandingan di antara hasil simulasi dan ujikaji.

Kata kunci: Parameter modal, frekuensi jati, bentuk ragam, analisis modal, filem piezoelektrik, meter pecutan

1.0 INTRODUCTION

Experimental Modal Analysis (EMA) is carried out to examine modal parameters which determine natural frequency, mode shape and damping ratio [1, 2]. The purpose of this study is to determine the natural frequency and mode shape of Aluminum 6061. The experiment is carried out using the Single Input Single Output (SISO) method. Modal Analysis is derived from Equation of Motion which stated that every motion occurs is incorporated with vibration alongside it [3]. By using signal analysis, the vibration response of the structures to the impact excitation [4] is measured and transformed into Frequency Response Functions (FRF) using fast Fourier Transformation Technique (FFT). Hence, the measurement of the FRF is the heart of modal analysis [5].

The natural frequency is the rate at which an object vibrates when it is not disturbed by an outside force [6]. Each degree of freedom of an object has its own natural frequency, expressed as f. This frequency is equal to the speed of vibration divided by wavelength, $f = v/\lambda$. Other related equations to find the natural frequency depend on the vibration system involved. Natural frequency can be either damped or undamped [7–9]. The natural frequencies are simple to measure and was claimed as a low cost experimental procedures. Due to this, many studies have been conducted by focusing on damage detection [10].

In some occasions, the stiffness and mass of a certain structure play important roles in determining the natural frequency of that structure [11, 12]. If frequency of any excitation source coincides with the resonance frequency of a structure, a resonance will occur and can eventually lead to a failure of the entire system. Therefore, the natural frequency is an important parameter that should be precisely analysed to prevent resonance [13, 14].

Mode shapes can be obtained through displacement (eigenvectors), referred to as mass-normalization with respect to the orthogonality properties of the mass-normalized modal matrix [15]. A mode shape is a specific pattern of vibration executed by a mechanical system at a specific frequency. Different mode shapes will be associated with different frequencies. The experimental technique of modal analysis discovers these mode shapes and frequencies [16-18].

The mode shape contributes in fixing the desired natural frequency by combining mode shapes to shape i.e. a beam to change its natural frequencies, numerically and experimentally [7, 19]. Mode shape for structure such like bridges can also be estimated by using Frequency Domain Decomposition (FDD) method from numerical investigation [20]. Mode shapes have significant role in detecting the mechanical properties of materials [21]. Practically, the study limited the mode shape not exceeded than 6 modes to obtain a reasonable outcome due to higher mode shape is proportional to lower vibrational speed which is ineffective to collect significant data [22].

The method in this study follows non-destructive testing (NDT) which emphasizes on the reusage of the specimen for another study. The NDT is important as this method contributes in a low cost experimental work. By reusaging the specimen, money and time waste can be minimised. [23, 24]. The relation between natural frequency from accelerometer and piezofilm thus can be understood by finding the regression ratio after comparing the result acquired using linear equation [25].

This study is focusing on the reduction in the experimental cost by applying an NDT method and a piezofilm as an alternative sensor for accelerometer in order to capture the modal parameter.

2.0 METHODOLOGY

Impact hammer is used to generate signal by exciting on one point to another. Accelerometer and piezoelectric acted as sensors to detect the signal. The resulting signal from the sensors is then sent to the computer for detailed analysis. Simulation procedures using ANSYS is conducted via finite element method. See Figure 1.

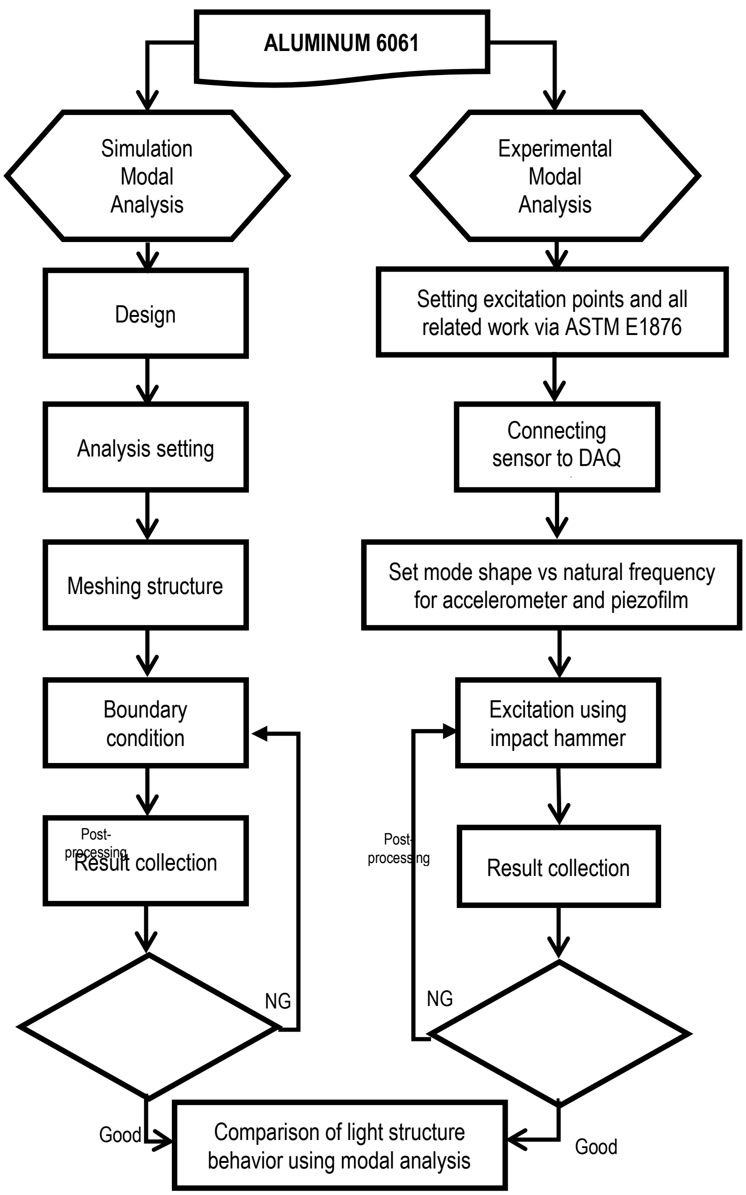


Figure 1 Experimental methodology

2.1 Experimental Set Up

Aluminum 6061 as the experimental specimen of choice is fabricated into circular shape, square shape and triangular shape. Two types of sensors were utilized in the experiment: the accelerometer and piezoelectric film.

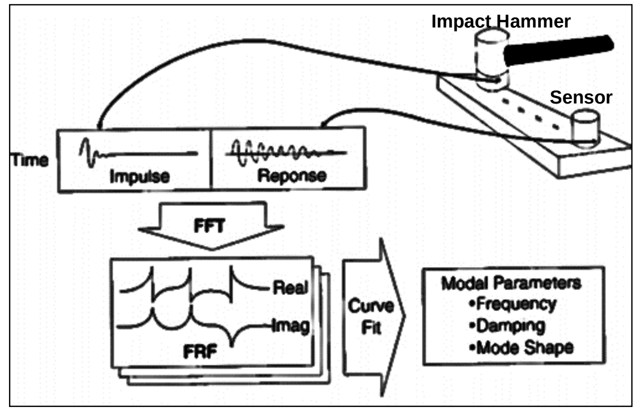


Figure 2 Impact Testing

Impact test is performed by using an impact hammer as a measurement tool to determine the impact force. Piezofilm sensor measures the response at every fixed point. Mode shapes will be displayed by post processing software that computes the FRF via FFT. Piezofilm has a unique function that can produce signal in voltage unit and is attached at the assigned point thus is able to capture the signals exaggerated by impact forces. FRFs were computed once at a time, between each impact point and the fixed response point. Modal parameters are defined by curve fitting the resulting set of FRFs. Figure 2 depicts the impact testing process.

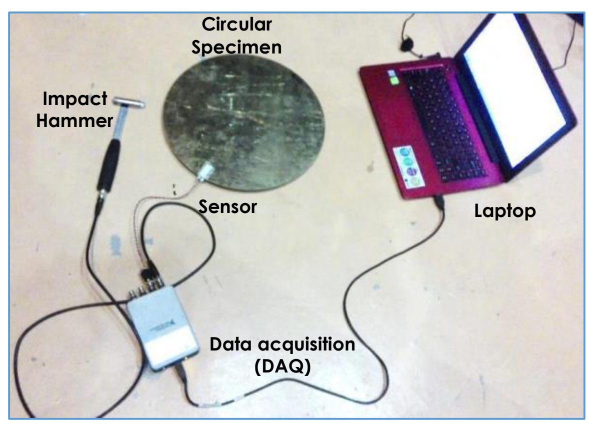


Figure 3 Experimental set up

Impact testing is performed to find mode shapes of the specimen. Modal analysis systems composed of impact hammer, sensor such as transducers (piezofilm sensor), data acquisition system (DAQ) and a host PC. Figure 3 shows the example of experimental set up of the circular shaped specimen using piezofilm sensor. However, during the actual experiment three specimens (circular, square and triangular-shaped) and both sensors (piezofilm and accelerometer) were used.

2.1.1 ANSYS Simulation

First, the proposed shapes was designed using ANSYS. ANSYS Simulation is a mechanical engineering software solution that uses Finite Element Analysis (FEA) for structural analysis by geometry preparation and optimization.

Next, mesh structure for the shapes (eg. selection of size etc.) was generated. Figure 4 displays the mesh structure of the shapes. This process extracts shifting magnitude and natural frequency of the structure and also verify mode shapes transition for every natural frequency available in the aluminum structure. These three shapes design were selected due to the uniformed in axial distribution and usually applied in industry for completing important area such as in automotive body parts or similar cases involving machinery parts.

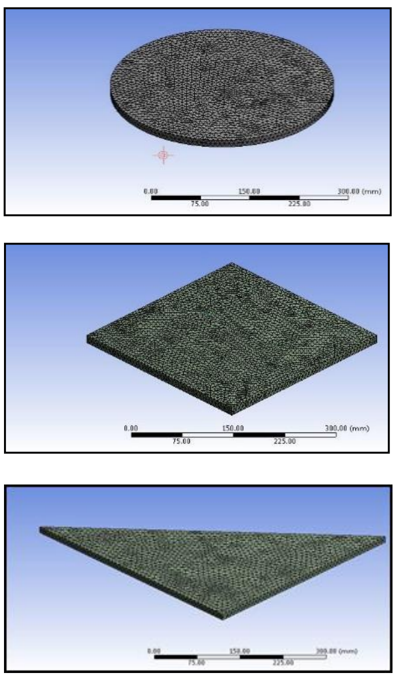


Figure 4 Meshing structure

2.1.2 Experimental Work

Initially, points of excitation in the form of knocking point by impact hammer were decided and then spotted using a marker. Channel fixing of impact hammer (called the first channel) was installed on the DAQ. The styrofoam with appropriate size and dimension has been used to support the structure from moving thus avoid unnecessary vibration during the experiment. Next, piezoelectric film was connected to the second channel while accelerometer was connected to the third channel of the DAQ. The DAQ was readily connected to the computer.

Masking tape was applied to the piezoelectric film (masking tape was used to ensure the film from sliding and also due to it lightness, its weight can be neglected) and special glue was put onto the accelerometer upon conducting the experiment. The sensor was positioned at three different points on the specimen shapes, as shown in Figure 5. All the works were conducted by following the ASTM E1876-09 standard procedure [26].

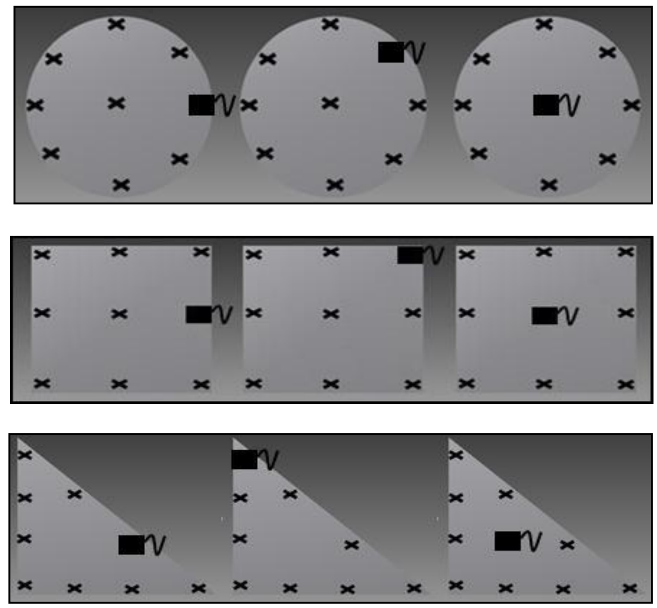


Figure 5 Sensor three-different position

3.0 RESULTS AND DISCUSSION

To compare between the simulation modal analysis and the experimental modal analysis on dynamic structure characteristics, the percentage error must be clarified first. Percentage of error are calculated as follow:

$$\text{Percentage error} = \frac{|f_1 - f_2|}{f_1} \text{ x } 100\% \quad (1)$$

or

$$\text{Percentage error} = \frac{|f_1 - f_3|}{f_1} \text{ x } 100\% \quad (2)$$

Where f_1 represents natural frequency by accelerometer, f_2 stands for natural frequency by piezoelectric film and f_3 represents natural frequency by simulation.

3.1 Simulation Result

Table 1 shows the result of simulation analysis for the natural frequency of the circle-shaped specimen.

Table 1 Simulation analysis of natural frequency for circle, square and triangle-shaped specimen

Mode shape	Natural frequency (Hz) (circle)	Natural frequency (Hz) (square)	Natural frequency (Hz) (triangle)
1	134.60	191.89	252.76
2	324.73	542.34	519.54
3	727.52	766.18	699.71
4	921.26	925.28	1030.00
5	1074.30	1181.90	1201.80
6	1491.20	1698.50	1786.40

The results showed that natural frequency increased proportionally with the increasing of mode shape. Figure 6 until Figure 8 show the mode shapes (1 – 6) of each specimen.

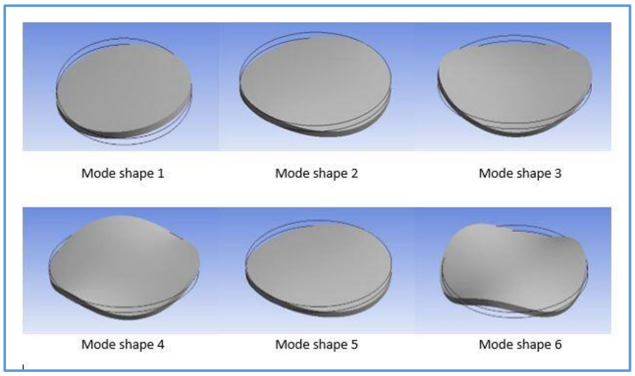


Figure 6 Circle mode shape 1 until 6

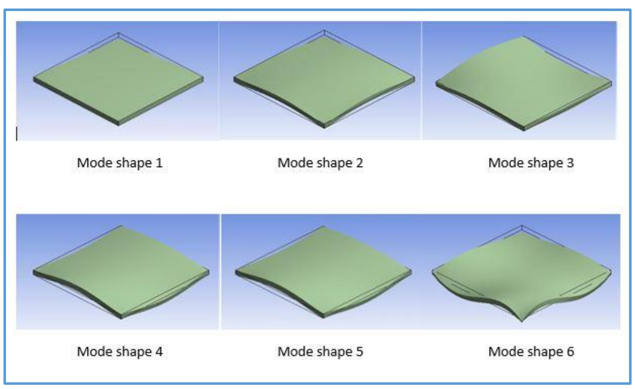


Figure 7 Square mode shape 1 until 6

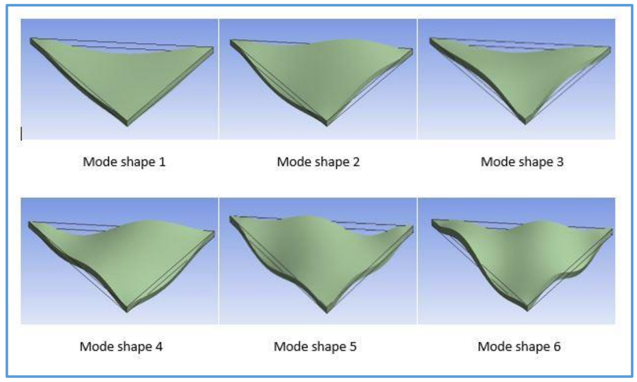


Figure 8 Triangle mode shape 1 until 6

The structural and its parameter changes in sort of stiffness, mass or geometrical parameters has influence on specific spectral or modal behavior. For example, mass changes has the greatest influence on the associated natural frequency where the amplitudes of a mode shape are high. In this case, natural frequency increased proportionally with the increasing of mode shape can be referred to the influence of mass attributed to the specimen (in solid state).

The increasing of mode shape following the increasing of natural frequency showed that the ratio of kinetic energy in the mass parameter of the specimen represent the ratio of potential energy during impact. When the impact hammer knocked the specimen, the signals were exaggerated through vibration thus changing the parameter which effect in the increasing of mode shapes. The eigenvectors (displacement mode shapes) and eigenvalue assist in finding out how parameter changes affect the mode shapes.

3.2 Experimental Work Result

Table 2 until Table 7 show the results that describe the natural frequency for every mode shape of piezoelectric film sensor and accelerometer for the circle, square and triangular specimens respectively.

Table 2 Natural frequency from analysis of piezoelectric film sensor for circle-shaped specimen

Mode shape	Natural Frequency (Hz)			
	Point 1	Point 2	Point 3	Average
1	144	143	136	141
2	362	357	244	321
3	520	515	478	504
4	804	1066	972	947
5	1191	1158	1277	1209
6	1453	1528	1477	1486

Table 3 Natural frequency from analysis of accelerometer for circle-shaped specimen

Natural Frequency (Hz)				
Mode shape	**Point 1**	**Point 2**	**Point 3**	**Average**
1	111	225	226	187
2	480	577	564	540
3	798	804	763	788
4	1293	1237	1120	1217
5	1382	1637	1498	1506
6	1846	1861	1782	1830

Table 4 Natural frequency from analysis of piezoelectric film sensor for square-shaped specimen

Natural Frequency (Hz)				
Mode shape	**Point 1**	**Point 2**	**Point 3**	**Average**
1	205	212	199	205
2	573	631	624	609
3	831	978	904	904
4	1263	1200	1147	1203
5	1631	1574	1611	1605
6	1698	1686	1762	1715

Table 5 Natural frequency from analysis of accelerometer for square-shaped specimen

Natural Frequency (Hz)				
Mode shape	**Point 1**	**Point 2**	**Point 3**	**Average**
1	201	191	193	195
2	582	574	515	557
3	891	885	819	865
4	1166	1116	1103	1128
5	1444	1442	1488	1458
6	1883	1885	1682	1817

Table 6 Natural frequency from analysis of piezoelectric film sensor for triangular-shaped specimen

Natural Frequency (Hz)				
Mode shape	**Point 1**	**Point 2**	**Point 3**	**Average**
1	228	359	244	277
2	506	810	644	653
3	760	1241	817	939
4	1125	1496	1221	1281
5	1454	1631	1488	1524
6	1782	1837	1844	1821

Table 7 Natural frequency from analysis of accelerometer for triangular-shaped specimen

Natural Frequency (Hz)				
Mode shape	**Point 1**	**Point 2**	**Point 3**	**Average**
1	204	128	144	159
2	352	435	477	421
3	492	644	739	625
4	877	1098	963	979
5	1096	1163	1145	1135
6	1574	1598	1489	1554

Referring to the results showed above (Table 2 until Table 7), both sensors (piezoelectric film and accelerometer) showed that natural frequency readings captured were the highest at point 2 (for both square and triangle-shaped specimen) mainly at all mode shapes. It can be concluded that according to the position the sensors were located, the natural frequency were clearly detected at the edge position of the structure (refer Figure 5).

Nevertheless, according to the average result for point 1 until point 3 for mode shape 1 to mode shape 6, it can be understood that the figure kept increasing following the increment of mode shape value. Assumption can be made that the average natural frequency value for circle shape is the lowest compare with square and triangle shape. The shape has significant role in vibrational propagation outcome.

The result justified that a specimen shape (with specific parameter in stiffness and mass) has significant effect to natural frequency. From the equation:

$$\omega = \sqrt{\frac{\kappa}{m}} \quad (3)$$

where;
ω: angular velocity
κ: stiffness
m: mass

and

$$\omega = 2\pi f \quad (4)$$

$$f = \frac{1}{2\pi}\sqrt{\frac{\kappa}{m}} \quad (5)$$

where;
f = natural frequency

Equation (5) clearly stated that the natural frequency is affected by the existence of stiffness and mass of the specimen.

3.3 Comparison in Dynamic Structure Characteristics of Modal Analysis Between Simulation and Experimental Work

The comparison in light structure was conducted by finding the difference and error ratio (refer eq. (1) and eq. (2)) between accelerometer versus simulation and accelerometer versus piezoelectric film sensor. Natural frequency for every mode shape transformation was compared for the structure. Results from the accelerometer is used as a reference for results from the simulation and piezoelectric film to be compared with. This is because modal analysis experimental work frequently relies on the use of an accelerometer as a sensor due to its accurateness.

The difference between natural frequency for the accelerometer and piezoelectric film is represented by f_1 - f_2 and the difference between natural frequency for the accelerometer and simulation is represented by f_1 - f_3.

Upon obtaining the error between the accelerometer and piezoelectric film sensor, the graph of natural frequency versus each mode for accelerometer and piezoelectric film sensor was plotted. By finding the equation from the graph, the coefficient between the accelerometer and piezoelectric film sensor was obtained. Thus, the relation between the accelerometer and piezoelectric film sensor was successfully determined. Refer Table 8 until Table 10.

Table 8 Comparison between accelerometer, piezoelectric film sensor and simulation for circle-shaped specimen

	Natural frequency (Hz)						
M s h p	Acc (f_1)	P.fllm (f_2)	Sim. (f_3)	Diff. 1 $\lvert f_1 - f_2 \rvert$	Diff. 2 $\lvert f_1 - f_3 \rvert$	Err. 1 (%) $\frac{f_1 - f_2}{f_1}$	Err. 2 (%) $\frac{f_1 - f_3}{f_1}$
1	158	141	134	17	24	11.1	15.2
2	421	321	324	100	96	23.8	22.9
3	625	504	727	120	102	19.3	16.4
4	979	947	921	32	58	3.3	5.9
5	1134	1208	1074	74	60	6.5	5.3
6	1553	1486	1491	67	62	4.4	4.0

From Table 8, for the accelerometer versus piezofilm, the difference of the natural frequency for each mode shape (mode 1 to mode 6) is 17Hz, 100Hz, 120Hz, 32Hz, 74Hz and 67Hz respectively. While the percentage of error for accelerometer versus piezofilm (mode 1 to mode 6) is 11.1%, 23.8%, 19.3%, 3.3%, 6.5% and 4.4% respectively.

In addition, for the accelerometer versus simulation, the difference for each mode shape (mode 1 to mode 6) based on natural frequency is 24Hz, 96Hz, 102Hz, 58Hz, 60Hz and 62Hz respectively. The percentage of error for accelerometer versus simulation (mode 1 to mode 6) is 15.2%, 22.9%, 16.4%, 5.9%, 5.3% and 4.0% respectively.

The result shown that for every mode shape, natural frequency is different and increasing proportionally with the increasing of natural frequency. The error percentage is decreasing for both experimental work and simulation. This agrees with the observation that piezofilm can be used as a replacement on behalf accelerometer.

Table 9 Comparison between accelerometer, piezoelectric film sensor and simulation for square-shaped specimen

	Natural frequency (Hz)						
M s h p	Acc (f_1)	P.fllm (f_2)	Sim. (f_3)	Diff. 1 $\lvert f_1 - f_2 \rvert$	Diff. 2 $\lvert f_1 - f_3 \rvert$	Err. 1 (%) $\frac{f_1 - f_2}{f_1}$	Err. 2 (%) $\frac{f_1 - f_3}{f_1}$
1	195	205	191	10	3	5.3	1.6
2	557	609	542	52	14	9.4	2.6
3	865	904	766	39	98	4.5	11.4
4	1128	1203	925	75	203	6.6	18.0
5	1458	1605	1181	147	276	10.1	18.9
6	1816	1715	1698	101	118	5.6	6.5

Meanwhile, from Table 9, for the accelerometer versus piezofilm, the difference between each mode shape (mode 1 to mode 6) based on the natural frequency is 10Hz, 52Hz, 39Hz, 75Hz, 147Hz and 101Hz respectively. While the percentage of error for accelerometer versus piezofilm (mode 1 to mode 6) is 5.3%, 9.4%, 4.5%, 6.6%, 10.1% and 5.6% respectively.

For the accelerometer versus simulation, the difference of the natural frequency between mode shapes (mode 1 to mode 6) is 3Hz, 14Hz, 98Hz, 203Hz, 276Hz and 118Hz respectively. The percentage of error for the accelerometer versus simulation (mode 1 to mode 6) is 1.6%, 2.6%, 11.4%, 18.0%, 18.9% and 6.5% respectively.

The result shown that for every mode shape, natural frequency is different and increasing proportionally with the increasing of natural frequency. The error percentage is decreasing for both experimental work and simulation. When compared with circle-shaped, the error observed were slightly higher, mainly at mode shape 4 and 5. The main reason here is due to specimen shape that has connection with eq. (5). This agrees with the observation that piezofilm can be used as a replacement on behalf accelerometer.

Table 10 Comparison between accelerometer, piezoelectric film sensor and simulation for triangular-shaped specimen

	Natural frequency (Hz)						
M s h p	Acc (f_1)	P.fllm (f_2)	Sim. (f_3)	Diff. 1 $\lvert f_1 - f_2 \rvert$	Diff. 2 $\lvert f_1 - f_3 \rvert$	Err. 1 (%) $\frac{f_1 - f_2}{f_1}$	Err. 2 (%) $\frac{f_1 - f_3}{f_1}$
1	187	277	253	90	66	48	35
2	540	653	520	113	20	21	4
3	788	939	700	151	88	19	11
4	1217	1281	1030	64	187	5	15
5	1506	1524	1202	18	304	1	20
6	1830	1821	1786	9	44	0.5	2

From Table 10, for the accelerometer versus piezofilm, the difference of mode shapes (mode 1 to mode 6) based on natural frequency is found to be 90Hz, 113Hz, 151Hz, 64Hz, 18Hz and 9Hz respectively. While the percentage of error for accelerometer versus piezofilm (mode 1 to mode 6) is 48%, 21%, 19%, 5%, 1% and 0.5% respectively.

Meanwhile, for the accelerometer versus simulation, the difference of mode shapes (mode 1 to mode 6) based on natural frequency is 66Hz, 20Hz, 88Hz, 187Hz, 304Hz and 44Hz respectively. The percentage of error for accelerometer versus simulation (mode 1 to mode 6) is 35%, 4%, 11%, 15%, 20% and 2% respectively.

In general, the percentage of error for the accelerometer versus piezofilm of mode 4 , 5 and 6 was satisfying the nominal percentage of error which is less than 10%. The percentage of error that is over than 10% occurred at modes 1, 2 and 3 for for both the circle and triangular shapes. The smallest percentage of error which is 0.5% occurred at mode 6 of the triangular shape.

As for accelerometer vs simulation, the trend was the same for circular shape but similar for square and triangular shapes where the percentage of error that is over than 10% accurred at modes 3, 4 and 5 (square). For the triangular shape it happened at mode 1, and modes 3 to 5. The highest percentage of error was at mode 1 with 35% (triangular shape), followed by mode 2 with 22.9% (circular shape).

The result shown that for every mode shape, natural frequency is different and increasing proportionally with the increasing of natural frequency. The error percentage is decreasing for both experimental work and simulation. When compared with circle and square-shaped, the error at mode shape 6 for triangular-shaped was the lowest. By referring to eq. (5), due to its sharp edge, when the wave propagation reached the node at the edge, this point reduce the exaggeration due to the changing in stiffness and mass value thus affect the eigenvectors and eigenvalue which resulted in stable natural frequency readings. This agrees with the observation that piezofilm can be used as a replacement on behalf accelerometer.

When compared with accelerometer vs piezofilm, it can be concluded that the average percentage of error of the piezofilm is better than the average percentage of error of the simulation.

The errors occurred at the highest point of certain mode shapes mainly because the experiment was conducted manually, therefore it is expected that the inconsistency in excitation of the developed node which has affected the inconsistency in wave propagation.

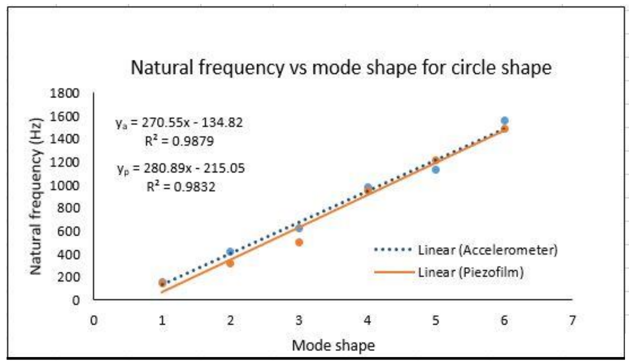


Figure 9 Natural frequency vs mode shape for circle-shaped specimen

By referring to Figure 9, the equation of gradient for accelerometer and piezofilm is:

$$\text{Accelerometer: } y_a = 270.55x - 134.82 \quad (6)$$

$$\text{Piezofilm: } y_p = 280.89x - 215.05 \quad (7)$$

Therefore, the relation between the natural frequency of accelerometer and piezofilm for the circle-shaped specimen:

$$y_a = 0.96y_p + 72.3 \quad (8)$$

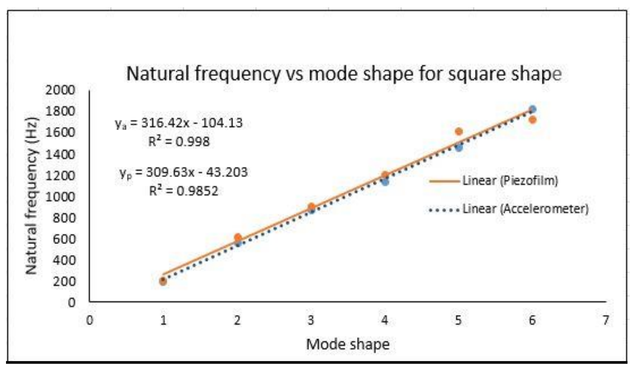


Figure 10 Natural frequency vs mode shape for square-shaped specimen

By referring to Figure 10, the equation of gradient for accelerometer and piezofilm is:

$$\text{Accelerometer: } y_a = 316.42x - 104.13 \quad (9)$$

$$\text{Piezofilm: } y_p = 309.63x - 43.20 \quad (10)$$

Therefore, the relation between the natural frequency of accelerometer and piezofilm for the square-shaped specimen:

$$y_a = 1.02y_p - 59.98 \quad (11)$$

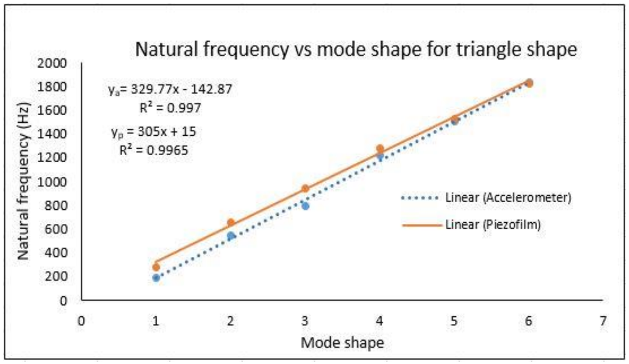


Figure 11 Natural frequency vs mode shape for triangle-shaped specimen

By referring to Figure 11, the equation of gradient for accelerometer and piezofilm is:

Accelerometer: $y_a = 329.77x - 142.87$ (12)

Piezofilm: $y_p = 305x + 15$ (13)

Therefore, the relation between the natural frequency of accelerometer and piezofilm for the triangle-shaped specimen:

$y_a = 1.08y_p - 159.08$ (14)

By referring to eq. (8), (11) and (14), it can be understood that the regression ratio of 0.96, 1.02 and 1.08 were approximately 1.0 which agree with the status of piezoelectric film sensor can be used as an alternative sensor for accelerometer.

4.0 CONCLUSION

In this study, the simulation analysis and experimental work have been successfully carried out to obtain the characteristics of natural frequency and mode shape for the aluminum 6061 that has been fabricated into circular, square and triangular shaped. The comparison between accelerometer with simulation and the comparison between accelerometer with piezoelectric film sensor have also been successfully executed.

In short, one could understand the relation between accelerometer and piezoelectric film as sensor in determining the natural frequencies and mode shapes in vibration. The graphs plotted were linear and can be concluded that piezoelectric film sensor could present approximately similar result when compare with accelerometer. For circle-shaped specimen it was $y_a = 0.96y_p + 72.3$, square-shaped $y_a = 1.02y_p - 59.98$ and triangular-shaped $y_a = 1.08y_p - 159.08$.

This study concentrates at using the piezofilm as an alternative sensor for accelerometer. This is a pilot study. In the future, we will discuss more about the usage of piezofilm through application on different material.

By obtaining the relation between the accelerometer sensor and piezoelectric film sensor, one could determine the natural frequency in aluminum components by using piezoelectric film sensor in the future. Thorough understanding of the natural frequency in the components allows for better control on the vibration range. This could assist the design and manufacturing industries by using low cost sensor, thus eliminating the risks of resonance occurrence. There was a good result agreement between simulation and experimental work outcome. As a result, damage control can be applied and potential lost in cost and life will be minimized.

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