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NOVEL TECHNIQUE OF MODAL ANALYSIS ON SMALL STRUCTURE USING PIEZOELECTRIC FILM SENSOR AND ACCELEROMETER

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ABSTRACT

Modal Analysis is a common practice to define parameters of structure under scientific view. Experimental Modal Analysis (EMA) is a well-known procedure to determine modal parameters. The usage of piezoelectric film sensor as viable and cost-saving device is indeed a need in this advance and sophisticated era. An experiment is conducted to determine modal parameters of aluminum 6061 (Al6061). Here, a free dynamic vibration analysis is conducted to obtain the parameters. Al6061 is chosen as the experiment component because of its wide application in manufacturing industries. Theoretically, if the component vibrates and produce frequency coherence with the natural frequency, resonance frequency will occur which can lead to structural failure. Modal analysis study is conducted by using both simulation and experimental methods. Simulation is conducted via ANSYS software while impact hammer testing is done for experimental work. Piezoelectric film and accelerometer are used as the sensor. The result obtained from simulation showed that frequencies for mode shape 1, 2 and 3 for square shape are 191.89Hz, 542.34Hz and 766.18Hz. The result gained from accelerometer showed that frequencies for mode shape 1, 2 and 3 for square shape are 195.00Hz, 557.00Hz and 865.00Hz. The result captured from piezoelectric film sensor appeared that frequencies for mode shape 1, 2 and 3 for square shape are 205.33Hz, 609.33Hz and 904.33Hz. The result obtained from simulation showed that frequencies for mode shape 1, 2 and 3 for circle shape were 134.60Hz, 324.73Hz and 727.52Hz. The result obtained from accelerometer showed that frequencies for mode shape 1, 2 and 3 for circle shape were 158.67Hz, 421.33Hz and 625.00Hz. Finally, the result captured from piezoelectric film sensor appeared that frequencies for mode shape 1, 2 and 3 for circle shape were 141.00Hz, 321.00Hz and 504.33Hz respectively. The equation of gradient for accelerometer and piezofilm is $y_a = 316.42x - 104.13$ and $y_p = 309.63x - 43.20$ respectively. Therefore, the relationship between the natural frequency of accelerometer and piezofilm for the square-shaped specimen is $y_a = 1.02y_p - 59.98$. The equation of gradient for accelerometer and piezofilm is $y_a = 270.55x - 134.82$ and $y_p = 280.89x - 215.04$ respectively. Therefore, the relation between the natural frequency of accelerometer and piezofilm for the circle-shaped specimen is $y_a = 0.96y_p + 72.3$. Both result showed the regression ratio of 1.02 and 0.96 which is approximately 1.0 and there was a good results agreement between simulation and experimental outcome.

Keywords: modal analysis, modal parameter, piezoelectric film sensor, Al6061, natural frequency, mode shape, accelerometer.

INTRODUCTION

Vibration has significant roles in our daily lives. It has good and bad effect to human nature. Therefore, an effort needs to be taken in order to estimate the vibration itself so that it can be controlled to some extent that it can be tolerated.

Experimental Modal Analysis (EMA) is done to determine modal parameters that include examining outcome of natural frequency, mode shape and damping ratio.The knowledge of structural modal parameters is a must in order to define the natural frequencies, mode shapes and modal damping ratios [1, 2]. EMA is a well-known procedure to determine modal analysis [3].

Piezo materials due to their properties of high speed operation and compact size have been popularly applied as core components in various precision work that relate with sensors and actuators [4, 5]. Actuators with high speed vibration are required in the fields such as ultra-precision machining [6, 7]. Due to its character, piezo materials are imminent in fields that require large force, fast response and cost-effective nature of work [8].Piezoelectric elements such as membrane supports have been used to generate vibration [9, 10]. The character proof that piezo is applicable in detecting tiny vibration in reliable circumstances. This relates with piezo that can practically exhibit itself as a sensor [11-13]. Piezoelectric effect based on its characteristics could therefore give good attribute to modal identification.

Normally, accelerometer is used as sensor to investigate modal parameter. One of its weak point is accelerometer is heavier compared to piezoelectric film sensor. The range in weight for accelerometer is approximately between 40g to 400g. When testing is to be conducted on small structure, the accuracy of experiment result will be affected. Therefore, the result obtained would be inaccurate.

The objectives of this study are as follows:

- To develop alternative method of modal analysis by using piezoelectric film sensor in determining natural frequency of Al6061.

- To obtain dynamic characteristics of natural frequency for Al6061 based on accelerometer vs piezoelectric film sensor and simulation.

Meanwhile, the scope of the study shall be conducted in two ways:

- Using finite element method via simulation (ANSYS).
- Using vibration test via experiment.

The result obtained from ANSYS represent structural dynamic characteristics via simulation comprises of natural frequency and mode shape.The study shall be extended by conducting modal analysis experimentally on the testing component. Finally, comparison shall be made between these two outcomes (simulation and experimental work).

Modal analysis

Modal Analysis is conducted to acquire two basic modal parameters of which are natural frequencies and mode shapes respectively. Modal Analysis solve for natural tendencies of the structure in the form of motions and frequencies. Vibration occurs in all scenarios of design to some extent. Even when designing steel in a building, a Modal Analysis is helpful to understand what happen in the event of an earthquake or even equipment that running in a building that might cause a sense of vibration.

Modal Analysis is derived originally from Equation of Motion (Figure-1) which stated that every motion occurs is incorporated with vibration alongside it [14, 15].

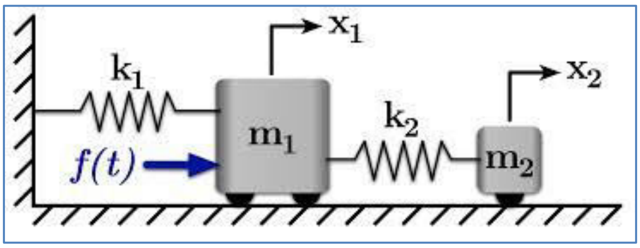


Figure-1. Spring equation of motion [16, 17].

$$m_1\ddot{x}_1 + (k_1 + k_2)x_1 - k_2x_2 = 0 \quad (1)$$

$$m_2\ddot{x}_2 - k_2x_1 + k_2x_2 = 0 \quad (2)$$

or in matrix,

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}\begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{Bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (3)$$

or

$$m\ddot{x} + kx = 0 \quad (4)$$

where,

m = mass,
k = spring stiffness,
x = displacement from static equilibrium position.

From here, we can derive the natural frequency equation.

$$\omega_n = \sqrt{\frac{k}{m}} \quad (5)$$

where,
ω_n = natural frequency.

Here, natural frequency appears which shall bear with mode shapes once the vibration takes place. Mode shapes on the other hand can be obtained through displacement (eigenvectors) that usually subjected to scaling procedures, referred to as mass-normalization with respect to the orthogonality properties of the mass-normalized modal matrix [16].

Piezoelectric

Piezoelectric is the electric charge that accumulates in certain solid materials (such as crystals and certain ceramics) in response to applied mechanical stress [17]. Piezoelectricity means electricity resulting from pressure [18]. The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and electrical state in crystalline materials with no inversion symmetry [19].

The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field).

For example, lead zirconatetitanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material. The inverse piezoelectric effect is used in production of ultrasonic sound waves [20].See Figure-2.

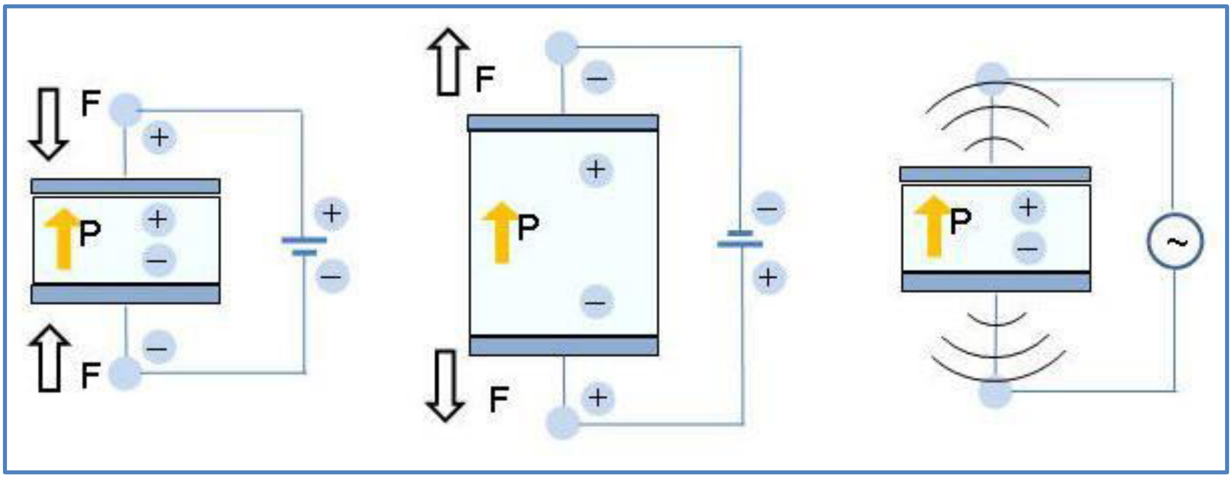


Figure-2. Inverse piezoelectric effect generates current when deformed [20].

Piezoelectricity is the combined effect of the electrical behavior of the material:

$$\mathbf{D} = \boldsymbol{\varepsilon}\,\mathbf{E} \quad \Longrightarrow \quad D_i = \varepsilon_{ij}\,E_j \tag{6}$$

where D is the electric charge density displacement (electric displacement), ε is permittivity and E is electric field strength, and Hooke's Law:

$$\boldsymbol{S} = \mathsf{s}\,\boldsymbol{T} \quad \Longrightarrow \quad S_{ij} = s_{ijkl}\,T_{kl} \tag{7}$$

where S is strain, s is compliance, T is stress and i,j,k,l is the imaginary unit (of linear independence 1, 2,…, n).

There are various materials that exhibit piezoelectricity, but mostly used in engineering application mainly are Piezo Zirconium Titanate (PZT) (synthetic ceramics) and Polyvinylidene Fluoride (PVDF) (polymers). At present, industrial and manufacturing is the largest application market for piezoelectric devices, then come automotive industry. The applications are in high voltage and power sources [17], sensors, actuators, motors among others [21].

METHODOLOGY

The purpose of this study is to determine the natural frequency and mode shape on Al6061. The experiment technique is by using Single Input Single Output (SISO) method. Impact hammer shall be used by exciting on one point to another to generate signal. Here, accelerometer and piezoelectric film will act as sensor to detect the signal. The signal shall be sent to computer for analysis and the result from these sensors will be analysed. Furthermore, simulation testing using ANSYS shall be conducted via finite element method. See Figure-3.

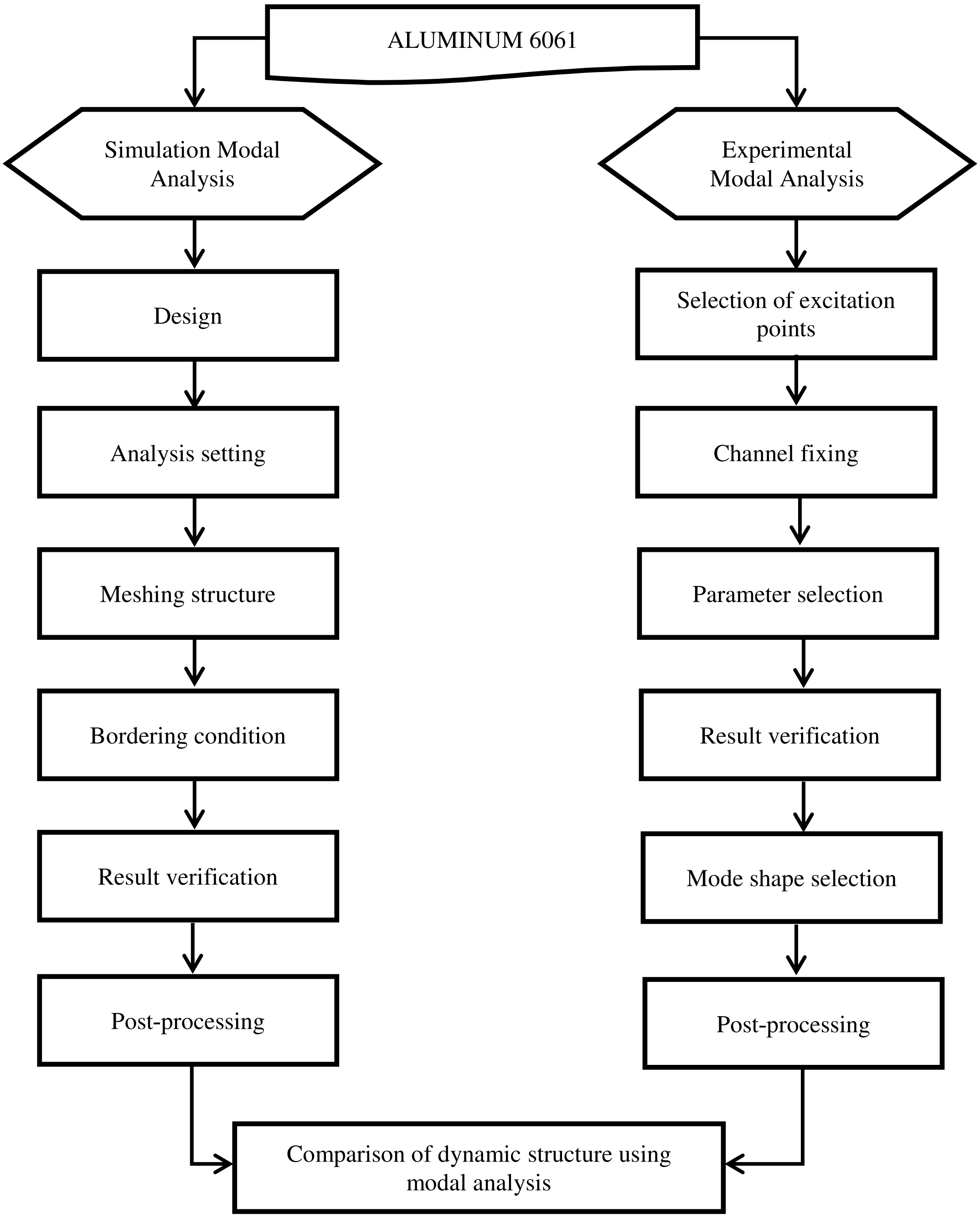


Figure-3. Experimental methodology.

Simulation modal analysis

First, the square and circle shape shall be designed using Autodesk Inventor. Next, conduct an analysis setting of basic parameter on the specimen material (Al6061) such as Young Modulus, Poisson ratio and density. As for ANSYS, the first step is selection of material (aluminum) and the parameter shall be fixed automatically. Then, the next step is generating mesh structure for the shape (eg. selection of size etc.). Figure-4 shows the mesh structure of the square shape. Furthermore, bordering condition and fixed support were set by assuming on the back surface of the specimen. Finally, result modification for the best outcome shall be done to obtain natural frequency and mode shape. Here, parameter verification such as numbers of mode shapes needed from deformation can be applied. The process can extract shifting magnitude and natural frequency of the structure. It also can verify mode shapes transition for every natural frequency available in aluminum structure.

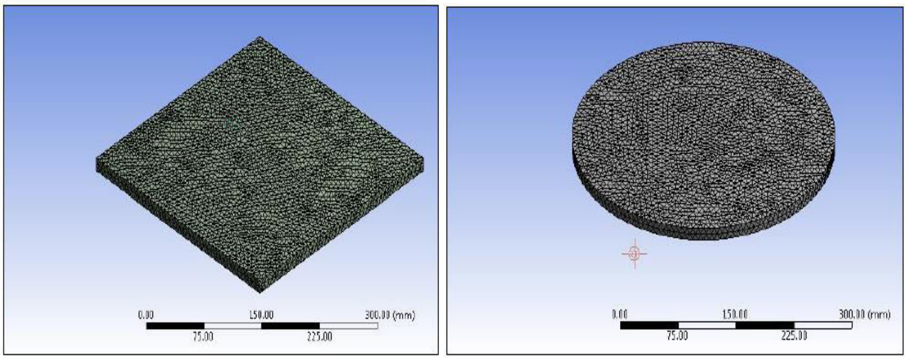
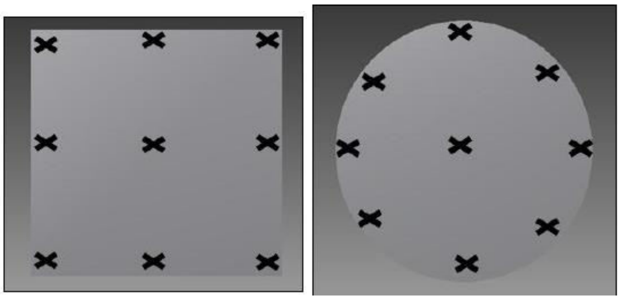


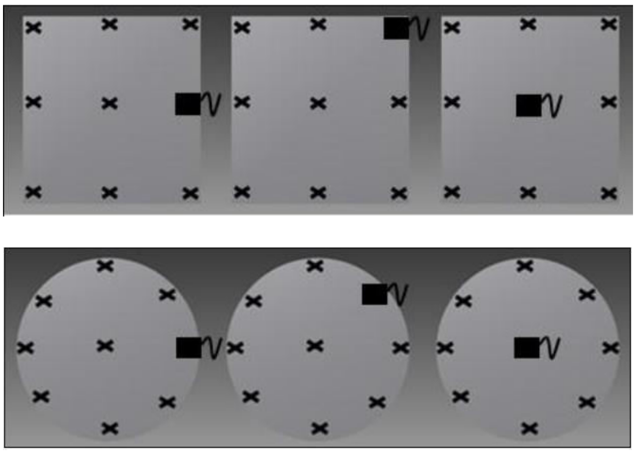
Figure-4. Mesh structure for square and circle shape.

Experimental modal analysis

Initially, points of excitation as knocking point by impact hammer must be decided. Next, by using marker, the excitation point will be spotted (Figure-5a). Channel fixing of impact hammer then shall be installed on DAQ. Then, connect piezoelectric film to second channel and accelerometer to third channel of DAQ. The DAQ shall be connected to computer. The sensor will be positioned in three different points (Figure-5b). The work is conducted following ASTM E1876 accordingly.



(a) Excitation points



(b) Sensor position

Figure-5. Excitation point and sensor position.

For parameter selection, start the Impact Hammer software on computer. Out of four channels, make sure there are only three channels activated (impact hammer, piezoelectric and accelerometer channel). First channel stands for force, second channel represents voltage and third channel stands for acceleration. Set the minimum sample rate and block size to 51200. Determine the project name on the folder. Before first knock, press 'run'. When first excitation starts, the sensor will send the signal and trigger will appear on screen. Amplitude of each trigger will be recorded. For mode shape selection, MATLab application shall take place. Import the data into 'workplace'. Type the appropriate command to plot the desired graph. From the result, mode shape and natural frequency for every data can be determined.

Experimental procedures

The experimental specimen of Al6061 was fabricated as follows:

a) Square (300mm in length x 300mm in width x 1.5mm in thickness)
b) Circle (350mm in diameter x 1.5mm in thickness)

Two types of sensors are accelerometer and piezoelectric film. The accelerometer model used was Endevco 751-100 USA. The piezoelectric film is laminated to a sheet of polyester. The dual wire lead attached to the sensor allows a circuit to produce the signal. The piezoelectric is from polymer, usually polyvinylidene fluoride (PVDF), model LDT1-028K, USA. The impact hammer which execute impact force onto Al6061 modelled SN LW31881, PCB 086C03, USA.

Meanwhile, the data acquisition system which processes the sampling signal that measure actual physical condition and converting the resulting sample into digital numeric values. Abbreviated as DAQ, the device converts analog waveforms into digital values for processing. DAQ include sensor, signal circuit, analog to digital converter. DAQ are controlled by software programs developed using general purpose programming languages such as LabVIEW, Fortran etc. Here, the model used was National Instrument DAQ, NI9234.

RESULTS AND DISCUSSIONS

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

$$\text{Percentage error} = \frac{|f_1 - f_2|}{f_1} \times 100\% \tag{8}$$

or

$$\text{Percentage error} = \frac{|f_1 - f_3|}{f_1} \text{ x } 100\% \quad (9)$$

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

Simulation modal analysis

In simulation modal analysis, center plane surface for mesh aluminum, material characteristics clarification shall be processed and analysed using ANSYS software. Here, the analysis result of natural frequency and mode shape for the specimen will be shown.

Simulation result for square shape specimen

Table-1 below shows the result of simulation analysis of natural frequency for square shape specimen.

Table-1. Simulation analysis of natural frequency for square shape specimen.

Mode shape	**Natural frequency** (Hz)
1	191.89
2	542.34
3	766.18
4	925.28
5	1181.90
6	1698.50

Referring to Table-1, analysis simulation result stated that there were 6 natural frequencies and mode shapes exist in square shape aluminum specimen in range 0 to 2000Hz. For mode 1 until mode 6, natural frequency obtained was 191.89Hz, 542.34Hz, 766.18Hz, 925.28Hz, 1181.90Hz and 1698.50Hz respectively. The value increased from mode 1 until mode 6.

Simulation result for circle shape specimen

Table-2 below shows the result of simulation analysis of natural frequency for circle shape specimen.

Table-2. Simulation analysis of natural frequency for circle shape specimen.

Mode shape	**Natural frequency** (Hz)
1	134.60
2	324.73
3	727.52
4	921.26
5	1074.30
6	1491.20

Referring to Table-2, analysis simulation result stated that there were 6 natural frequencies and mode shapes exist in circle shape aluminum specimen in range 0 to 2000Hz. For mode 1 until mode 6, natural frequency obtained was 134.60Hz, 324.73Hz, 727.52Hz, 921.26Hz, 1074.30Hz and 1491.20Hz respectively. The value increased from mode 1 until mode 6.

Experimental modal analysis

IMPACT HAMMER software was used to analyse the experimental result. Altogether there were 9 knocking points chosen as excitation point. Parameter for this experimental work is sensor. Therefore, there will be 2 types of sensor namely piezoelectric film and accelerometer to be utilised for the specimen.

Hence, to gain average result, the sensors shall be located at 3 different points. The piezoelectric film and accelerometer will be attached to these 3 points for the square shape. The result obtained will be averaged and analysed to get the final result. To ensure the accuracy of the result, excitation on every point shall be done repeatedly to extract the precision reading. The work is conducted following ASTM E1876 accordingly.

Experimental result for square shape specimen

From frequency function graph, mode shape and its natural frequency for square shape specimen can be obtained. Table-3 and Table-4 showed the result of natural frequency for every mode shape for piezoelectric film sensor and accelerometer respectively.

Table-3. Natural frequency from analysis of piezoelectric film sensor for square shape specimen.

Mode shape	**Natural frequency** (Hz)			
	Point 1	**Point 2**	**Point 3**	**Average**
1	205	212	199	205.33
2	573	631	624	609.33
3	831	978	904	904.33
4	1263	1200	1147	1203.33
5	1631	1574	1611	1605.33
6	1698	1686	1762	1715.33

Table-4. Natural frequency from analysis of accelerometer for square shape specimen.

Mode shape	**Natural frequency** (Hz)			
	Point 1	**Point 2**	**Point 3**	**Average**
1	201	191	193	195.00
2	582	574	515	557.00
3	891	885	819	865.00
4	1166	1116	1103	1128.33
5	1444	1442	1488	1458.00
6	1883	1885	1682	1816.67

Experimental result for circle shape specimen

From frequency function graph, mode shape and its natural frequency for circle shape specimen can be obtained. Table-5 and Table-6 showed the result of natural frequency for every mode shape for piezoelectric film sensor and accelerometer respectively.

Table-5. Natural frequency from analysis of piezoelectric film sensor for circle shape specimen.

Mode shape	**Natural frequency** (Hz)			
	Point 1	**Point 2**	**Point 3**	**Average**
1	144	143	136	141.00
2	362	357	244	321.00
3	520	515	478	504.33
4	804	1066	972	947.33
5	1191	1158	1277	1208.67
6	1453	1528	1477	1486.00

Table-6. Natural frequency from analysis of accelerometer for circle shape specimen.

Mode shape	**Natural frequency** (Hz)			
	Point 1	**Point 2**	**Point 3**	**Average**
1	204	128	144	158.67
2	352	435	477	421.33
3	492	644	739	625.00
4	877	1098	963	979.33
5	1096	1163	1145	1134.67
6	1574	1598	1489	1553.67

Comparison in dynamic structure characteristics of modal analysis between simulation and experimental work

Natural frequency for every mode shape transformation will be compared for each structure from error ratio. Accelerometer result will act as the foundation for actual value to compare with. This is becausemodal analysis experimental work has been frequently utilized an accelerometer as a sensor for it accurateness.

The natural frequency for accelerometer is represented by f_1, natural frequency for piezoelectric filmf_2 and natural frequency for simulationf_3 respectively (refer Table-4). The difference between natural frequency for accelerometer vs piezoelectric film is represented by $f_1 - f_2$ and difference between natural frequency for accelerometer vs simulation is represented by $f_1 - f_3$.

Upon obtaining the error between accelerometer vs piezoelectric film and accelerometer vs simulation, the relation among accelerometer, piezoelectric film sensor and simulation will be determined.

Relation between natural frequency of accelerometer and piezoelectric film sensor for square shapespecimen

Table-7. Comparison between accelerometer, piezoelectric film sensor and simulation for square shape specimen.

Mode shape	**Natural frequency** (Hz)					**Error 1** (%) $\frac{f_1 - f_2}{f_1}$	**Error 2** (%) $\frac{f_1 - f_3}{f_1}$
	Accelerometer (f_1)	**Piezoelectric film sensor** (f_2)	**Simulation** (f_3)	**Diff. 1** $\lvert f_1 - f_2 \rvert$	**Diff. 2** $\lvert f_1 - f_3 \rvert$		
1	195.00	205.33	191.89	10.33	3.11	5.30	1.60
2	557.00	609.33	542.34	52.33	14.66	9.40	2.60
3	865.00	904.33	766.18	39.33	98.82	4.50	11.40
4	1128.33	1203.33	925.28	75.00	203.05	6.60	18.00
5	1458.00	1605.33	1181.90	147.33	276.10	10.10	18.90
6	1816.67	1715.33	1698.50	101.33	118.17	5.60	6.50

For accelerometer vs piezoelectric film, the difference of mode shapes (mode 1 to mode 6) based on natural frequency were 10.33Hz, 52.33Hz, 39.33Hz, 75.00Hz, 147.33Hz and 101.33Hz respectively. Percentage of error for accelerometer vs piezoelectric film (mode 1 to mode 6) showed 5.30%, 9.40%, 4.50%, 6.60%, 10.10% and 5.60% respectively.

For accelerometer vs simulation, the difference of mode shapes (mode 1 to mode 6) based on natural frequency were 3.11Hz, 14.66Hz, 98.82Hz, 203.05Hz, 276.10Hz and 118.17Hz respectively. Percentage of error for accelerometer vs simulation (mode 1 to mode 6) showed 1.60%, 2.60%, 11.40%, 18.00%, 18.90% and 6.50% respectively.

As overall, percentage of error for accelerometer vs piezoelectric film was satisfying. The highest error was at mode 5 with 10.10% followed by error at mode 2 with 9.40%. The minimum error was at mode 3 with 4.50%. Percentage of error for accelerometer vs simulation was also satisfying. The highest error was at mode 5 with 18.90% followed by error at mode 4 with 18.00%. The minimum error was at mode 1 with 1.60%. Refer Table-7.

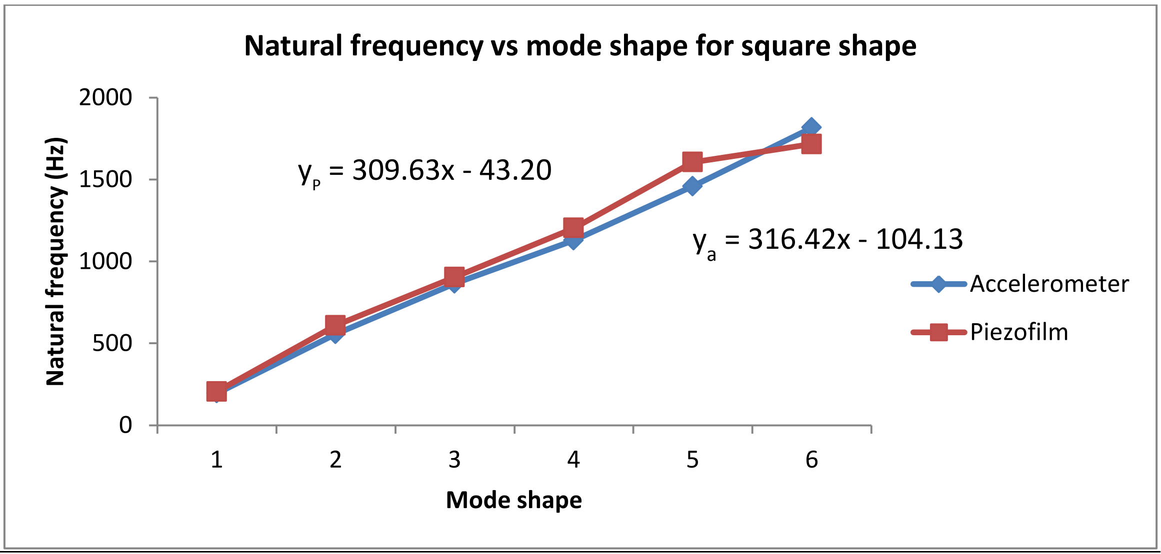


Figure-6. Natural frequency vs mode shape for square shape specimen.

By referring to Figure-6, the equation of gradient for accelerometer and piezofilm is:

Accelerometer: $y_a = 316.42x - 104.13$
Piezofilm: $y_p = 309.63x - 43.20$

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

y_a = $1.02y_p - 59.98$
R^2 = 0.9980 for accelerometer
R^2 = 0.9852 for piezoelectric film

Relation between natural frequency of accelerometer and piezofilm for circle shape specimen

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

Mode shape	**Natural frequency** (Hz)					**Error 1** (%) $\frac{f_1 - f_2}{f_1}$	**Error 2** (%) $\frac{f_1 - f_3}{f_1}$
	Accelerometer (f_1)	**Piezoelectric film sensor** (f_2)	**Simulation** (f_3)	**Diff. 1** $\lvert f_1 - f_2 \rvert$	**Diff. 2** $\lvert f_1 - f_3 \rvert$		
1	158.67	141.00	134.60	17.67	24.07	11.1	15.2
2	421.33	321.00	324.73	100.33	96.60	23.8	22.9
3	625.00	504.33	727.52	120.67	102.52	19.3	16.4
4	979.33	947.33	921.26	32.00	58.07	3.3	5.9
5	1134.67	1208.67	1074.30	74.00	60.37	6.5	5.3
6	1553.67	1486.00	1491.20	67.67	62.47	4.4	4.0

For accelerometer vs piezofilm, the difference of mode shapes (mode 1 to mode 6) based on natural frequency were 17.67Hz, 100.33Hz, 120.67Hz, 32.00Hz, 74.00Hz and 67.67Hz respectively. Percentage of error for accelerometer vs piezofilm (mode 1 to mode 6) showed 11.1%, 23.8%, 19.3%, 3.3%, 6.5% and 4.4% respectively. For accelerometer vs simulation, the difference of mode shapes (mode 1 to mode 6) based on natural frequency were 24.07Hz, 96.60Hz, 102.52Hz, 58.07Hz, 60.37Hz and 62.47Hz respectively. Percentage of error for accelerometer vs simulation (mode 1 to mode 6) showed 15.2%, 22.9%, 16.4%, 5.9%, 5.3% and 4.0% respectively.

As overall, percentage of error for accelerometer vs piezofilm was satisfying. The highest error was at mode 2 with 23.8% followed by error at mode 3 with 19.3%. The minimum error was at mode 4 with 3.3%. Percentage of error for accelerometer vs simulation was also satisfying. The highest error was at mode 2 with 22.9% followed by error at mode 3 with 16.4%. The minimum error was at mode 6 with 4.0%. Refer Table-8.

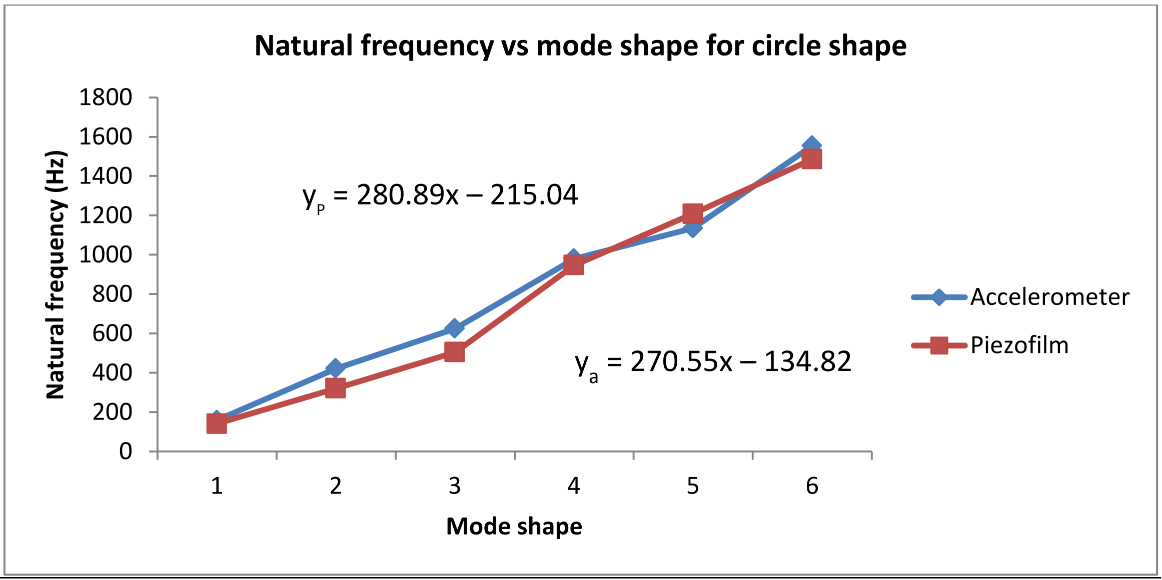


Figure-7. Natural frequency vs mode shape for circle shape specimen.

By referring to Fig. 7, the equation of gradient for accelerometer and piezofilm is:

Accelerometer: $y_a = 270.55x - 134.82$
Piezofilm: $y_p = 280.89x - 215.04$

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

$y_a = 0.96y_p + 72.3$
$R^2 = 0.9879$ for accelerometer
$R^2 = 0.9832$ for piezoelectric film

Factors for result inaccuracy

As overall, the results obtained were satisfying. Nonetheless, there were also error occurred. The error therefore contributed in result inaccuracy. Factors that might be taken into consideration:

a) For inaccuracy in simulation, due to meshing was inappropriate, such like improper type of meshing used. Some mesh may be not suitable for certain shape.
b) For inaccuracy in simulation, the sensor mass was not taken into consideration. The sensor mass might cause

the simulation result in disarray because the component used (aluminum) was light.

c) For inaccuracy in experimental work, this might occur during hammer impact where the force excited for every node was not similar between one another. Every excitation manually by hand was difficult to ensure the impact force were the same for every node. Therefore, the forces were inconsistent. The data absorbed by piezofilm would become inconsistent. Thus, error occurred in frequency function data collection.

d) For inaccuracy in experimental work, was sensor location on aluminum component. Although the sensor were located at 3 different location and average result were taken, the accurateness could not be guaranteed. This is because may be the location of the sensor might be not suitable. Hence improper readings were taken for analysis. This could contribute error in average result.

CONCLUSIONS

In this study, the simulation analysis and experimental work have been successfully done to obtain dynamic characteristics such like natural frequency and mode shape for Al6061 component of square and circle shape. The comparison between accelerometer and piezoelectric film and comparison between accelerometer and simulationhave been successfully executed. The frequency range applied in these mode shape analysis is 0-2000Hz. Altogether there were 6 natural frequencies and mode shapes were determined in that range.

In short, one could understand the relation involved among accelerometer as base, piezoelectric film as sensor and simulation as theoretical reference in determining the natural frequencies and mode shapes in vibration. By obtaining the relation between accelerometer and piezoelectric film sensor, one could determine the natural frequency on aluminum component when engage with piezoelectric film sensor in the future. By understanding the natural frequency in the component, vibration range could be control.

Further declaration were made to elaborate the effect which contributed by piezo as tool to identify modal analysis. It was clear that piezo has significant role to be part of modal analysis that secure data which emphasized on result obtained using recent software technology. Out of three modal parameters, consist of natural frequency, mode shape and damping ratio, piezo assist in determination of natural frequency and mode shape respectively. This could assist in designing or manufacturing component which can avoid the component from vibrating on its natural frequency thus eliminating the risks of resonance occurrence. As a result, damage control can be applied and lost in cost and life will be minimized.

The result obtained from simulation showed that frequencies for mode shape 1, 2 and 3 for square shape are 191.89Hz, 542.34Hz and 766.18Hz. The result gained from accelerometer showed that frequencies for mode shape 1, 2 and 3 for square shape are 195.00Hz, 557.00Hz and 865.00Hz. The result captured from piezoelectric film sensor appeared that frequencies for mode shape 1, 2 and 3 for square shape are 205.33Hz, 609.33Hz and 904.33Hz. The result obtained from simulation showed that frequencies for mode shape 1, 2 and 3 for circle shape were 134.60Hz, 324.73Hz and 727.52Hz. The result obtained from accelerometer showed that frequencies for mode shape 1, 2 and 3 for circle shape were 158.67Hz, 421.33Hz and 625.00Hz. Finally, the result captured from piezoelectric film sensor appeared that frequencies for mode shape 1, 2 and 3 for circle shape were 141.00Hz, 321.00Hz and 504.33Hz respectively.The equation of gradient for accelerometer and piezofilm is $y_a = 316.42x - 104.13$ and $y_p = 309.63x - 43.20$ respectively. Therefore, the relationship between the natural frequency of accelerometer and piezofilm for the square-shaped specimen is $y_a = 1.02y_p - 59.98$. The equation of gradient for accelerometer and piezofilm is $y_a = 270.55x - 134.82$ and $y_p = 280.89x - 215.04$ respectively. Therefore, the relation between the natural frequency of accelerometer and piezofilm for the circle-shaped specimen is $y_a = 0.96y_p + 72.3$. Both result showed the regression ratio of 1.02 and 0.96 which is approximately 1.0 and there was a good results agreement between simulation and experimental outcome.

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