EXPERIMENTAL STUDY ON VIBRATION LEVEL OF AUTOMOTIVE FLEXIBEL WIPER SYSTEM

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ABSTRACT

This study represent the experimental study of automotive flexible wiper system by using analytical and test rig analysis. In order to doing so, conservation and newtonian approach is applied to develop two dimensional of differential equation for the system. In analytical approach, the results have shown in time and frequency domain, which are represented the annoying noise and vibration level during the system operate. These results were compared with experimental study using Fast Fourier Transform (FFT) technique. In this comparison, these two results have shown a corelation data and it is believed trustworthy to make a further analysis. The percentage of corelation is more than 97 percent.

KEYWORDS*: Flexible wiper system, analytical, experimental, noise, vibration.*

1.0 INTRODUCTION

The industry of automotive has been growing all over the world. Two components are required to be considered in order to make sure that automobile industry running in smooth conditions. The first component is basic parts such as door, window, seat and etc. The second component is the system such as wiper system, steering system, braking system and etc. Most of car makers spend a lot of money in research and development to reduce the unwanted noise and vibration happen in cars passenger (Shinya Goto *et. al.,* 2001).

Wiper is an important element in a vehicle that functions to wipe rain drop and dirt from windscreen. Wipers are used in almost every vehicle, such as cars, buses, trams, locomotives, aircrafts and ships. In automotive industry, majority of car manufacturer spend quite an amount of resources, efforts and researches to reduce unwanted vibration produces in car wiper (Grenouillat *et. al.,* 2002). Car engines optimize engine design with an intention to reduce noise and vibration (Grenouillat *et. al.,* 2002). However, when the engine had been successfully optimized, different types of sources will occur and one of the sources is produced from car wiper system (Grenouillat *et. al.,*2002).

Vibration and noise are two major problems in many moving components, such as engine, transmission, suspension and many more. The vibration that takes place under the excitation of external forces is called forced vibration. If excitation is harmonic, the system is forced to vibrate at excitation frequency. This vibration is occurred in wiper system rottenly. Noise can explain as unwanted sound or noise pollution. The noise in wiper system is directly influence by the vibration.

Noise and vibration in wiper blade can be divided into three main categories (M.A.Salim *et. al.,* 2009a), (M.A.Salim *et. al.,* 2009b), (Shinya Goto *et. al.,* 2001), (Stalleart *et. al.,* 2006), (Regis *et. al.,* 2002), (Abu Bakar *et. al.,* 2008). There are:

i. Squeal noise and it also known as squeaky noise. It is high frequency sound and range approximate to 1000 Hz.
ii. Chattering noise also called beep noise. This is low frequency with the range 100 Hz or less.
iii. Reversal noise is an impact sound of 500 Hz and less. It was created by the wiper bumps against the glass when the wiper reversed.

This wiper system is a device that to wipe out rain and dirt to maintain the visibility of the driver (M.A.Salim *et. al.,* 2009a). Unfortunately, the system has a big potential to generate noise and vibration during it operation both in forward and vice versa direction, respectively (M.A.Salim *et. al.,* 2009a). In safety precautions, all of the automobile needs the system and it was make as a authorized to the seller before sell the car to the customers. It was an issues because clear vision for both driver and passenger during driving a car is a very important to make it safety in traffic and at the same time to avoid an accident. According to this statement, the study of unwanted noise and vibration inside wiper system is compulsory and it also can give advantages to researchers to know the real phenomenon that happen to the system.

The aerodynamic properties of the wiper blades have become increasingly important due to the design of the vehicle as different air currents flow on and around the windscreen area. The strip on top of the rubber element is often perforated to reduce air drag. A good quality blade will have a contact width approximately 0.1 mm. The lip wipes the surface of the windscreen at an angle approximate to 45^0 and the pressure of the blade on the windscreen known as coefficient of friction between rubber and glass and the range is around 0.8 to 2.5 for dry and 0.1 to 0.6 for wet, respectively.

There are two types of wiper blade which is rubber and silicone. Wiper blades are like squeegees. The arms of the wiper drag a thin rubber strip across the windscreen to clear away the water. When the blade is new, the rubber is clean and has no nicks or cracks. It wipes the water away without leaving streaks. When the wiper blades are old, nicks or cracks form, road grime builds up on the edge and it does not make as tight a seal against the window, so it leaves streaks. A little extra life can be obtained out of the wiper blade by wiping the edge with a cloth soaked in window cleaner until no more dirt comes off the blade. Figure 1 shows a wiper blade on a windscreen.

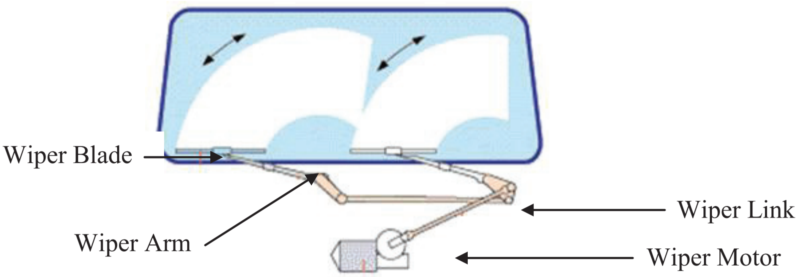

Figure 1 Wiper system on a windscreen

The functional of windscreen wiper system is drive in the rain and show and also clean the windshield when it is dirty, so that the driver can drive safety (M.A.Salim *et. al.,* 2009c). The windscreen wiper system is compromised of the wiper switch, the wiper motor, the washer switch, the washer motor, delay box and wiring from the ignition and fuse panel.

The wipers themselves are metal or plastic arms, which carry rubber blades. The wiper arms are connected to the wiper motor via a series of arms and bushings. When the windshield wiper motor turns, it moves the arms those are hooked to the motor and the windshield wiper arms, therefore moving the arms holding the blades back and forth across the windshield. The rubber on the windshield wiper arms works like a squeegee, wiping water, ice and snow from the windshield.

Moreover, wiper system is a device that operates to wipe windscreen from rain and dust. A clear vision during these bad weathers is important to the safety of driver and passenger. Then, the back and forth movement of wiper at the same times will produce an unwanted vibration level. Figure 2 shows a schematic diagram of a simple wiper system (Shun *et. al.,* 2003).

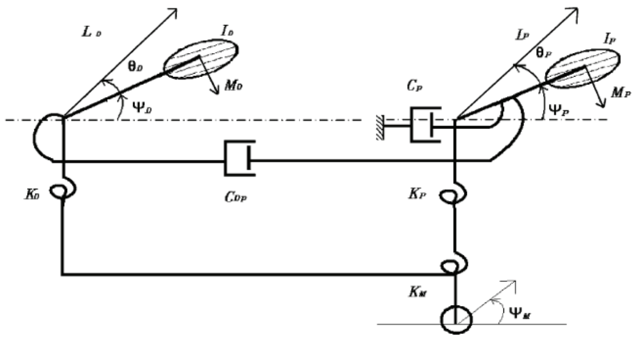

Figure 2 Schematic diagram of wiper system

2.0 RESEARCH METHODOLOGY

The methodology flow chart describes the methods sequence that is going to be implemented to complete this study. The process is started with reviewing the core element of the study; windscreen wiper system and analytical method. Each category has its own activities, procedures and tools.

The evaluation of vibration in wiper system was developed using analytical model, while experiment was conducted to find the vibration response in wiper. A comparison is made between the analytical and experimental result. Figure 3 shows the flow chart for the methodology.

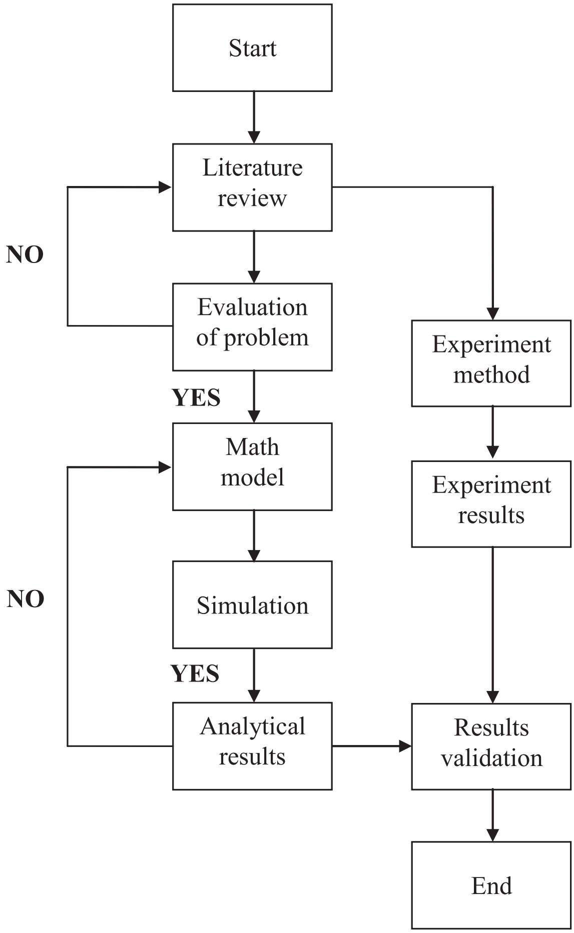

Figure 3 Flow chart

3.1 Analytical Approach

The wiper system should derive in mathematical equation to do the simulation using a simulation tools. Figure 4 shows the actual mechanical model of wiper system contains applied dynamic and static forces (Shigeki *et. al.,* 2000). The derivation of the mathematical model was required to represent the differential equation which was derived from the conservation laws.

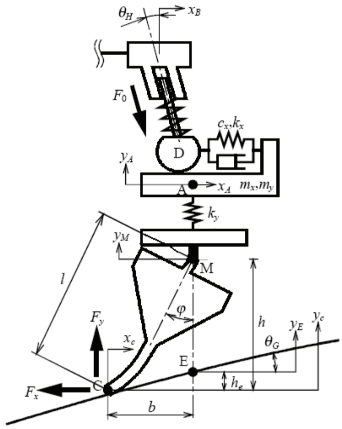

Figure 4 Actual model of wiper system (Shigeki et al., 2000)

Newton's second law is written as

$$\sum F = ma \tag{1}$$

And the rectangular coordinate component written by:

$$\sum F_x = ma_x \tag{2}$$

$$\sum F_y = ma_y \tag{3}$$

In wiper system, the system is in a rigid body condition. The applied forces are subjected to the bodies of wiper blade. General vector to represent a form of Newton's second law is:

$$\sum_{i=1}^{N} F_i = ma_c$$

$$= \sum_{j-1}^{n} m_j a_{cj}$$

$$= m_1 a_{c1} + m_2 a_{c2} + m_3 a_{c3} + \ldots + m_n a_{cn} \tag{4}$$

Where

$$m = \sum_{j=1}^{n} m_j$$

F_i	=	*i*th of applied physical force
a_c	=	rigid body absolute acceleration at the center mass
a_{cj}	=	*j*th rigid body absolute acceleration at the center mass

In order to calculate component form in x and y direction, form of Newton's second law can be written as:

$$\overset{+}{\rightarrow} \sum_{i=1}^{N} F_{ix} = m a_{cx}$$
$$= \sum_{j-1}^{n} m_j a_{cjx}$$
$$= m_1 a_{c1x} + m_2 a_{c2x} + m_3 a_{c3x} + \ldots + m_n a_{cnx} \quad (6)$$

$$+\uparrow \sum_{i=1}^{N} F_{iy} = m a_{cy}$$
$$= \sum_{j-1}^{n} m_j a_{cjy}$$
$$= m_1 a_{c1y} + m_2 a_{c2y} + m_3 a_{c3y} + \ldots + m_n a_{cny} \quad (7)$$

Equation (6) and (7) is a rectangular coordinate or Cartesian coordinate system in x- and y-direction, respectively. The dynamic model of blade wiper is representing in Figure 5 below.

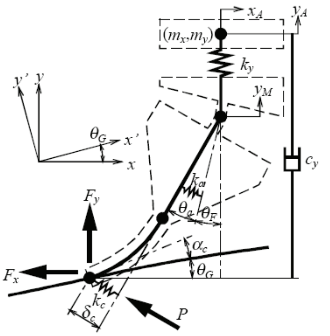

Figure 5 Dynamic model of blade rubber (Shigeki et al., 2000)

The initial reaction forces react at F_{x0} and F_{y0} can be written as:

$$F_{x0} = \frac{-sin\theta_F}{cos(\theta_H + \theta_F)} F_0$$

$$F_{y0} = \frac{cos\theta_F}{cos(\theta_H + \theta_F)} F_0 \qquad (9)$$

where

$$F_0 = F_{y0} cos\theta_H + F_{x0} sin\theta_H$$

Using Newton's second law, the summation forces in x- and y-direction can be derived as:

$$m_x\ddot{x}_A + c_x(\dot{x}_A + \dot{y}_A tan\theta_H - \dot{x}_B) + k_x(x_A + y_A tan\theta_H - x_B) + Fx = 0 \qquad (10)$$

$$m_y\ddot{y}_A + c_y(\dot{y}_A - \dot{y}_C) + \{c_x(\dot{x}_A + \dot{y}_A tan\theta_H - \dot{x}_B) + k_x(x_A + y_A tan\theta_H - x_B)\} tan\theta_H - F_y + F_{y0} = 0 \quad (11)$$

This equations then was simulated with parameters which some are measured and some are taken from open literature (Shigeki et al., 2000). The parameters are shown in Table 1 and 2.

Table 1 Parameter of arm and blade analytical description

Parameter	Description
m_x	Equivalent mass of arm and blade to the x direction
m_y	Equivalent mass of arm and blade to the y direction
c_x	Equivalent damping coefficient of arm to the x direction
k_x	Equivalent spring coefficient of arm to the x direction
x_B	Arm tip virtual position without arm deformation
θ_H	Arm head twist angle
F_0	Arm pressure
c_y	Equivalent damping coefficient of blade to the y direction

Table 2 Properties of parameters

Parameter	Data	Unit
m_x	0.25	kg
m_y	0.21	kg
c_x	0.2	Ns/m
k_x	10	N/m
θ_H	0.52	rad
F_x	0	N
c_y	6	Ns/m

3.2 Experimental Approach

Experiment is about the measurements of vibration of wiper system when the system is operated in certain speeds. It was conducted in two conditions and there are wet and dry. The accelerometer was applied as a sensor and locate and two different positions in sequence and the system was operated in three different speed. It is because the distance between centre of rotation and sensor position may cause different frequencies and might affect the results. The rotational speed will increase when the distance or radius or rotational region decrease.

The first test was done at dry condition. The windscreen remains dry and the wiper was operated at speed 1. It was tested by placing accelerometers at point 1 and 2. The results been analyzed by Fast Fourier Transform (FFT). The second test was done at wiper operating speed 2 at dry condition. The wiper blade moved faster than speed 1, but almost similar vibration is recorded. Finally, the test is continued with operating speed at 3. At this speed, the wiper blade is struggled to move back and forth because the windscreen has a higher friction coefficient because the surface is dry.

4.0 RESULTS AND DISCUSSION

4.1 Analytical Results

The complete control structure of wiper system is stimulated using simulation tool. Then the results draw up as a acceleration versus time domain for x- and y-direction, respectively. It is because the changes in displacement of wiper blade for both directions are considered as a vibration of the system. Figure 6 and 7 showed the pattern of the vibration occur in wiper system. There is continues vibration with a variable amplitudes and frequencies in the system. It is transpire due to the existing forces at rubber contact and from arm blade which constantly exists at wiper blade. These act as the input signal for the wipe system in analytical model. The varying acceleration corresponds to the frequency of wiper in different modes. Values of acceleration in both graphs signify to the system vibration amount.

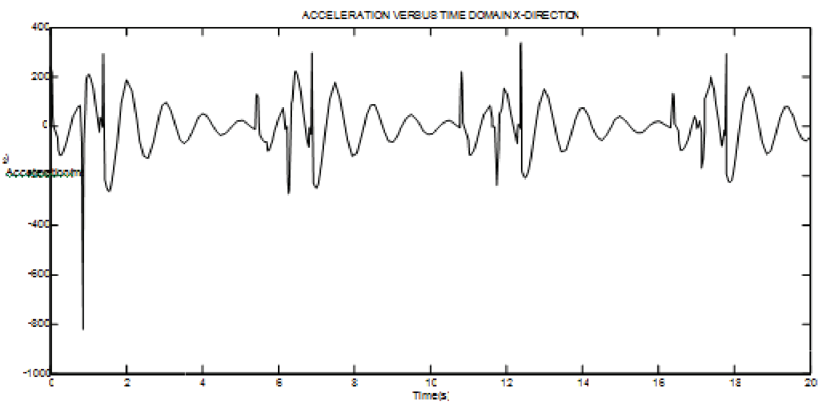

Figure 6 Analytical result in x-direction

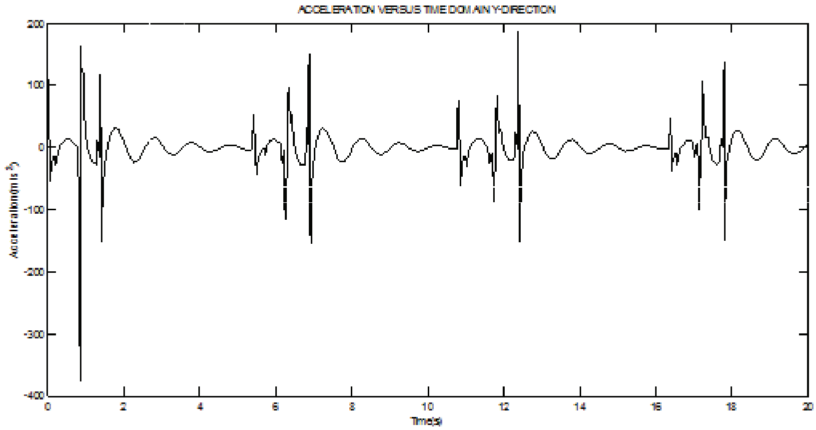

Figure 7 Analytical result in y-direction

4.2 Experimental Results

The results are shown in Figure 8,9, and 10.

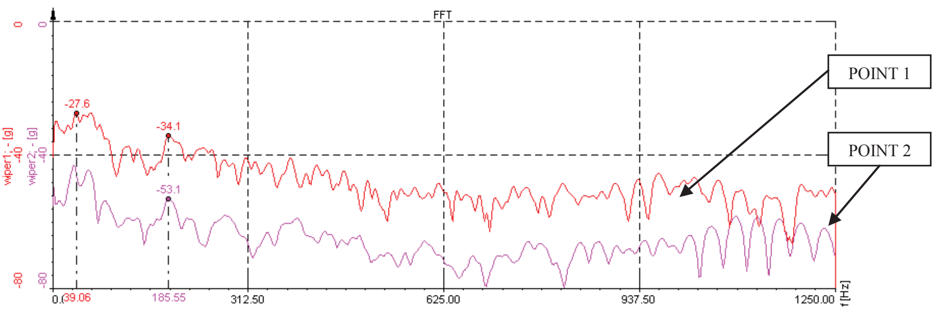

Figure 8 FFT graph for speed 1 at dry condition

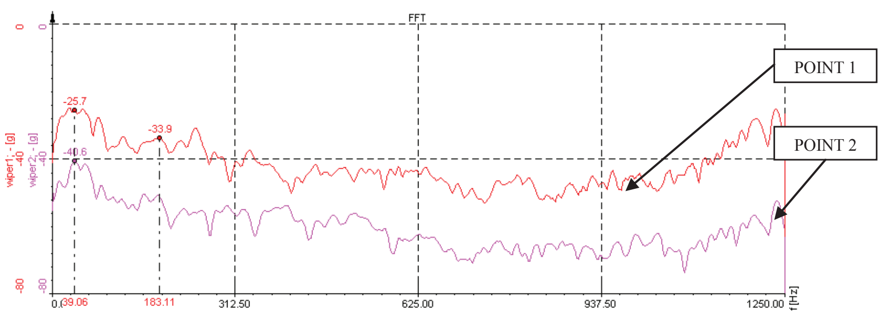

Figure 9 FFT graph for speed 2 at dry condition

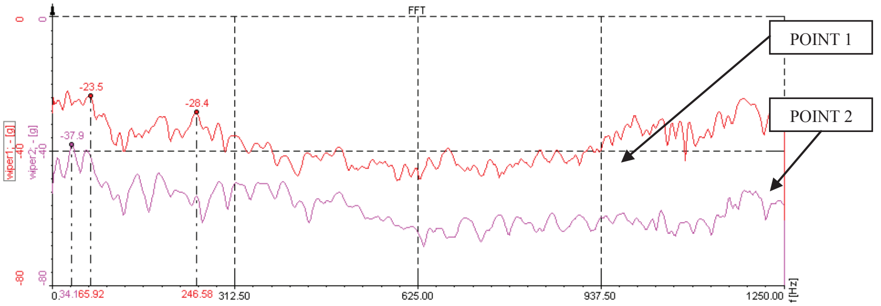

Figure 10 FFT graph for speed 3 at dry condition

Then, the experiment was continued at wet condition. The wiper is also depending on three different speeds. Water sprinkled at windscreen is used to make the screen likely as a wet surface. The movement of wiper blade was finer than compare to dry condition. From this experiment, it is found that the wiper system also produced the vibration. The graphs, showed the shape of vibration generate by wiper blade occurred when the system operated. Then graphs are clearly illustrate the difference in wiper speed can be noticed and the peaks of frequencies curve fall almost on the same position on the x-direction. The dominant peaks which show the natural frequency falls exactly on the value. This is very noticeable especially at wet condition. It can be assumed the rotational speed at different position of accelerometer is do not effect the frequency of the wiper system. The results for wet condition are shown in Fig. 11, 12 and 13, respectively with different rotational speed.

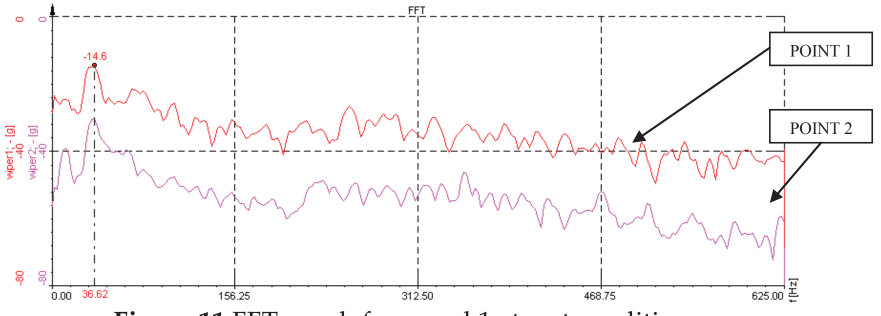

Figure 11 FFT graph for speed 1 at wet condition

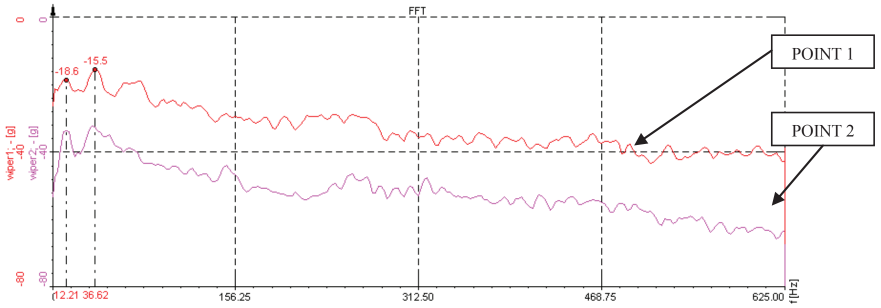

Figure 12 FFT graph for speed 2 at wet condition

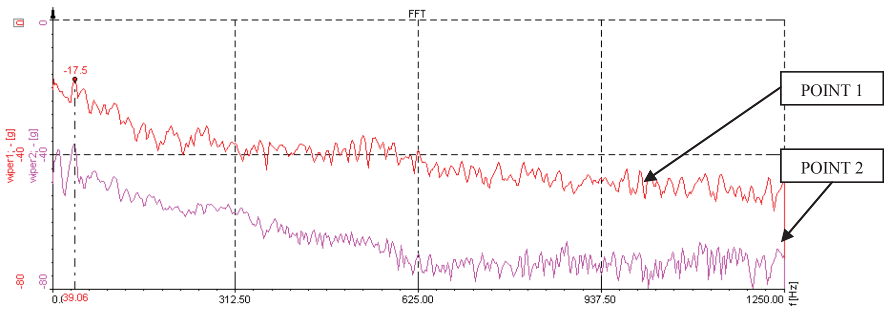

Figure 13 FFT graph for speed 3 at wet condition

4.3 Validation Results

In analytical and experimental approach were tabulated for easiness to discuss in this section. Table 3 and 4 are shown the analytical and experimental results of the wiper system.

Table 3 Analytical result of the wiper system

Mode	Acceleration(m/s²)
1	14.35
2	165
3	118.5
4	30.12
5	15.67
6	53.55
7	12.83
8	95.91
9	31.06
10	15.19
11	74.65
12	14.44
13	26.01
14	47.97

Table 4 Experimental result of the wiper system

Speed	**1**		**2**		**3**	
Position	**Dry, m/s²**	**Wet, m/s²**	**Dry, m/s²**	**Wet, m/s²**	**Dry, m/s²**	**Wet, m/s²**
1	68.36	12.44	85.45	39.06	141.60	39.06
2	39.06	14.24	36.06	12.21	34.10	39.06
3	41.50	39.06	39.06	21.21	39.06	12.21

The analytical results showed the values of vibrations at several modes are nearest to experimental measurement value. Table 5 is shows the data of the comparison.

Table 5 Comparison data

Experimental Acceleration(m/s²)	**Analytical Acceleration(m/s²)**
12.44	12.83
14.24	14.44

The data proved that the analytical approach result is nearly having same vibration with the experimental approach. There are two values were taken as a reference for validation. At mode 7 in analytical approach, the result is 12.83 m/s² and in experiment the value is 12.11 m/s² and it was identified as a natural frequency of wiper system. Then, it was tested for second value locate at mode 12, which is 14.24 m/s² and 14.44 m/s² for both analytical and experimental, respectively. Both values are nearly equal. Hence, the analytical results can be validating by the experiment.

For validate the percentage error of the analytical and experimental result, the calculation is shown below.

$$Percentage\ of\ error = \frac{simulation - experimental\ value}{experimental\ value} \times 100\%$$

$$Percentage\ of\ error = \frac{12.83 - 12.44}{12.44} \times 100\%$$

$$Percentage\ of\ error = 3.14\%$$

The analytical result does not similar with experiment result and it has a small number in percentage of error, 3.14%. According to this value, the further analysis could be made using the mathematical model derived in equation (10) and (11).

5.0 CONCLUSION

Characteristic study of wiper system is done by using analytical and experimental approach. Two dimensional mathematical model of wiper system is derived by using open literature and conservation law method. Then, this mathematical model was applied into analytical tool to generate a respond in x- and y-direction. An experimental study was completed using the actual instrumentation. Accelerometer is used as a sensor to detect the vibration level in both direction of wiper system during forth and vice versa movement. The results in analytical and experimental were validated each other and result shows it was reasonably closed where the percentage of error is only 3.14%. According to this value, there a agreement and for further analysis, two dimensional mathematical model can be used.

7.0 ACKNOWLEDGEMENT

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8.0 REFERENCES

A.R.Abu Bakar, M.Z.Md Zain. 2008. Modeling and simulation wiper noise and vibration using finite element method. 2nd Regional on Vehicle Engineering and Technology.

B.Stalleart, F.Daucet, J.Rys. 2006. Application of dither control for automobile wiper squeal. Proceedings of ISMA.

Grenouillat, C. Leblanc. 2002. Simulation of chatter vibrations for wiper systems. SAE Technical Paper. 2002-01-1239.

M.A.Salim, F.R.Ramli, M.Z.M.Zain, A.R.A.Bakar. 2009c. Modelling and simulation of unwanted noise and vibration in wiper system. ICAME 2009.

M.A.Salim, M.Z.Md Zain, A.R.Abu Bakar, A.Noordin. 2009b. Simulation of an input shaping scheme technique to investigate unwanted noise and vibration in wiper blade. Journal of Mechanical Engineering and Technology. pp. 1-13.

M.A.Salim, M.Z.Md Zain, A.R.Abu Bakar, S.Mat, M.N.Rahman. 2009a. The application of input shaping scheme for arm force in automotive wiper blade. International Conference on Instrumentation, Control & Automation. IEEE Indonesia Section. pp. 160-166.

Shigeki Okura, Tohru Sekiguchi, Takio Oya, "Dynamics analysis of blade reversal behavior in a windshield wiper system", The Engineering Society for Advancing Mobility Land Sea Air and Space (SAE), 2000.

Shinya Goto, Hiroshi Takahashi, Takio Oya. 2001. Investigation of wiper blade squeal noise reduction measures. Society of Automotive Engineers. 2001-01-1410.

Shun Chang Chang, Hai Ping Lin. 2003. Chaos attitude motion and chaos control in an automotive wiper system. International Journal of Solids and Structures 41. 3491-3504.