Modeling and Simulation of Acting Force on a Flexible Automotive Wiper

I. Salleh[*], M. Z. Md. Zain and A. R. Abu Bakar

School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Malaysia.

[*]Corresponding author: ismasyariff@gmail.com

Abstract: A vehicle wiper system has a potential to generate noise and vibration during its operation. These unwanted dynamics provide poor visibility to drivers and passengers especially during raining condition. It can also bring annoy to them while the wiper continuously sweeping the windscreen. This paper focuses on the development of a simulation model for a wiper system based on the mathematical expression using the Newtonian method. The model is compared with the previous model based on a numerical method to verify the developed analytical approach. A parametric analysis is then conducted to examine behavior of the dynamic system when the parameters are varying. Two acting forces of different speed levels to run the wiper blade are applied to the model and the levels of noise and vibration for the model are compared both in time and frequency domains.

Keywords: Contact force; Newton method; Noise; Vibration; Wiper system.

1. INTRODUCTION

Automotive industry keeps evolve and growing rapidly in the last decade. Various improvements on the vehicle have been done to improve the vehicle capability and attract the customers. Normal vehicle contains a lot of components that made a complicated system such as engine, wiper and braking run smoothly. However, these systems cannot avoid noise and vibration phenomenon. In engineering terms, noise and vibration can be described as a motion result of a forcing force [1–3]. Noise and vibration are becoming serious in automotive industries and car manufacturers have spent a lot of efforts in research and development to counter these unwanted noise and vibration [4–6]. One of the systems that producing noise and vibration is a wiper system. A wiper has a sweeping roles by sweep rain drops, fog, dirt and other contamination stick on the vehicle windscreen. Its main objective is to give a clear view and good visibility to the driver and passengers for a safety and comfortable driving condition. Noise and vibration in the wiper system can be divided into three types which are squeal noise, chattering noise and reversal noise. Squeal noise or squeaky noise is a high frequency sound ranging at least 1000 Hz whereas chattering noise or beep noise is a low frequency noise ranging between 100 Hz and below. Reversal noise is an impact sound occurred when the rubber inside the wiper bumps against the windscreen during reversing sweep at frequency level of 500 Hz and less [3–10].

In order to solve the problem, the behavior of the system needs to be studied. Based on two and three dimensional mathematical models of the wiper system developed by Shigeki et.al. [4], the reaction force at the wiper blade would be smaller by using small rotational spring contact angle. The arm twist angle can also prevent the speed level of wiper during the operation. A study using Finite Element Model (FEM) approach has also been conducted by Goto et al. [6], which focused on the blade squeal noise. They had also derived the mathematical equation for system motion and found out that dampness and friction are the highest sensitive parameters and has the potential of creating squeal noise [6]. By controlling these two parameters, the unwanted squeal noise can be reduced. To suppress squeal noise, Chang et al. [8] proposed a vibration control scheme and implemented the control scheme to reduce the noise and vibration in the wiper system.

The objective of this study is to examine the responses of the rubber blade based on contact force between the blade and the windscreen. In order to study their dynamic behaviour, mathematical expression of wiper system is developed using the Newtonian method.

2. RESEARCH METHODOLOGY

The development of two dimensional mathematical model of wiper system using Newtonian method is described in this section based on previous mathematical expression studies on the system conducted by several researchers. The physical system was adopted from a model developed by Shigeki et.al [4]. Prior to the modelling, a knowledge on the system physical behaviour must be fully understood. During the operation, the wiper blade will move forward and backward to wipe the windscreen. This

back and forth motions can produce unwanted noise and vibration in the system. Figure 1 shows the schematic diagram of a lowest order system of the wiper blade.

Figure 1. Schematic diagram of wiper system [8]

Modeling is a process to identify the physical dynamic and the response of the system. Several steps involve in developing the model and running the simulation. The first step is understanding the actual or physical model of the wiper system. Based on the model, all the dynamic response of the system has to be presented. The second step is to understand the modeler perception once the dynamic response of the system is finalised. Modeler perception is required before start the modelling process. In this case, all dynamic responses in x-axis and y-axis are considered in nonlinear motion. A linear model is less complicated and easy to analyze. The derivation of the mathematical model is required to represent the differential equation and its derived from conservation laws for step three. The derivation for the first order system is much easier compared to the complex multi order system. Analytical approach is used in step four to identify the physical response of wiper system. The verification process needs to be done between actual model and the analytical solution [11].

2.1 Mathematical Model of a Wiper System

Figure 2 shows the spring mass damper model of the arm and blade of wiper and Table 1 shows their parameters.

Figure 2. Spring-mass model of wiper arm and blade [4]

Table 1. Parameters in analytical model

Parameter	Description
$F_0 = 8.3$ N	Arm pressure
θ_F	Arm front twist angle
θ_H	Arm head twist angle
θ_G	Windshield glass profile
θ_a	Rotational angle of rubber neck
$m_y = 0.21$ kg	Equivalent mass of arm and blade to the y-direction
$m_x = 0.25$ kg	Equivalent mass of arm and blade to the x-direction
$c_x = 0.2$ Ns/m	Equivalent damping coefficient of arm to the x-direction
$l = 5.3 \times 10^{-3}$ M	Length of the rubber
$k_x = 1.1 \times 10^4$ N/m	Equivalent spring constant of arm to the x-direction
$k_y = 3 \times 10^4$ N/m	Equivalent spring constant of arm to the y-direction
x_B	Arm tip virtual position without arm deformation
$y_M = y_A$	Neck rotation center position (free length of spring)

Newton's second law is used to derive the mathematical expression of wiper system, written as:

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

The summation force of the wiper system in *x*-axis and *y*-axis can be represented as:

$$\sum F_x = ma_x \qquad \sum F_y = ma_y \tag{2}$$

As the system can be considered a rigid body and the force applied to the system is only subjected to the wiper system bodies, the general vectors involved in Newton's second law are:

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

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

$$= m_1 a_{c1} + m_2 a_{c2} + m_3 a_{c3} + \cdots + m_n a_{cn} \tag{3}$$

Where:

$$m = \sum_{j=1}^{n} m_j \tag{4}$$

$F_i = i$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

The wiper blade reaction force based on dynamics model of rubber blade as shown in Figure 3 can be summarised as:

$$F_{x0} = \frac{-sin\theta_F}{cos(\theta_H + \theta_F)} F_0 \tag{5}$$

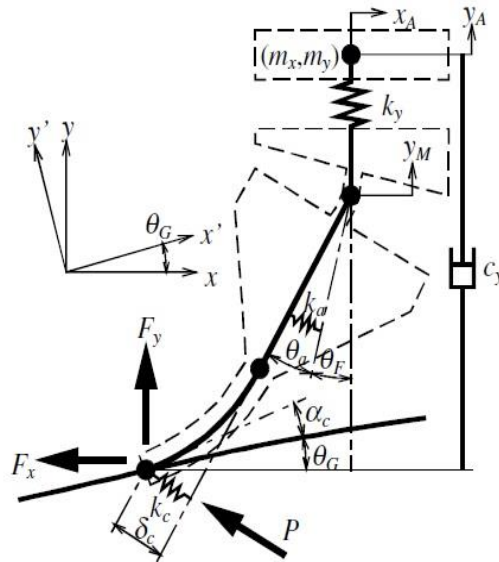$$F_{y0} = \frac{cos\theta_F}{cos(\theta_H + \theta_F)} F_0 \tag{6}$$

Figure 3. Dynamic model of wiper rubber blade [4]

Therefore, the summation of force at *x*-axis and *y*-axis are represented as Equations (7) and (8) respectively.

$$m_x\ddot{x}_A + c_x(\dot{x}_A + \dot{y}_A tan\theta_H - \dot{x}_B) + k_x(x_A + y_A tan\theta_H - x_B + F_x) = 0 \tag{7}$$

$$m_y\ddot{y}_A + c_y(\dot{y}_A - \dot{y}_C) + \{c_x(\dot{x}_A + \dot{y}_A tan\theta_H - \dot{x}_B) + k_x(x_A + y_A tan\theta_H - x_B)\}tan\theta_H - F_{y0} = 0 \tag{8}$$

3. SIMULATION RESULTS

3.1 Noise and Vibration Level in Baseline Model

Figure 4 shows a continuous step signal representing the input of the system. The time range of step input represented the time of the wiper operation for approximately four cycles, enough to get a suitable response of the system. The velocity range is between -0.25 to 0.25 m/s. The velocity of 0.25 m/s is the initial value of wiper system to make a movement of the arm and blade from an initial stage to the end point on the windscreen. Besides, the velocity of -0.25 m/s indicates the backward movement at the end point on the windscreen to initial point [11].
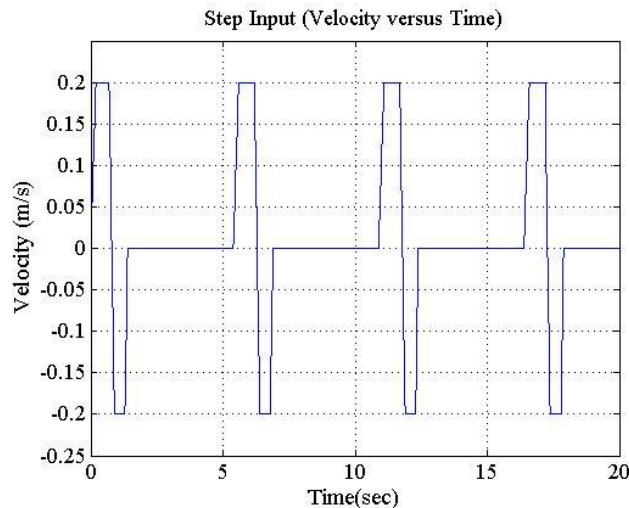
Figure 4. Continuous unit step input of the wiper system

Figures 5 and 6 show the noise and vibration of the wiper system in time and frequency domains for *x*- and *y*-axes respectively. For the *x*-axis, the maximum noise was identified at the starting point and the range of acceleration was between -5 to 5 m/s². This is because more force from the motor is required to make a forward movement direction. Noise decreased when the wiper blade reached at the end point of the windscreen. In the backward motion, the noise increased again but smaller as compared to the starting point. This situation continued until the wiper blade stopped wiping the windscreen. The maximum noise was recorded at 4.2 m/s² and vibration at 0.02 m²/Hz located at 92.72 Hz. For *y*-axis, the results were quite similar to the result of *x*-axis but the acceleration range was almost half. The maximum noise was recorded at 1.5 m/s², with vibration of 4.2×10^{-3} m²/Hz and located at 128.2 Hz.
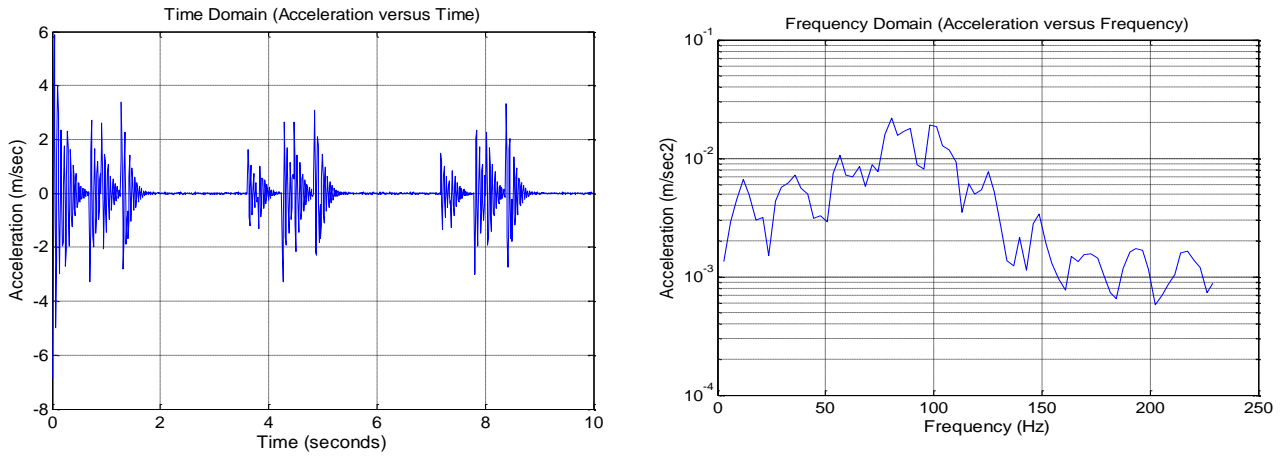
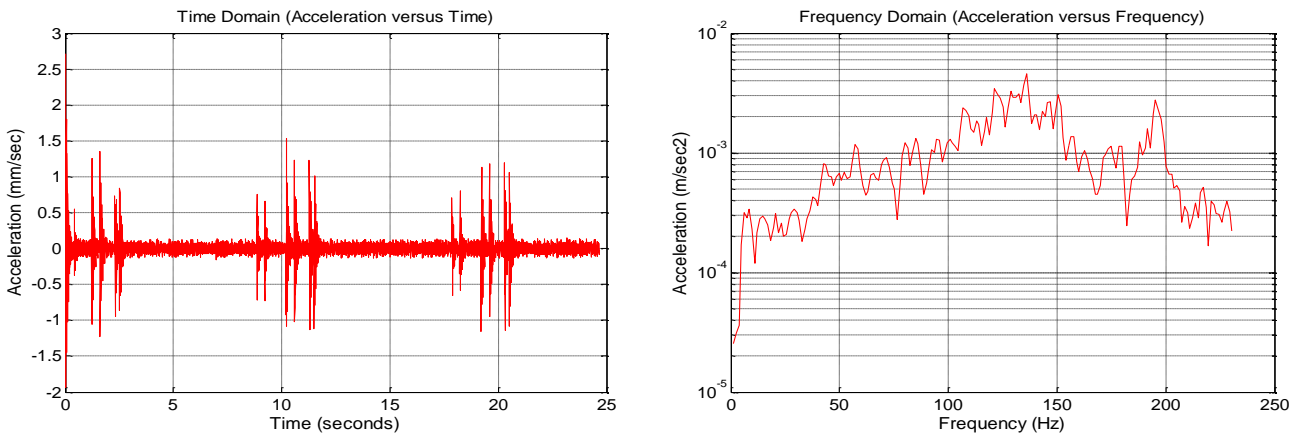Figure 5. Noise and vibration level for the wiper system at *x*-axis

Figure 6. Noise and vibration level for the wiper system at *y*-axis

A numerical approach is another method to investigate the unwanted noise and vibration of the wiper system during operation. It can also be used to verify the analytical model by compared the analysis results. The numerical analysis results were taken from the previous study by Ibrahim et al. [12]. Figures 7 and 8 tabulate the noise level in *x*- and *y*-axes respectively. The maximum values in *x*- and *y*-axes were obtained as 99.08 Hz and 137.46 Hz respectively. It was found that both approaches were reasonably close with maximum frequency differences were less than 7% as shown in Figure 9. Therefore the model can be used for further analysis and for development of control schemes.
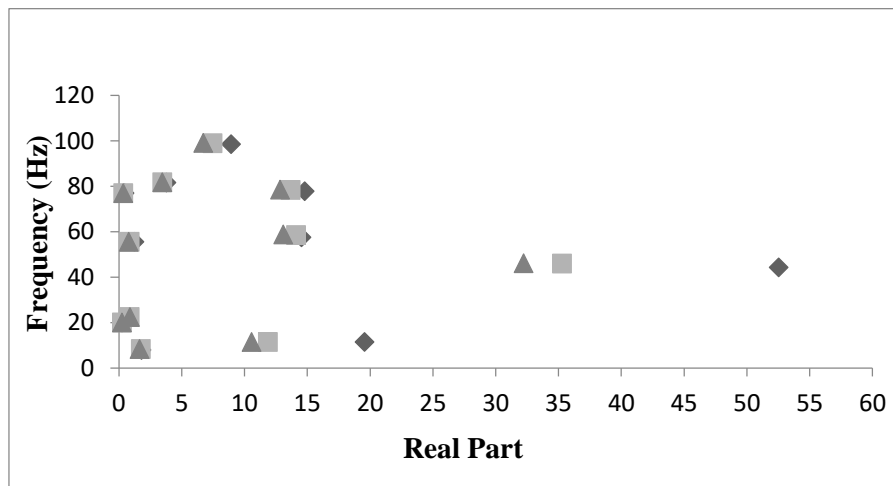
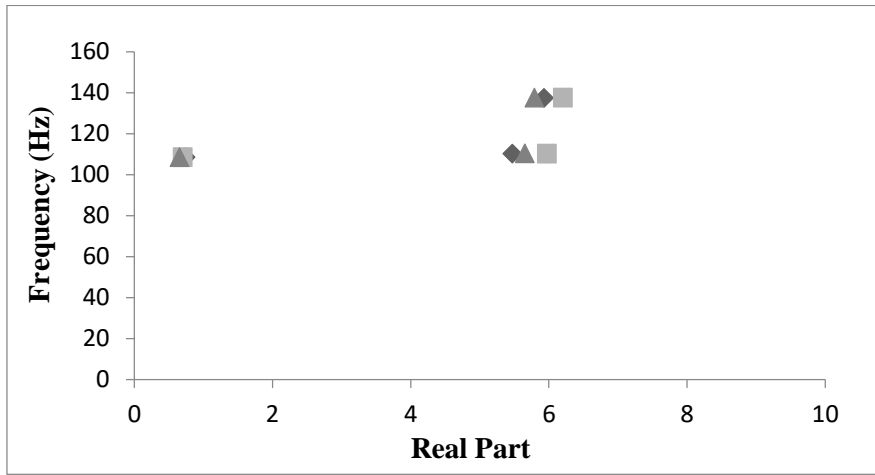Figure 7. Numerical analysis results in *x*-direction [12]

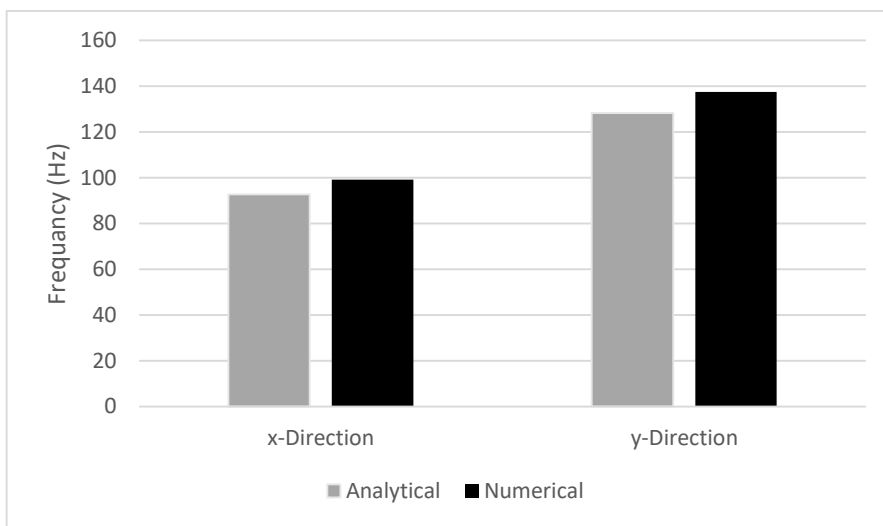Figure 8. Numerical analysis results in *y*-direction [12]

Figure 9. Level of noise comparison using analytical and numerical methods

3.2 Effect of Force on the Noise and Vibration of the Wiper System

Parametric analysis was conducted to study the effect of different level of force on the unwanted noise and vibration. These parametric analysis can be used to specify a range of values as inputs for a number of parameter. The wiper system was tested using three levels of operation with levels 1 and 2 used the same speed. Level 1 runs intermediately, level 2 runs continuously and level 3 runs fast and continuously. The forces applied to the system for the normal and fast speeds are 8.3 N and 10.5 N respectively.

The results in time and frequency domains for *x*- and *y*-axes are shown in Figures 10 and 11 respectively. In *x*-axis, the highest noise was recorded for 10.5 N force with the range of acceleration between -5 to 5 m/s^2 as compared to the 8.3 N force with the acceleration range between -4 to 4 m/s^2. For the frequency domain in *x*-axis, the 10.5 N force applied to the system was more effective in reducing the noise as compared to the 8.3 N force. In *y*-axis, the result was quite similar with fluctuated at a range of 2 to -2 m/s^2 for both forces.

4. CONCLUSION

In this work, the model of a wiper system was developed using the Newtonian method and verified using a numerical approach. Noise and vibration of the wiper system was evaluated in the time and frequency domains. Different forces were also applied to examine their effects on the noise and vibration the system. Based on the parametric study, it was shown that certain applied force yields in a lower noise and vibration.
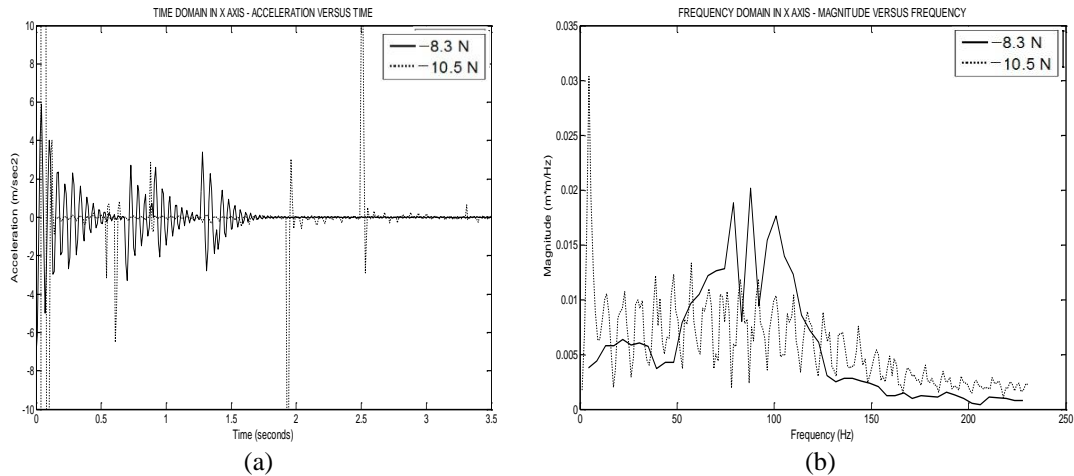
(a)   (b)

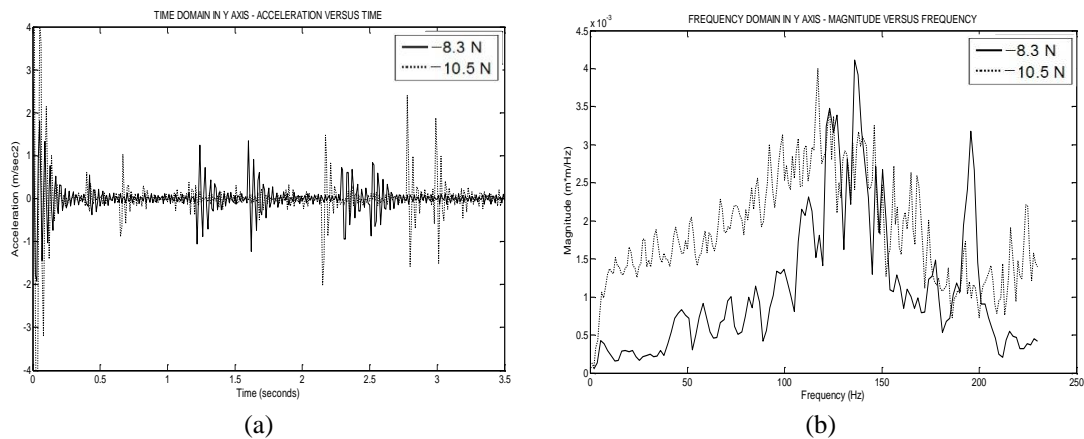Figure 10. Noise and vibration levels in *x*-axis: (a) Time domain, (b) Frequency domain

(a)   (b)

Figure 11. Noise and vibration levels in *y*-axis (a) Time domain, (b) Frequency domain

ACKNOWLEDGMENT

REFERENCES

[1] S. Goto, H. Takahashi and T. Oya, Investigation of wiper blade squeal noise reduction measures, *SAE Technical Paper*, 2001-01-1410, 2001.

[2] Y. Fujii, Method for measuring transient friction coefficients for rubber wiper blades on glass surface, *Tribology International*, 41(1), 17–23, 2008.

[3] C. Chevennement-Roux, T. Dreher, P. Alliot, E. Aubry, J.-P. Lainé and L. Jézéquel, Flexible wiper system dynamic instabilities: Modelling and experimental validation, *Experimental Mechanics*, 47(2), 201–210, 2007.

[4] S. Okura, T. Sekiguchi and T. Oya, Dynamic analysis of blade reversal behavior in a windshield wiper system, *SAE Technical Paper*, 2000-01-0127, 2000.

[5] A. Koenen and A. Sanon, Tribological and vibroacoustic behavior of a contact between rubber and glass (application to wiper blade), *Tribology International*, 40(10–12), 1484–1491, 2007.

[6] M. A. Salim, A. Noordin and M. Z. Zin, Simulation of an input shaping scheme technique to investigate unwanted noise and vibration in wiper blade, *Journal of Mechanical Engineering and Technology*, 1(1), 1–14, 2009.

[7] S. Goto, H. Takahashi and T. Oya, Clarification of the mechanism of wiper blade rubber squeal noise generation, *JSAE Review*, 22(1), 57–62, 2001.

[8] S. C. Chang and S. C. Chen, Dither signals with particular application to the control of windscreen wiper blades, *International Journal of Solids and Structures*, 43(22–23), 6998–7013, 2006.

[9] R. Grenouillat and C. Leblanc, Simulation of chatter vibrations for wiper systems, *SAE Technical Paper*, 2002-01-1239, 2002.

[10] Y. Fujii and T. Yamaguchi, Dynamic characteristics measurements of a car wiper blade, *JSME International Journal Series C Mechanical Systems, Machine Elements and Manufacturing*, 49(3), 799–803, 2006.

[11] A. R. Salim, M. A. Ramli, F. R. Md Zain and M. Z. Abu Bakar, Modeling and simulation technique of unwanted noise and vibration in wiper system, *International Conference on Advances in Mechanical Engineering*, Kuala Lumpur, Malaysia, 2009, pp. 1–6.

[12] I. M. Awang, C. Y. Leong, A. R. Abu-Bakar, B. Abd-Ghani, R. Abd-Rahman and M. Z. Md-Zain, Modeling and simulation of automotive wiper noise and vibration using finite element method, *2nd Regional Conference on Vehicle Engineering & Technology*, Kuala Lumpur, Malaysia, 2008, pp. 1–6.