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Vibration Measurement and its Consequence on Hand Arm System (HAS)

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Abstract*: Driving vehicles and hand-held power tools produce mechanical vibrations and are transmitted to the human hand affects the hand grip and instability. In this study, the measurement of vibration transmissibility while executing holding activities of hand is represented by a four and five degree of freedom human Hand Arm System (HAS) through mass-spring-damper system model. The proposed model, investigated biodynamic reaction properties of HAS at different parts of hand joints. The HAS Model simulated in MATLAB-SIMULINK software to analyse the displacement and acceleration. The vibration insulators have been proposed as grippers on handle of machine tools for minimize the vibration transmission through hand contact. The simulation output graph of HAS with vibration insulator model shows considerably improved damping features and limiting of the vibration transmission consequence as compared with Hand-Arm System model. The MATLAB-SIMULINK simulation model is validated with state space model (Analytical Solution) for both with and without isolator HAS model. The experimental study was carried out for a bike handle vibration with and without insulators by using Ni-LAB VIEW.*

Keywords: *Hand Arm System, Hand Arm Vibration Syndrome, Biodynamic model, Vibration Insulator, Isolator, MATLAB-SIMULINK, Accelerometer, NI-LABVIEW.*

I. Introduction

Nomenclature

HAS	Hand–Arm System	HAVS	Hand-Arm Vibration Syndrome
m1	Mass of Upper arm	k1	Stiffness coefficient at upper arm
m2	Mass of wrist-forearm	k2	Stiffness coefficient at wrist-forearm
m3	Mass of palm	k3	Stiffness coefficient at palm
m4	Mass of Fingers	k4	Stiffness coefficient at Fingers
m5	Mass of isolator material	k5	Stiffness coefficient of isolator material
c1	Damping coefficient at upper arm	x1 to x5	Displacements
c2	Damping coefficient at wrist-forearm	$\dot{x}_1$ to $\dot{x}_5$	Velocity
c3	Damping coefficient at palm	$\ddot{x}_1$ to $\ddot{x}_5$	Acceleration
c4	Damping coefficient at Fingers	DOF	Degree of Freedom
c5	Damping coefficient of isolator material		

Different type of machineries having high level of vibrations like bulldozers, heavy duty vehicles, road breaker machines, land level machines, constructions machines, stone mining machineries, etc. are broadly in use. People are exposed to high level mechanical vibrations during travelling and handling the heavy machineries. Researches are working to reduce the vibration level which are unpredictable and uncontrollable. The human hand is a delicate and sensitive organ which are used for holding the items [1]. The Hand Arm System consists of the human hand from upper arm to fingers [2]. The damage in the arm muscles, arm joints, veins and nerves in the delicate tissues of the hand are due to vibration when holding hand tools. This overall effect of vibration on human Hand is termed as Hand-Arm Vibration Syndrome (HAVS) [4][10]. HAVS parallelly increases with increasing exposure time and level of vibration. At the extreme stage, White Finger Syndrome (WFS) arises at specific location of the fingers generally at gripped location which loses the finger sensitivity, increase discomfort and pain [5]. So, the detailed analysis of vibration from a machine handle to the operator hand is necessary. This vibration is called hand arm vibration (HAV) [8]. The human hand parts like fingers, palm-wrist and upper arm are combinedly termed as Hand-Arm System (HAS). The biodynamic reaction of Human HAS is a branch of science which describes the motion and forces affected hand and their relationship by integrating physics and engineering concepts. Human hand plays important role for grasping and non-grasping activities. Hence, the study of Biodynamic model is important to investigate vibration risk and predict serious injuries due to vibration like white finger syndrome. The vibration characteristic observed through displacement and acceleration parameters in time domain and frequency domain.

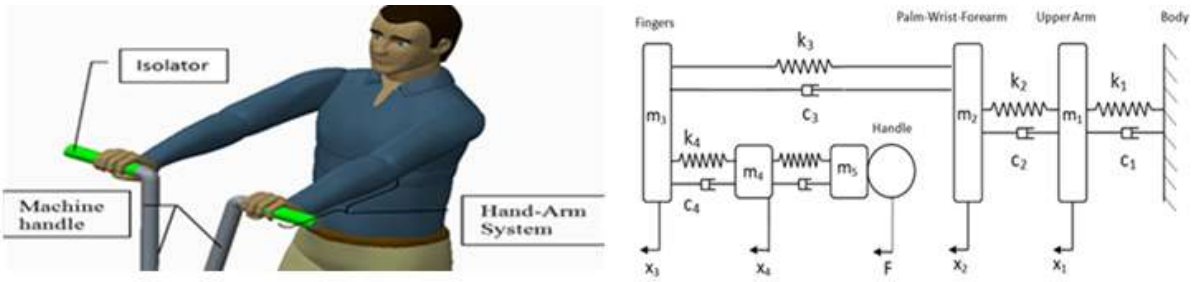
II. Mathematical Modeling

The human HAS mathematical model described in literature was constructed according to the Newton's second law of motion. In this study 4 and 5-degree of freedom mass-spring-damper system model developed to derive characteristic of vibration transmission. Two types of models described as follow to investigate and analyze the effect of isolator to reduce work stress by minimizing vibration transmission.

1) 5-DOF HAS model integrated with vibration isolator model.
2) 4-DOF HAS model represents handle griped hand posture.

2.1 5-DOF Hand Arm System integrated with vibration isolator model.

In this model the biodynamic reaction of the hand under relatively significant excitation of the handle when gripped fingers to the handle which is covered by isolator as appeared in Fig. 1. The human hand arm system posture when holding the machine handle covered by isolator is shown in fig. (1). This model is equipped for obliging translational developments as lumped-parameter of linear Mass Spring Damper system with isolator appeared in fig. 1(b).



(a) (b)

Fig. 1: (a) Handle with vibration Isolator grasped operator posture, (b) Mathematical model of 5-DOF finger-Hand-Arm System with Vibration Isolator

Equations of motion for HAS with isolator model

The Equation of motion were derived from Hand-Arm System with isolator spring-mass-damper model. The horizontal 5-DOF model shown in Fig. 1 can be expressed by the following coupled differential equations:

The equation of motion for Upper Arm:

$$m_1\ddot{x}_1 + c_2(\dot{x}_1 - \dot{x}_2) + k_2(x_1 - x_2) + c_1\dot{x}_1 + k_1x_1 = 0 \quad \ldots\ldots (1)$$

The equation of motion at Palm-Wrist-Forearm can be derived as:

$$m_2\ddot{x}_2 + c_3(\dot{x}_2 - \dot{x}_3) + k_3(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_1) + k_2(x_2 - x_1) = 0 \quad \ldots\ldots (2)$$

The equation depicting the motion at Fingers is as follows:

$$m_3\ddot{x}_3 + c_3(\dot{x}_3 - \dot{x}_2) + k_3(x_3 - x_2) + c_4(\dot{x}_3 - \dot{x}_4) + k_4(x_3 - x_4) = 0 \quad \ldots\ldots (3)$$

$$m_4\ddot{x}_4 + c_4(\dot{x}_4 - \dot{x}_3) + k_4(x_4 - x_3) + c_5(\dot{x}_4 - \dot{x}_5) + k_5(x_4 - x_5) = 0 \quad \ldots\ldots (4)$$

$$m_5\ddot{x}_5 + c_5(\dot{x}_5 - \dot{x}_4) + k_5(x_5 - x_4) + F = 0 \quad \ldots\ldots (5)$$

Where,

x_1 to x_5 are displacement, $\dot{x}_1$ to $\dot{x}_5$ are Speed/Velocity, $\ddot{x}_1$ to $\ddot{x}_5$ are Acceleration.

2.1.1 MATLAB-SIMULINK simulation coding for Hand-Arm System with isolator model

The simulation model was developed by using MATLAB-SIMULINK software. Different model parameters are given to this model to generate the results and graphs. The study analyzed the acceleration and displacement behavior at each segments of human hand with respect to vibration transmission at Z-axis. The MATLAB simulations model for HAS with vibration isolator are generated as appeared in Fig. 2.

2.1.2 STATE SPACE Model Analytical Solution for Hand-Arm System with isolator

A State Space Model developed with MATLAB-SIMULINK Software by developing the by creating matrix from linear differential equations 6 to 10.

The model of the system can be illustrated in differential equations as shown below:

$$\dot{z}_2 = -\frac{-(k_1+k_2)}{m_1}z_1 - \frac{-(c_1+c_2)}{m_1}z_2 + \frac{k_2}{m_1}z_3 + \frac{c_2}{m_1}z_4 \quad \ldots\ldots (6)$$

$$\dot{z_4} = \frac{k_2}{m_2} z_1 + \frac{c_2}{m_2} z_2 - \frac{-(k_2+k_3)}{m_2} z_3 - \frac{-(c_2+c_3)}{m_2} z_4 + \frac{k_3}{m_2} z_5 + \frac{c_3}{m_2} z_6 \qquad \text{…… (7)}$$

$$\dot{z_6} = -\frac{k_3}{m_3} z_3 + \frac{c_3}{m_3} z_4 - \frac{-(k_3+k_4)}{m_3} z_5 - \frac{-(c_3+c_4)}{m_3} z_6 + \frac{k_4}{m_3} z_7 + \frac{c_4}{m_3} z_8 \qquad \text{…… (8)}$$

$$\dot{z_8} = \frac{k_4}{m_4} z_5 + \frac{c_4}{m_4} z_6 - \frac{(k_4+k_5)}{m_4} z_7 - \frac{c_5}{m_4} z_8 - \frac{k_5}{m_4} z_9 + \frac{c_5}{m_4} z_{10} \qquad \text{…… (9)}$$

$$\dot{z_{10}} = \frac{k_5}{m_5} z_7 + \frac{c_5}{m_5} z_8 - \frac{k_5}{m_5} z_9 - \frac{c_5}{m_5} z_{10} + F \qquad \text{…… (10)}$$

The State-space model of spring-mass-damper model written as following general form equation as:

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

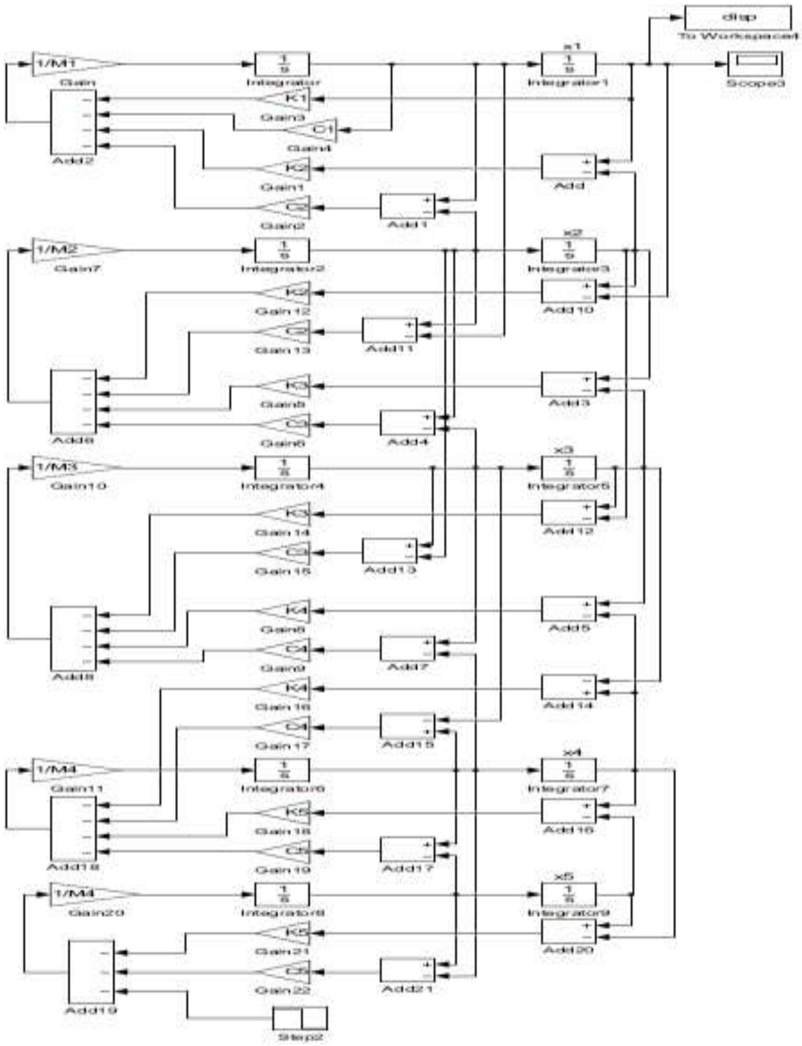


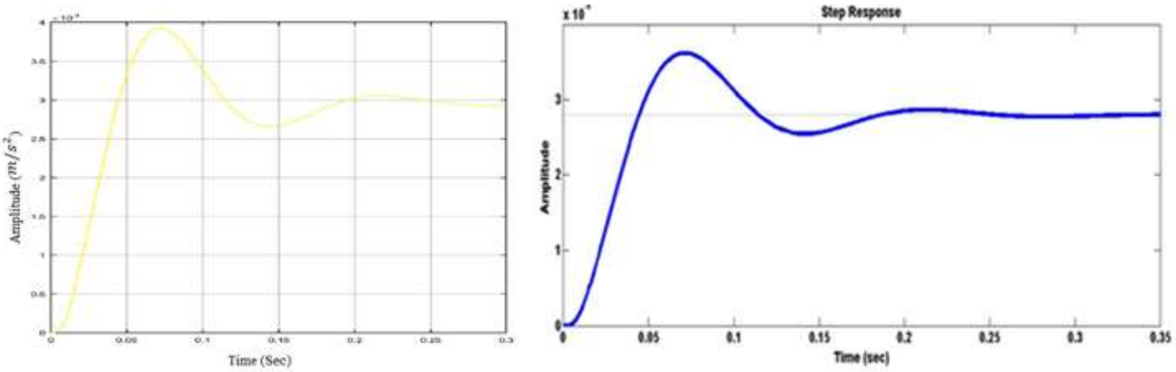
Fig. 2: A block diagram of 5-DOFs HAS with isolator model

Model Parameters

Table. 1 Model Parameters

Mass M (kg)		**Damping Coefficient C (Ns/m)**		**Stiffness Coefficient K (N/m)**	
M1	1.4329	**C1**	50.6	**K1**	3377
M2	0.0897	**C2**	35.2	**K2**	12710
M3	0.0230	**C3**	74.5	**K3**	29906
M4	0.0147	**C4**	127.6	**K4**	190041
M5	0.0149	**C5**	280	**K5**	5269

The isolator model graph as appeared in fig. 3(a) shows the maximum amplitude at 3.7 m/s^2. The state-space model graph appeared in fig. 3 (b) shows the amplitude maximum at 3.7m/s^2 and system rest at time 0.25 sec. The appraisal of the vibration behavior is analyzed in time domain.

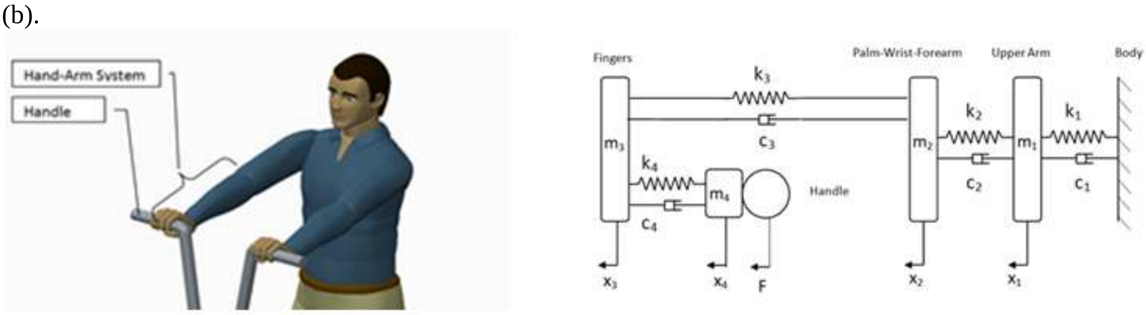


(a) (b)

Fig. 3: (a) MATLAB-SIMULINK simulation graph for Hand-Arm System with isolator model (b) State space model MATLAB graph for Hand-Arm System with isolator

2.2 4-DOF Hand-Arm System model represents handle griped hand posture.

The created linear-horizontal HAS model comprises of three fragments which is fingers, palm and wrist arm, upper arm as appeared in fig. 4 (a). The spring mass damper system model for HAS is appeared in fig 4 (b).



(a) (b)

Fig. 4: (a) Handle without isolator grasped operator posture, (b)Mathematical model for human hand grasping machine/ vehicle handle

By using same Newton's law of motion formula Simulink model was developed for hand arm system model.

2.2.1 MATLAB-SIMULINK simulation coding for HAS model

To examine the vibration reaction in form of acceleration at upper arm, fingers and palm wrist of the hand when step force input applied block diagram developed in MATLAB-SIMULINK Software shown in fig. no. 5.

2.2.2 State Space model analytical solution for HAS

A state space model developed and processed in MATLAB-SIMULINK Software by creating matrix A to D by using same process used for above model.

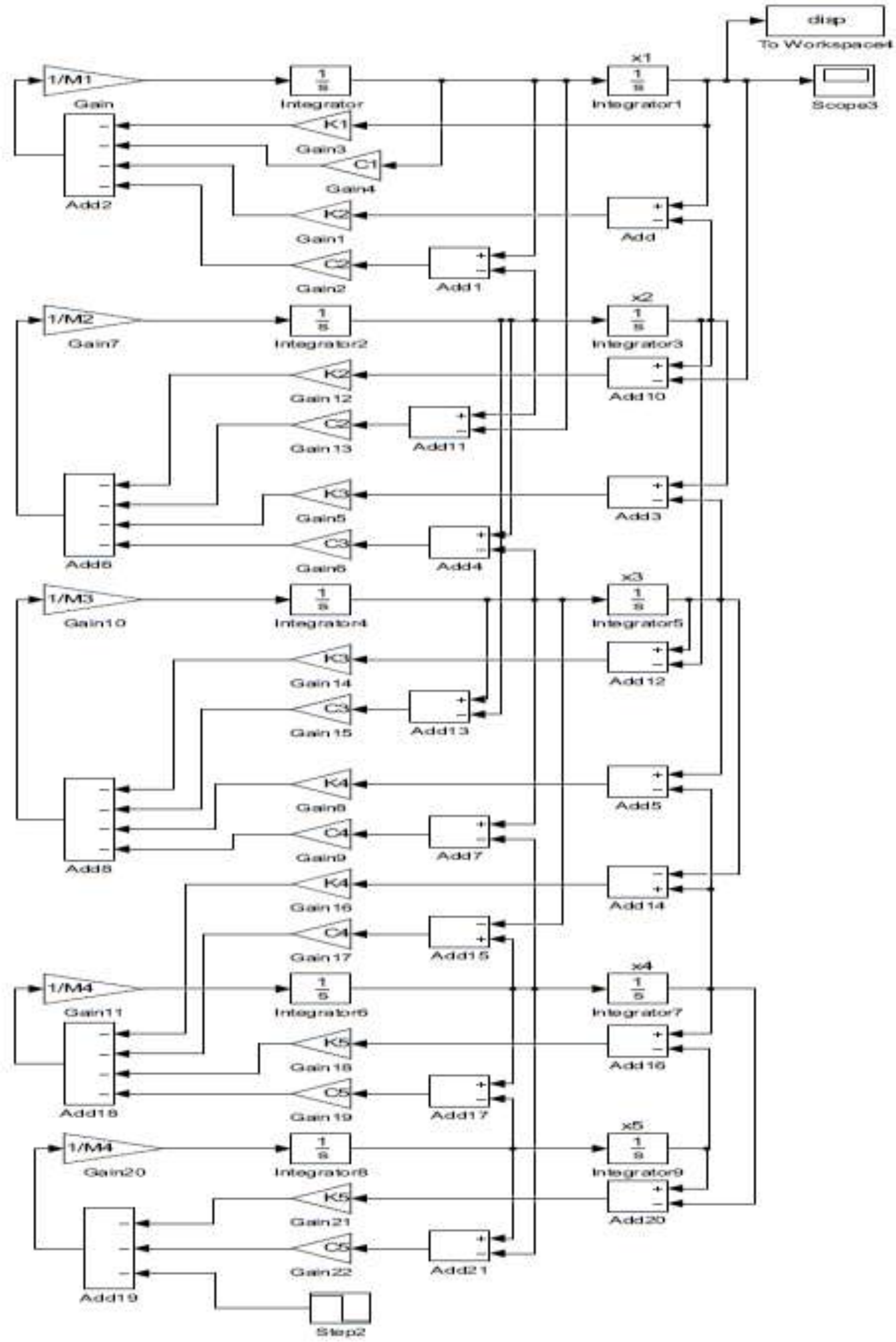
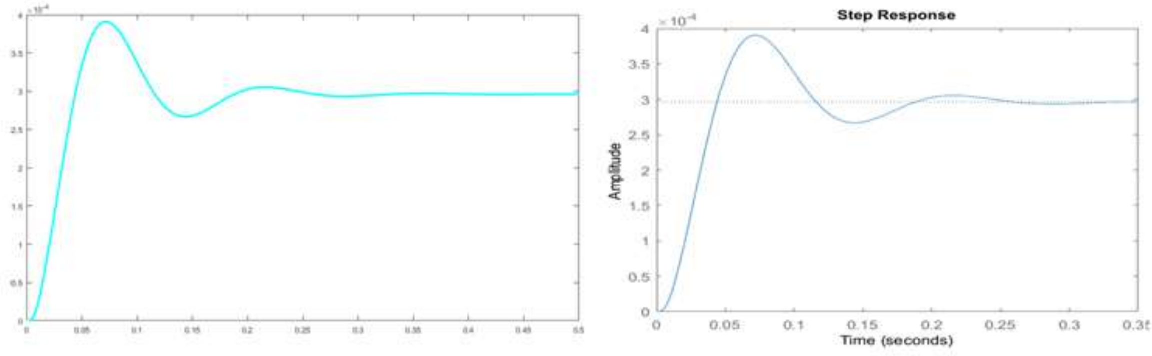


Fig. 5: A SIMULINK block diagram of 4-DOFs HAS model

After simulating model in MATLAB-SIMULINK Software by setting simulation time 0.35 sec graph showing bump effect highest at nearly 3.8 m/s^2 and then it starts to descending acceleration up to 0.15 sec time. At the time 0.35 sec graph shown in fig. no. 6(a). Graph getting from state space model as shown in fig. no. 6(b) amplitude rises up to 3.8 m/s^2 and it showing linear nature from time 0.3 sec.



(a) (b)

Fig. 6: (a) MATLAB-SIMULINK simulation of Hand-Arm System model graph, (b) State space model MATLAB graph for Hand-Arm System

1.3 Relative Study of HAS model with and without Vibration Isolator in MATLAB-SIMULINK software

For comparing both HAS model for bare hand and with isolator, created two sub-system in MATLAB Software and applied common step input as appeared in fig. 7.

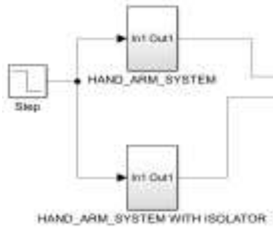


Fig. 7 MATLAB-SIMULINK Simulation Combined HAS model and HAS with isolator model

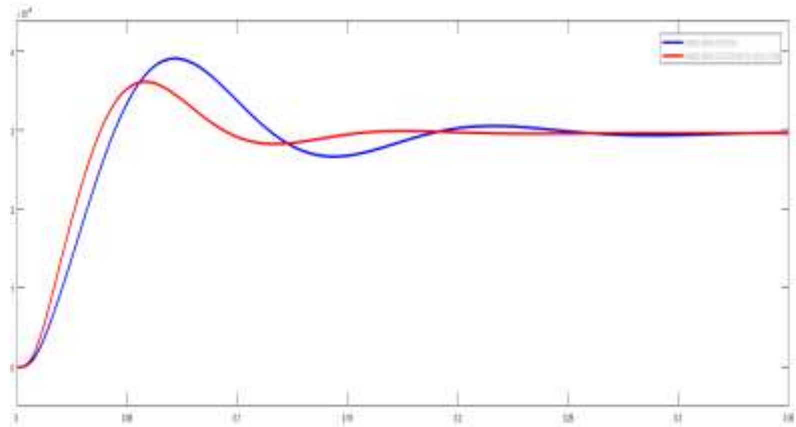
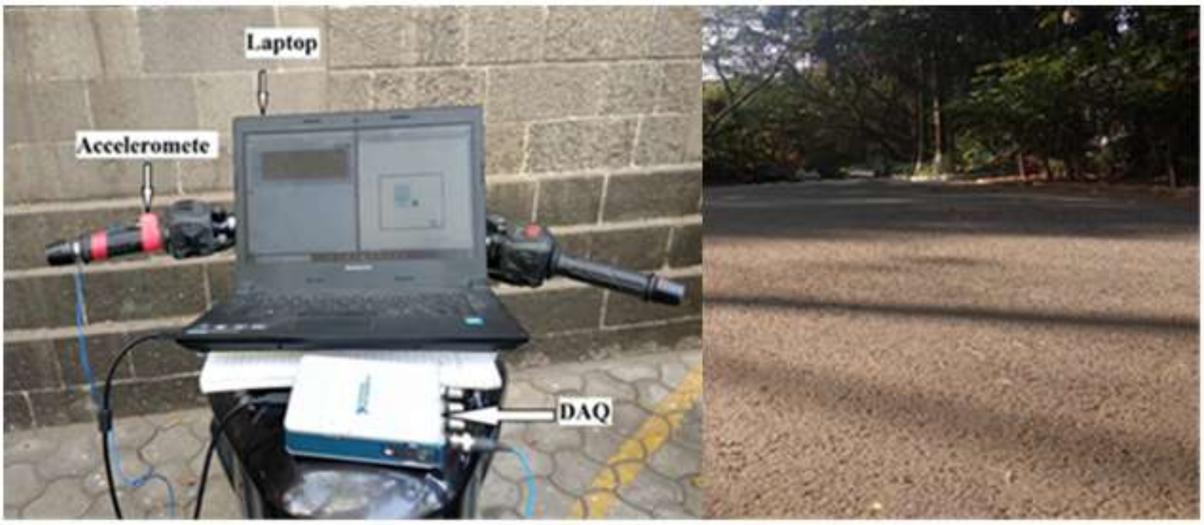


Fig. 8: MATLAB-SIMULINK Simulation Graph obtained by Combined HAS model and HAS with isolator model

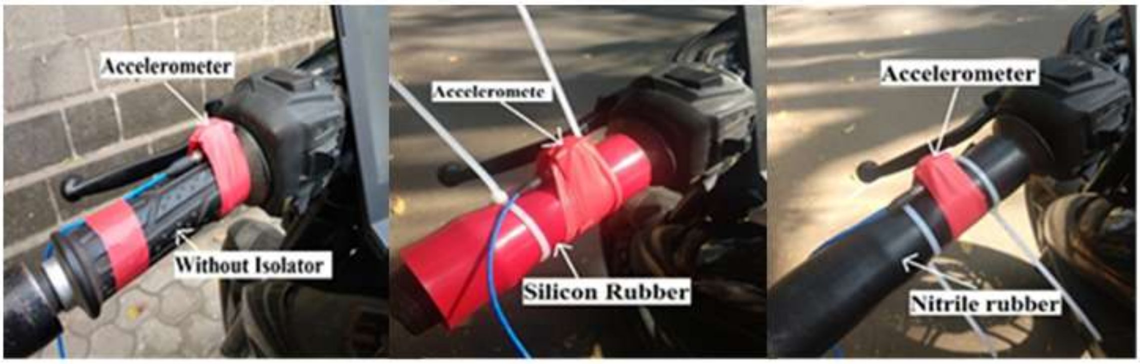
III. Experimental Study

The experiment performed for vibration measurement at the time of riding a bike on a plain road surface by attaching accelerometer, NI Lab-view module NI9234, chassis 9171 as appeared in fig. 9. In this study 2 types of isolator material are used for analysis as shown in table no 2. In this experiment accelerometer is attached on bike handle with and without isolator as appeared in fig. 10. Based on Lab-View programming as appeared in fig. 11. The experiment performed for vibration measurement at the time of bike running at constant speed of 25 kmph on a plain road surface. The vibration measured for both with and without vibration isolator on bike handle as appeared in fig 15.



(a) (b)

Fig. 9 (a) Experimental set-up for testing of Handle vibration, (b) Plain road surface



(a) (b) (c)

Fig. 10 Accelerometer attachment (a) without isolator, (b) Silicon, (c) Nitrile

In this study two type of isolator material used for the experiment which are listed below table. 2. The 2mm thick isolator material used for the experiment.

Table 2 Isolator Materials Used in Experiment

Sr. No.	Isolator Material
1	Nitrile Rubber (2mm)
2	Silicon Rubber (2mm)

The programming developed in Lab-VIEW software to measure the acceleration data in time domain as well as frequency domain. Lab-VIEW software is connected to DAQ card and accelerometer sensor for building a front panel. In Lab-VIEW front panel, shows acceleration signal by converting and filtering voltage signal through the controls (formula block). The Lab-VIEW front panel shows the frequency and acceleration graphs which consist of vibration signal from bike handle and isolator. In Lab-VIEW software graphical programming environment can be developed easily and display all signal in a front panel by acquiring, recording, analyzing vibration input signal within start to end run time. The Fast Fourier Transformation (FFT) analysis used in this project to convert the time domain to frequency domain vibration signal.

Lab-VIEW Programming

In this experiment accelerometer was attached on handle. Based on Lab-View programming as shown in fig. 19, the time domain and frequency domain graph was generated

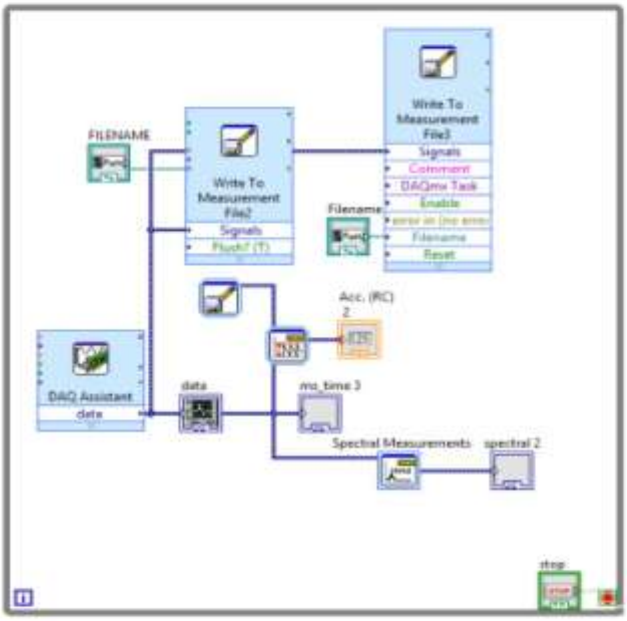


Fig. 11 Lab-VIEW Programming

IV. Result And Discussion

The two types of Elasto-plastic isolator material were taken for experiment with RMS values as shown in table no. 3. The RMS value for without isolator is 0.9162. After applying silicon and nitrile rubber as a vibration isolator the RMS values are 0.6063 and 0.8138 respectively. According to percentage vibration transmission values Silicon rubber showing higher vibration absorption of 33.82%, which actually decrease vibration effect on hand.

Table 3 Experimental Analysis Results

Material	RMS	% Reduction in vibration transmittivity
Without Isolator	0.9162	---
Silicon Rubber	0.6063	33.82%
Nitrile Rubber	0.8138	11.17%

V. Conclusion

In this study, the HAS model simulated in MATLAB-SIMULINK software by applying step signal inputs. The MATLAB-SIMULINK simulation model validated with state space model (Analytical Solution) for HAS model as well as HAS with isolator model. Experimental study on bike handle with and without vibration isolator are carried out on a plain road surface at constant speed. As a result, the isolator materials have reduced the vibration consequence on Human HAS (HAS). The silicon and nitrile rubber helped to reduce the vibration transmissivity at 33.82% and 11.17% respectively. The silicon rubber is more effective as a vibration isolator material. From this study it is concluded that the use of vibration isolator can reduce the vibration transmissivity from machine handle to human hand.

Conflict of interest: The authors declare that there is no conflict of interests regarding the publication of this paper.

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