The Analysis of Friction Effect in Automotive Wiper System Using Input Shaping Technique

M.A.Salim, A.Noordin, M.Z.Md Zain, A.R.Abu Bakar

***Abstract*— Wiper is a device to wipe out dirt and raindrops from the windscreen. Hence, when a wiper system is operated, it has a potential to generate unwanted noise and vibration level. Reversal is one of the noise and vibration generated during the wiper operations. It is a medium frequency and self excited vibration that is often generated before and vice versa the direction. This leads to poor visibility and annoying sound to the driver and passengers. This paper investigates the effect of friction coefficient on vibration response in the wiper assembly. The adjusted values of friction have been made in order to reduce the noises and vibrations level. Besides, an input shaping (IS) control technique is proposed to reduce the reversal noises and vibrations level in this wiper system. A two dimensional mathematical model of wiper system is used in this analysis which shows that the noise and vibration level can be reduced up to 30 percents.**

***Index Terms*—Input shaping, wiper system, vibration**

I. INTRODUCTION

Recently, automobiles industry increases steadily where noises during operation of the wiper system are noticeable. A survey in a market information analysis has been made and the result shows that one of the critical noises happen in wiper system. In general, wiper system is a device to wipe out raindrops and dirt to clean the windscreen in front of the driver and passenger. During operation this system has a potential to generate unwanted noise and vibration. This noise can be classified into three categories which are squeal noise, chattering noise and reversal noise. Squeal noise is called as squeaky noise where it is a high frequency noise in a range of 1000Hz. Chattering noise or beep noise is a low frequency noise in a range of 100Hz and less while reversal noise within a range of 100 to 500 Hz [1] – [7]. These noises may lead to visual and audible annoyance to driver and passenger during a raining day.

Unwanted noise and vibration in a wiper system has been actively investigated and identified by researchers using three different techniques that are the analytical approach, the numerical approach and the experimental approach. Shigeki et al. [8] has developed 2-dimesional and 3-dimensional mathematical model of wiper system to identify the behavior of reversal noise and vibration in the system. In their research, they had stimulated various conditions and found that the reaction of this noise could be reduced using a small neck angel or a large neck rotational spring.

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Shinya Goto et al. [2] have investigated a squeal noise reduction measured in wiper system. They had studied the mechanism of squeal noise generation to identify the reverse direction before and after turnover. In their study, they had found that the relation between the friction coefficient and the blade velocity is inverse each other.

In other research, Granouillat et al. [4] had studied the contact pressure distribution of the wiper blade using numerical and experimental approaches. In their studies, the researchers had found that the predicted contact pressure for various arm loads is much closer to the experimental data.

In modifying the material and design of the wiper system, Chang and Chen [9] in their studies found that the dither control has a potential to suppress the unwanted squeal noise in the wiper system.

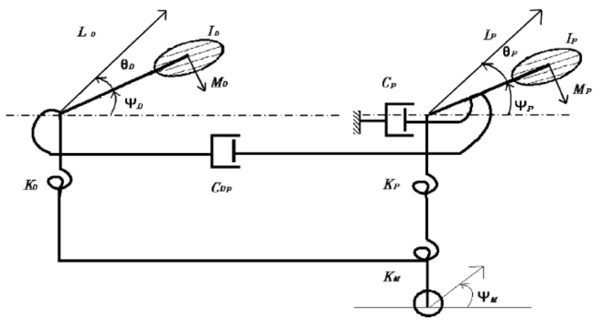

Fig. 1: Schematic Diagram of Wiper System [10]

Based on previous work of the researchers, then in this research it is decided to investigate the effect of friction coefficient between wiper blade and windscreen in order to identify the unwanted level of noise and vibration. A two dimensional mathematical model of wiper system in open literature is adopted and the parameter values are modified to suppress the noise and vibration in the system. This paper also presented a simple control technique, namely input shaping scheme (IS) to reduce reversal noise and vibration in the wiper system. A MATLAB-SIMULINK is used to simulate the vibration response and the results are plotted and analyzed.

II. MODELING APPROACH

Modeling is a process to identify the principal of physical dynamic system. In order to modeling a system, a differential and algebraic equation is required to be understand and the derivation is coming from conservation law which is also known as a property of laws [12].

Most of engineering disciplines used modeling and simulation approach to analyze engineering problem since it gave better analysis and result. Based on this modeling and

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simulation approach, the result can be analyzed and predicted without any physical testing.

There are several stages in execute modeling and simulation approach. Firstly, the actual model or physical model of the system needs to be understood. Based on this actual model, all the dynamic response characteristics in the system have to be represented whether they are in linear or in nonlinear behavior [11]. Besides, the actual model demonstrates the real response in real time that needed to analyze further.

The second stage is to know the modeler perception of the system. Modeler perception is required before the modeling approach of the system is made. Here, a number of nonlinearities or higher order of the system will be neglected for simplification.

The derivation of mathematical model of the system is a very important stage in this approach. In this third stage, the mathematical model is required to express the whole system which is derived referring to conservation laws. The derivation can be easier for a first order system but is more complex for a higher order system.

The approximation technique was applied for simplification of the complex model. Then the responses of the system need to be known and has to be calculated using an analytical solution. This analytical solution is represented by a differential equation to show the exact solution of the equation.

Then a verification process is necessary to identify the errors occurs between both actual model and the analytical solution [11]. Fig. 2 shows the modeling sequences applied in this study.

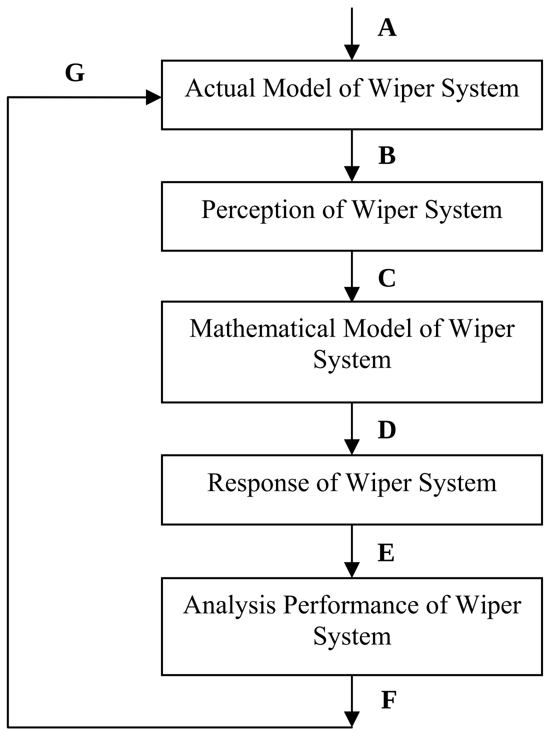

Fig. 2: Modeling sequences [10]

A	=	Actual model representation
B	=	Determine the effects (must be considered)
C	=	Identify the system configuration
D	=	Classical differential equation or transfer function or state space equations
E	=	Analytic/numerical solution
F	=	Dynamic characteristics
G	=	System modification

III. Mathematical Model of Wiper System

In this study, the mathematical model of the wiper is derived by using Newtonian's approach. Fig. 3 shows a spring mass model of the arm and blade for the wiper system.

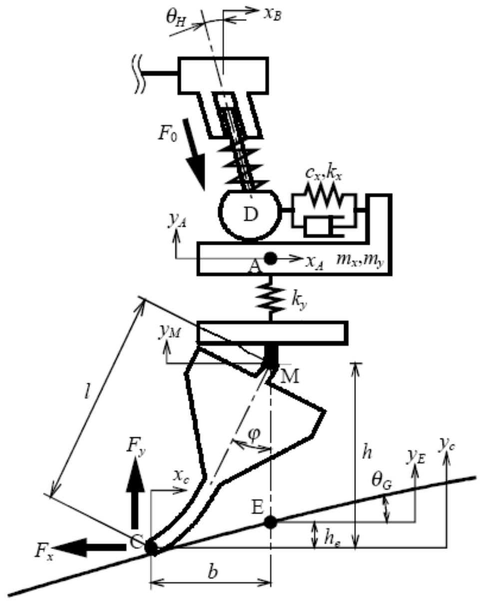

Fig. 3: Spring mass model [8]

Newton's second law can be expressed by:

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

The rectangular coordinate component in x- and y-direction can be expressed by:

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

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

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

$$\sum_{i=1}^{N} F_i = ma_c = \sum_{j-1}^{n} m_j a_{cj} = m_1 a_{c1} + \cdots + m_n a_{cn} \tag{4}$$

Where

$$m = \sum_{j=1}^{n} m_j \tag{5}$$

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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

To calculate component in x- and y- direction, Newton's second law can be expressed by:

$$\overset{+}{\rightarrow}\sum_{i=1}^{N} F_{ix} = ma_{cx} = \sum_{j-1}^{n} m_j a_{cjx} = m_1 a_{c1x} + \cdots + m_n a_{cnx} \quad (6)$$

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

Based on equation (6) and (7), they are a rectangular coordinate system in x- and y- direction. Fig. 4 shows the dynamic model of the wiper system and the coordinate of system.

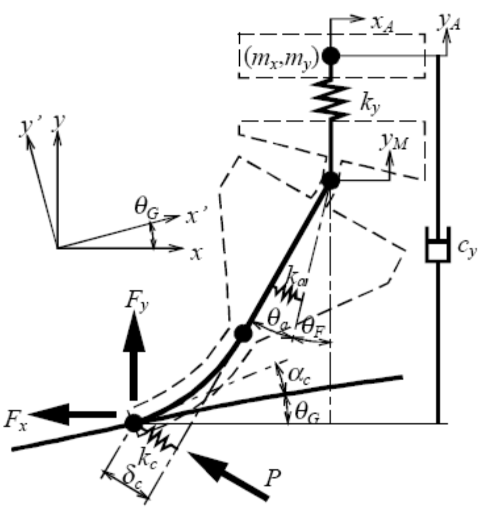

Fig. 4: Dynamic system [8]

Based on Fig. 4, the initial reaction forces react at F_{x0} and F_{y0} can be expressed by:

$$F_{x0} = \frac{-sin\theta_F}{cos(\theta_H + \theta_F)} \quad (8)$$

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

Where

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

By using Newton's second law, the summation forces in x- and y-direction can be expressed by:

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

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

Then from y-direction summation forces equation forces, the actual extended equation can be expressed by:

$$m_y \ddot{y}_A + c_y\left[\dot{y}_A - \{(\theta_G - l\theta_G sin\varphi)\dot{x}_A - l\theta_G \dot{\theta}_a cos\varphi\}\right] + c_x\left\{\left(l\dot{\theta}_a\left\{\left(1+\frac{1}{K}\right)cos\varphi - \left(\frac{\theta_a}{K}\right)sin\varphi\right\}\right) + (\dot{y}_A tan\theta_H - \dot{x}_B) + k_x\left\{\left(x_c + l\left\{sin\varphi + \left(\frac{\theta_a}{K}\right)cos\varphi\right\} + y_A tan\theta_H - x_B\right)\right\} tan\theta_H\right\} - \left[-k_y(y_A - y_M) + \frac{cos\theta_F}{cos(\theta_H - \theta_F)}F_o\right] + \frac{cos\theta_F}{cos(\theta_H - \theta_F)}F_o = 0 \quad (12)$$

Equation (11) and (12) then is used to develop a simulation model to find the approximation result.

IV. Approximate result

Simulation technique is a methodology that was applied to make an approximation result in this study. Two dimensional mathematical models in equations (11) and (12) were used to simulate the response of the wiper. These two equations have been represented by a block diagram in MATLAB SIMULINK.

Fig. 5 shows the input data applied to the system. This input represents the applied force to the wiper system during the system motion. In this analysis, both time and frequency domain is plotted. The parameter data is given by Tab. 1.

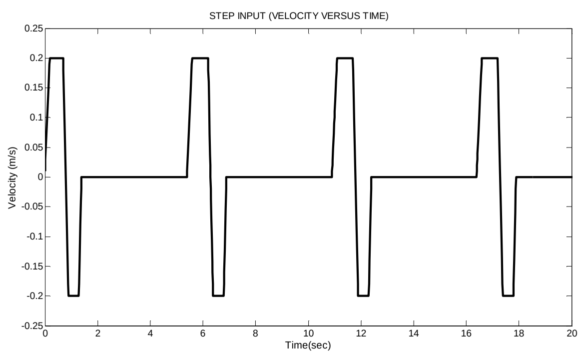

Fig. 5: Input data

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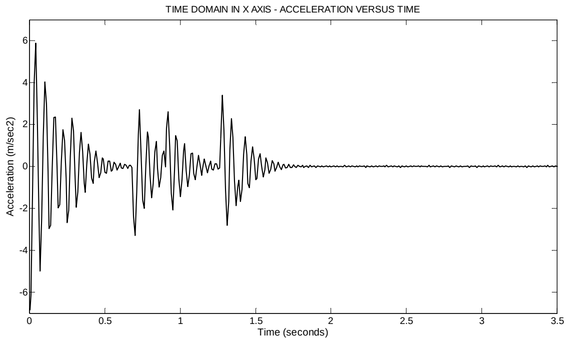
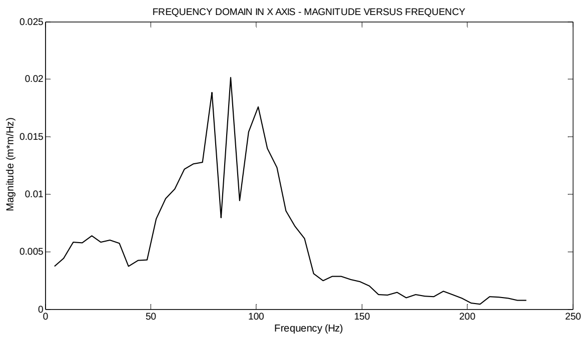
Tab. 1: Parameter of Arm and Blade of Wiper System

Parameter	Data	Unit
m_x	0.25	kg
m_y	0.21	kg
c_x	0.20	Ns/m
k_x	1.1x104	N/m
l	5.3x10-3	M
θ_o	0.52	Radian
k_a	2.5x10-2	Nm/radian
k_c	8x103	N/m
k_y	3x104	N/m
c_δ	5	Ns/m
F_{yo}	8.3	N



(a) Time domain

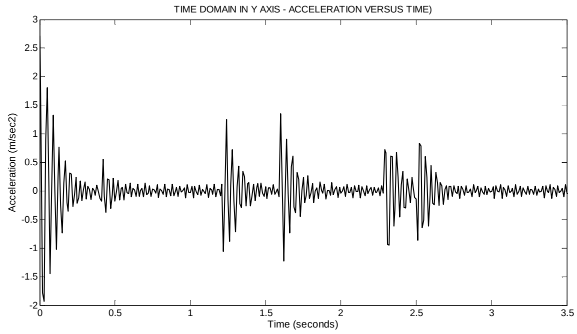


(a) Frequency domain

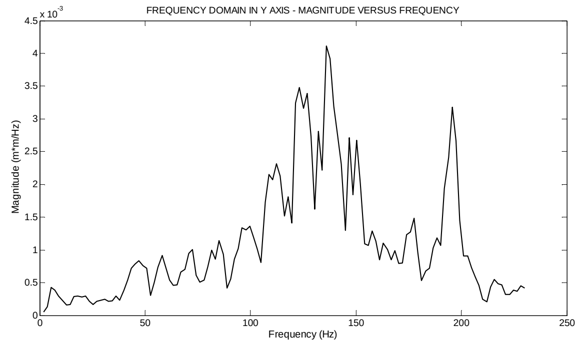
Fig. 6: Approximate result in x-direction

In x-direction, the result was represented in time and frequency domain. These time and frequency domains represent the variety of unwanted noise and vibration level in wiper system, respectively. The maximum level of unwanted noise is 4.3 meter per seconds2 and the highest vibration is 0.02 m*m/Hz and locate at 92.72 Hz.

In y-direction, the highest level of noise and vibration are 1.5 meter per seconds2 and 4.2 x 10-3 m*m/Hz locates at 128.2 Hz.



(a) Time domain



(a) Frequency domain

Fig. 7: Approximate result in y-direction

V. VERIFICATION RESULT

Verification process is a vital step in system identification for two mathematical model of wiper system [13]. In this study, the numerical approach is applied to verify the analytical result to ensure the data is more reliable and trustworthy before make further analysis.

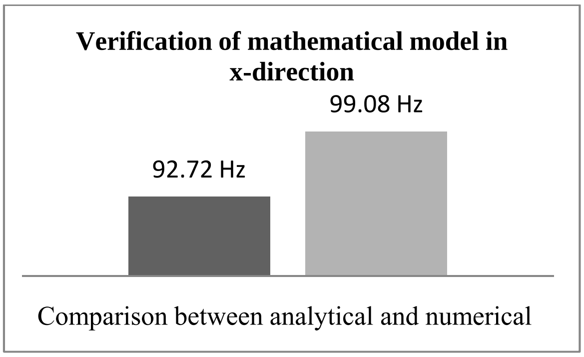


Fig. 8: Verification in x-direction

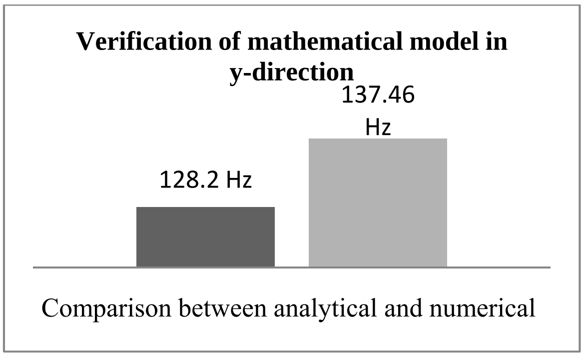


Fig. 9: Verification in y-direction

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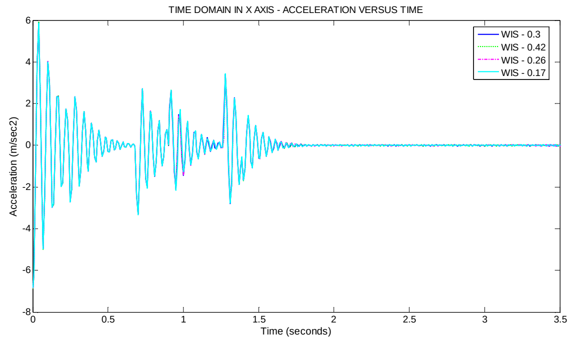
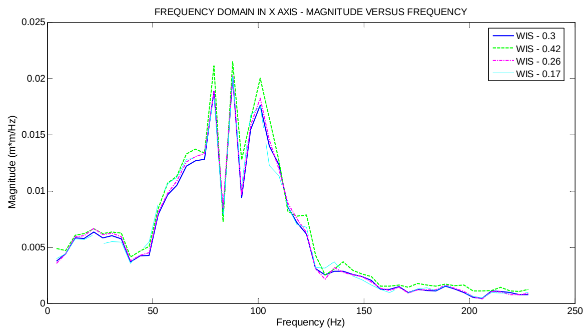
In this verification process, these two approaches (analytical and numerical) give a reasonably closed correlation between each other and from this result; the analytical result is suitable to use to make the further analysis.

VI. Friction Effect Analysis

In this friction analysis, four different friction coefficient values are applied into the wiper system and vibration response in the x- and y- direction. The friction coefficient values are 0.17, 0.26, 0.3 and 0.42. Fig. 10 and Fig. 11 show the result in time and frequency domain for both x- and y- direction.



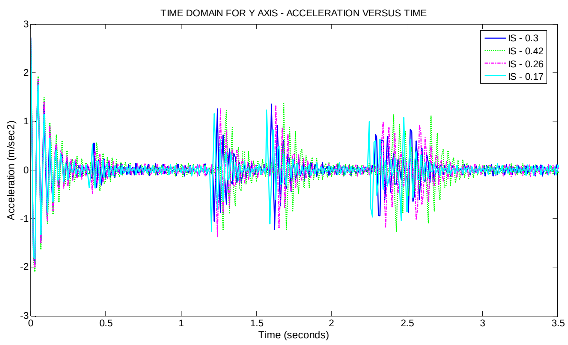
(a) Friction effect in time domain



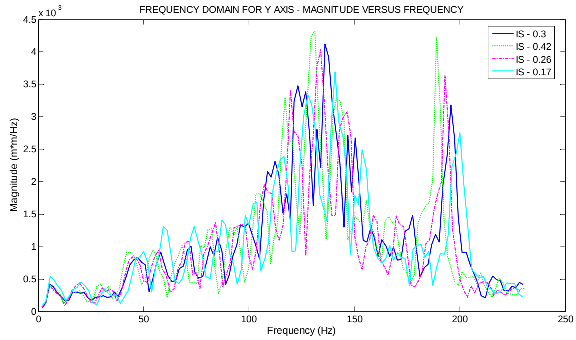
(b) Friction effect in frequency domain

Fig. 10: Friction effect in x-direction

Fig. 10 shows the friction effect in x- direction for both time and frequency domain. The unwanted noise ad vibration level in this direction becomes less when 0.17 and 0.26 friction coefficient is applied to the wiper system. In other words, the friction coefficient is proportional due to the unwanted noise and vibration level.



(a) Friction effect in time domain



(b) Friction effect in frequency domain

Fig. 11: Friction effect in y-direction

Fig. 11 shows the friction coefficient effect in y- direction for the wiper system. In time domain, the level of unwanted noise is still increasing when the different values of friction is applied to the wiper system. But in frequency domain, the values of friction coefficient at 0.17 and 0.26 have decreased the unwanted vibration level.

Based on this friction effect analysis, changes of friction coefficient are not a best way to decrease the level of unwanted noise and vibration in wiper system. Due to the statement, another method is suggested to reduce the noise and vibration level. Therefore, input shaping (IS) scheme method is proposed.

VII. Input Shaping Scheme

Input shaping (IS) scheme involves a desired command according the sequence of impulses, otherwise it also known as an input shaper where the system produced the shaped system command [14]. The main purpose using this IS scheme is to calculate the eliminated vibrations at certain amplitude, time location and desired frequencies. This scheme can be made insensitive to make a variation in resonant frequencies and at the same time it also more effective to minimize noise and vibration level in a wiper system. Then the vibratory system of any order system can be modeled as a superposition of the second order system and the transfer function on the IS equation is shown in equation (13) [14] – [16].

$$G(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad (13)$$

Where:

ω_n= natural frequency and ξ = damping ration of the system. The impulse response of the system can be expressed as:

$$y(t) = \frac{A\omega_n}{\sqrt{1-\xi^2}} e^{-\xi\omega_n(t-t_o)} sin\left[\omega_n\sqrt{1-\xi^2(t-t_o)}\right] \; () \quad (14)$$

Where:

A = amplitude and t_o = time of the impulse

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The response of impulses can be represented by the superposition of the impulse response. For N impulses, with $\omega_d = \omega_n\sqrt{1-\xi^2}$.

The impulse can be expressed as a:

$$y(t) = Msin(\omega_d t + \alpha) \qquad (15)$$

Where;

$$M = \sqrt{\left(\sum_{i=1}^{N} B_i cos\Phi_i\right)^2 + \left(\sum_{i=1}^{N} B_i cos\theta_i\right)^2} \qquad (16)$$

$$B_i = \frac{A_i \omega_n}{\sqrt{1-\xi^2}} e^{-\xi\omega(t-t_i)} \qquad (17)$$

Where;

A_i = magnitudes and t_i = times

$$\Phi_i = \omega_d t_i \qquad (18)$$

$$\alpha = tan^{-1}\left(\sum_{i=1}^{N} \frac{B_i cos\Phi_i}{B_i sin\Phi_i}\right) \qquad (19)$$

The residual single model amplitude of the vibration is base on the impulse response can be evaluating at the time of the last impulse, t_N as a:

$$V = \sqrt{V_1^2 + V_2^2} \qquad (20)$$

Where;

$$V_1 = \sum_{i=1}^{N} \frac{A_i \omega_n}{\sqrt{1-\xi^2}} e^{-\xi\omega_n(t_N - t_i)cos(\omega_d t_i)} \qquad (21)$$

$$V_2 = \sum_{i=1}^{N} \frac{A_i \omega_n}{\sqrt{1-\xi^2}} e^{-\xi\omega_n(t_N - t_i)sin(\omega_d t_i)} \qquad (22)$$

To achieve zero vibration after the input has been ended, it is required that both V1 and V2 are directly equal to zero. To ensure the shaped command gives the same value of the rigid body motion such as an unshaped command, it is required to make a summation of the amplitude of impulses is unity. For avoid delay, the first impulse must be zero bases on the time. Hence, the value of V1 and V2 must be set to zero [14] – [16], therefore:

$$\sum_{i=1}^{N} A_i = 1 \qquad (23)$$

And solving yields of four impulse response sequence with parameters as a:

$$t_1 = 0, t_2 = \frac{\pi}{\omega_d}, t_3 = \frac{2\pi}{\omega_d}, t_4 = \frac{3\pi}{\omega_d} \qquad (24)$$

$$A_1 = \frac{1}{1 + 3K + 3K^2 + K^3} \qquad (25)$$

$$A_2 = \frac{3K}{1 + 3K + 3K^2 + K^3} \qquad (26)$$

$$A_3 = \frac{3K^2}{1 + 3K + 3K^2 + K^3} \qquad (27)$$

$$A_4 = \frac{K^3}{1 + 3K + 3K^2 + K^3} \qquad (28)$$

Where;

$$K = e^{\frac{-\xi\pi}{\sqrt{1-\xi^2}}} \qquad (29)$$

According to this IS scheme, the higher vibration responses can be handled when an impulse sequence for each vibration mode is designed independently. In this design, the input is a set of impulse with positive and negative cycle that is repeating in every setting period through the end. Fig. 12 shows the IS scheme for wiper system.

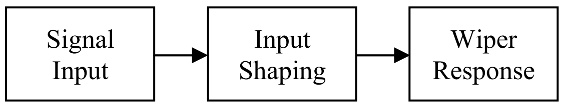

Fig. 12: IS scheme in wiper system

VIII. Result using input shaping scheme

The two dimensional mathematical model of wiper system has been used in this analysis. Fig. 13 shows the repeating sequence input applied to the system. In this figure, the continuous line is the input without input shaping technique (WIS) while the dotted line is input to the system which apply input shaping scheme (IS). By using IS, the period of the input step be smallest as a possible at time delays between one complete cycles of the initial step input (Fig. 5).

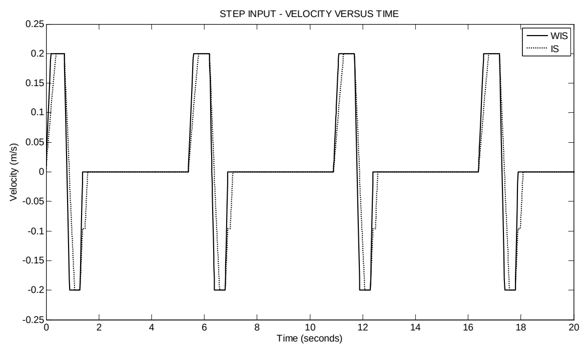

Fig. 13: Input to system

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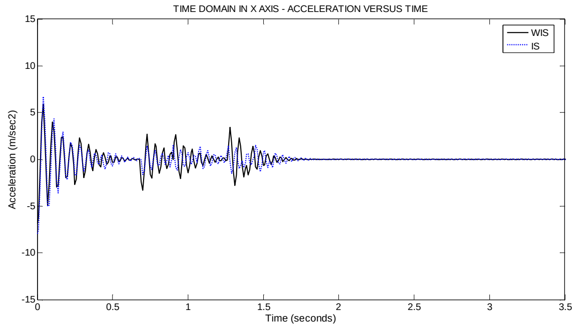
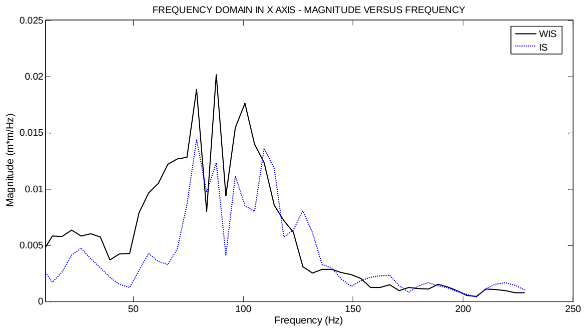
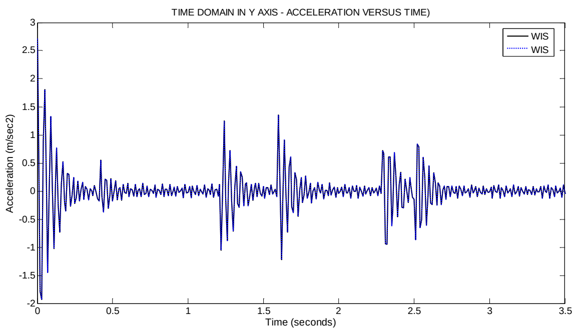


(a) WIS and IS in time domain

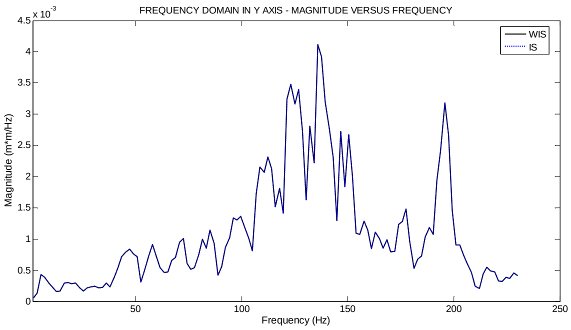


(b) WIS and IS in frequency domain

Fig. 14: WIS and IS in x-direction



(a) WIS and IS in time domain



(b) WIS and IS in frequency domain

Fig. 15: WIS and IS in y-direction

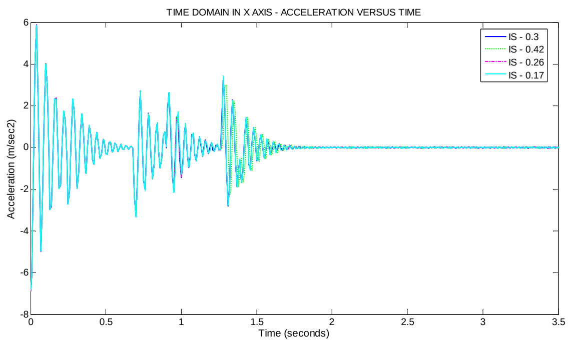
A summary of Fig. 14 and Fig. 15 is shown in Tab. 2 below:

.Tab. 2: Summary of Fig. 14 and Fig. 15

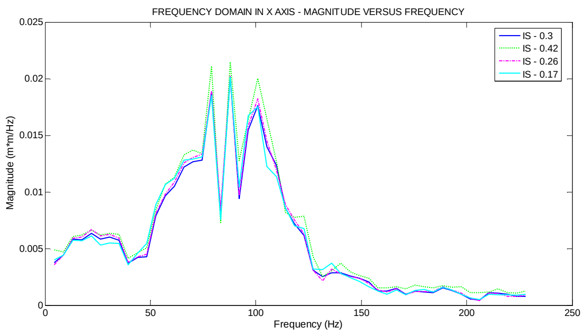
	X-Direction	Y-Direction
Unwanted Noise Without Input Shaping, (WIS)	4.3 meter per seconds^2	1.5 meter per seconds^2
Unwanted Vibration Without Input Shaping, (WIS)	0.02 magnitude (m*m/Hz)	4.2 x 10^{-3} magnitude (m*m/Hz)
Unwanted Noise With Input Shaping, (IS)	3.7 meter per seconds^2	1.3 meter per seconds^2
Unwanted Vibration With Input Shaping, (IS)	0.015 magnitude (m*m/Hz)	2.7 x 10^{-3} magnitude (m*m/Hz)

The unwanted noise and vibration in x- and y- direction are decreased by implementing IS scheme. Then this IS scheme is implemented to analyze the friction effect in wiper system.

IX. Result using Input Shaping Scheme in Friction Effect



(a) IS effect in time domain



(b) IS effect in frequency domain

Fig. 16: IS effect in x-direction

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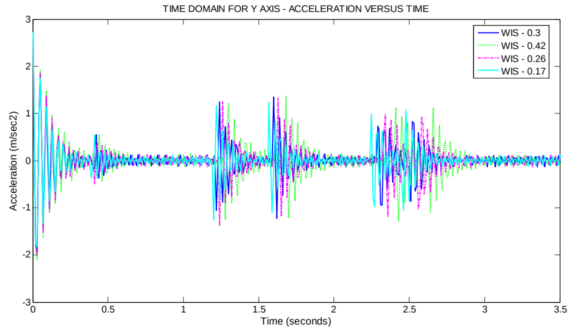
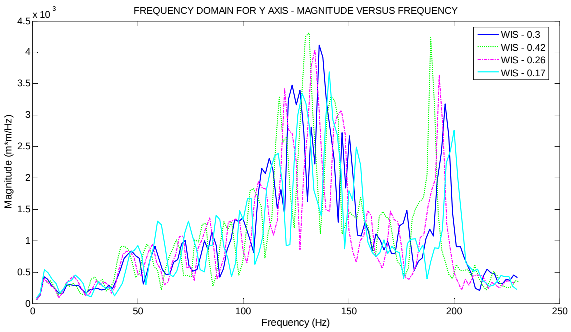


(a) IS effect in time domain



(b) IS effect in frequency domain

Fig. 17: IS effect in y-direction

Fig. 16 and Fig. 17 shows the result by using IS scheme. According to this scheme, the level of unwanted noise and vibration in wiper system has reduced up to 30 percent. It is hoped that with this reduction, driver and passenger visibility can be improved and the reversal noise can be controlled to certain level.

X. CONCLUSION

This paper presents a study of friction coefficient effect in wiper system. In order to reduce the unwanted noise and vibration level, the values of the friction coefficient need to be changed. The friction coefficient value at 0.17 and 0.25 is the best value to reduce the noise and vibration for both x- and y- direction. In addition, this paper demonstrate a simple control scheme, known as input shaping (IS) scheme in order to reduce the unwanted noise and vibration level. Implementing this scheme, the noise and vibration has reduced up to 30 percent.

NOMENCLATURE

m_x	Equivalent mass of arm and blade to the x-axis
m_y	Equivalent mass of arm and blade to the y-axis
c_x	Equivalent damping coefficient of arm to the x-axis
k_x	Equivalent spring constant of arm to the x-axis
x_B	Arm tip virtual position without arm deformation
y_m	Neck rotation center position
θ_H	Arm head twist angle
θ_F	Arm front twist angle
θ_G	Windshield grass profile
F_0	Arm pressure
θ_a	Rotational angle of rubber neck
δ_c	Rubber lip displacement
α_c	Attack angle of rubber lip
k_a	Rotational spring constant of rubber neck
k_c	Translational spring constant of rubber lip
k_y	Spring constant of blade tournament to the y-axis
c_y	Damping coefficient of blade to the y-axis

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