Design of Vibration Simulator with Output Vibration in Translational Direction

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Abstract— Machinery has helped human work but also generate mechanical vibration. Mechanical vibration decrease human reaction time performance, increase mental workload, higher back muscle activity, higher discomfort, and disturb human balanced. Researches about effect of mechanical vibration to human in laboratory have been done using vibration simulator, commonly using electro hydraulic shaker. This research will design a simulator using mechanical concept. Purpose of this research is designing and building vibration simulator to produce translational vibration at some direction combination and some level acceleration with dominant frequency under 50 hertz and acceleration up to 7 m/sc2. Simulator was separated of two parts, motion driver and shaking platform. Motion driver is using electric motor as power supply. Simulator has six vibration acceleration, three levels in vertical direction and three levels on horizontal direction. This simulator can be used in ergonomic researches about vibration effect to human,

Index Terms—Mechanical vibration, Translational vibration, vertical direction, horizontal direction

1 INTRODUCTION

Development of mechanical technology has helped human working in many sectors. In manufacturing, machinery has done human work in mass production. But machinery also impact to bad environment condition. Mechanical vibration almost always happened when a machine is running. Vibration effects human in two ways, Whole Body Vibration (WBV) and Tool Hand Vibration (THV). WBV has decrease human reaction time performance and increase mental workload [9], higher back muscle activity [5], higher discomfort [20], and disturb human balanced [17] depend on frequency, amplitude, acceleration, and vibration exposure time.

Beside vibration magnitude, human perceptive depend on vibration direction [8]. In a vehicle like car, motor cycle, truck, tractor, soil compactor, or quadbike, mechanical vibration dominant in vertical direction [2], [6], [13], [16], [18]. Magnitude Whole Body Vibration on vehicle is influenced by road surface, vehicle load, and velocity [3]. But in industry, machine process will impact vibration in any direction. In Sugar cane factory, machine high grade and low grade fugal generate vibration in lateral and fore aft direction is higher than vertical vibration. Translational vibration acceleration is 1 – 7 m/sc2 exposure operator in local sugar cane industries in Indonesia at some combination direction [4], [19]. In sorting process for kernels like cocoa sort process, machinery will vibrate in fore-aft direction, so generate fore-aft vibration. Vibration energy absorption been influenced by vibration direction [1]. Energy absorption at hand tractor driver is higher at vertical direction [12]. Seat translational vibration effect human discomfort significantly, meanwhile rotational and back translational vibration just effect very small to human discomfort [22]. In assumption each direction of translational vibration (vertical, lateral, fore-aft direction) will also effect to human physiology, reaction time performance, and mental workload in difference level. For test this assumption a research will be done in laboratory using vibration simulation.

Research of effect mechanical vibration to human in laboratory had been done using vibration simulator. Hacaambwa [20], Santos [5], Newell [9], and Giacomin [10] using simulator with electro hydraulic shaker and band pass filter 0,5 – 50,5 Hz. Simulator is vibrated in frequency and condition like subject of research. This research will design a simulator using mechanical concept. This research is beginning research with purpose designing table shaker which exposure translational vibration in any direction. Simulator will vibrate like sugar cane factory condition, dominant frequency under 50 hertz and acceleration up to 7 m/sc2. Commonly purpose of this research is designing and building vibration simulator to produce translational vibration at some direction combination and some level acceleration with dominant frequency under 50 hertz and acceleration up to 7 m/sc2.

2 METHODS

This research consist of three stages, 1: concept of design and sketching, 2: calculating and designing machine, and 3: trying machine. In concept of design had been selected how is change of acceleration mechanism, mechanism of table shaker motion, and mechanism in focusing vibration direction.

There are two types of mechanical vibration, translational and rotational. Rotational vibration is generated by rotational motion, meanwhile translational vibration is generated by linier motion. First stage on this design is select mechanism for generate linier motion. This simulator used electric motor as source of power which runs in rotational motion.

2.1 Linier motion mechanism

In design, simulator will generate translational vibration and minimize rotational vibration. Simulator was separated of two parts. They are motion driver and shaking platform.

Motion driver using electric motor as source of power, rotational motion from motor was changed to linier motion. Shaking platform is run by motion driver in linier motion.

Power from motor is transmitted to unbalance shaft by pulley. Unbalance shaft was made by shifting shaft circle point 7 mm from its origin point and reducing shaft diameter from 30 mm to 25 mm. So if shaft rotate, it make unbalance rotation. Rotation from shaft is transmitted to lever to make linier motion. Linier motion is connected to legs of shaker platform to pull and push the table. This mechanism will make translational vibration at shaker platform.

Position of lever at unbalance shaft can be changed from vertical to horizontal and reverse. Vertical lever position is for vertical vibration and horizontal lever position is for lateral and fore-aft vibration.

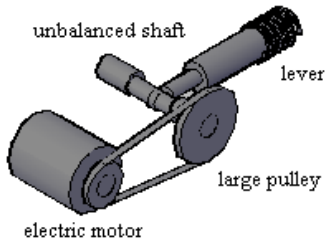

Fig 1. Mechanism of changing rotational to linier motion.

2.2 Mechanism of Changing Acceleration

Electric motor with output 2 Hp and 1400 rpm is used as power supply to vibrate 110 kg weight of load. Electric motor used pulley with diameter 3 inch. Power is transmitted from electric motor to large pulleys using V belt. This research used three large pulleys to produce three level velocity, they are 3, 6, and 8 inches. This simulator has six vibration combinations, three combinations in vertical lever position and three combinations in horizontal lever position.

Linier motion frequency is congruent to rotary of unbalance shaft. This rotary is the same as rotary of large pulley and be calculated refer to (1):

$$d_p \; x \; \omega_1 = D_p \; x \; \omega_2 \qquad (1)$$

where : d_p = pulley diameter of electric motor
ω_1 = angular velocity of electric motor
D_p = large pulley diameter
ω_2 = angular velocity of large pulley

In design, center distance is 34.5 cm or 13.58 inch and small pulley diameter is 3 inch. Length of the belt is calculated refer to (2) based on schema in fig 2. Table 1 description linier motion frequency and length of the belt is used for each pullev.

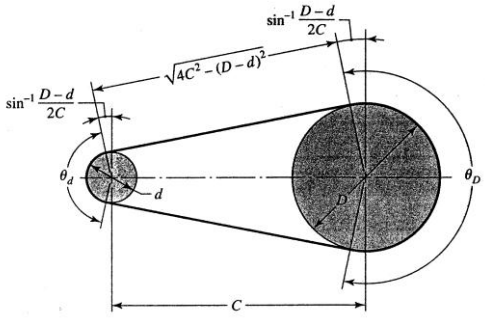

Fig 2. Belt geometry
Source : Shigley [11], *Mechanical Engineering Design.* 7th edition.

$$L = +\sqrt{4C^2-(D-d)^2} + 1/2(D\emptyset_L + d\emptyset_S)$$

$$\emptyset_S = \pi - 2sin^{-1}\frac{D-d}{2C}$$

$$\emptyset_L = \pi + 2sin^{-1}\frac{D-d}{2C} \qquad (2)$$

where :
L = length of the belt (inch)
C = center distance (inch)
D = large pulley diameter (inch)
d = small pulley diameter (inch)

Table 1. Vibration frequency and length of the belt

Large pulley diameter Dp (inch)	Rotary of unbalance shaft, □2 (rpm)	Length of the belt (inch)
3	1400	36
6	700	41
8	525	45

We also can use larger diameter pulley to get lower vibration frequency.

2.3 Shaking Platform

Platform is placed on motion driver with four of platform legs connected to unbalance shaft using lever. Platform dimension are 50 x 100 cm. Shaft motion will push and pull platform in linier motion. When lever make horizontal motion, wheels are used on its legs to help the motion, and

the platform will vibrate on one axis direction. When lever make vertical motion, springs are used on its legs. A shaft is placed in every spring to straighten up its motion in straight line.

Selection of spring is based on weight of load on the table. Calculation use next equation.

$$F = \frac{\tau \pi d^3}{k8D} \quad (3)$$

where : F = Force on spring
τ = allowed shear stress
d = wire diameter
D = spring diameter
k = constant number, based on ratio of spring to wire diameter

In design, the shaking platform will load 15 kg platform, 5 kg chair, 90 kg person. Total weight is 110 kg (1078 N). Load on every leg is 269.5 N. We were used spring with diameter 18 mm fit to its shaft. If we use spring from steel wire 3.5 mm in diameter, shear stress (τ) is 353 N/mm². Meanwhile based on literature $\tau_{allowed}$ for steel wire is 780 N/mm² maximum. It is mean steel wire 3.5 mm in diameter is safe for this load. Spring from steel wire have high strength, this material influence frequency of vibration will be lower.

3 VIBRATION CONDITION

When a machine is running, vibration is generated to any directions. Difficulty in this design is to focus vibration direction to specific axis and minimize vibration to another axis.

Mechanism of horizontal vibration using wheels and vertical vibration using springs haven't optimum in focusing vibration to specific axis. Isolation against unlike direction of vibration use rubber wheels at fourth side of table. The wheels will rotate up and down if platform is in vertical vibration and rotate fore-aft if platform is in horizontal vibration. When focus to specific direction, vibration in that direction is dominant, and another direction is low. Without rubber wheel on the sides, we can't get dominance in vibration direction. Using rubber wheel we can focus to specific direction, meanwhile acceleration on another direction is lower. Schema of simulator is in next figure.

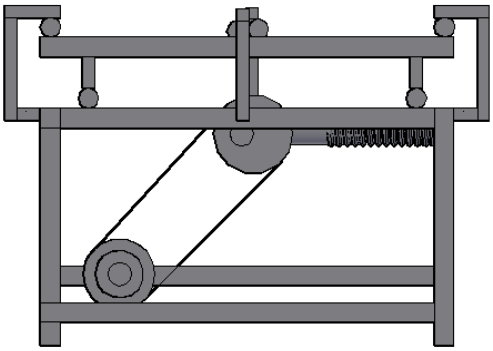

Fig 3. Simulator schema on horizontal vibration with wheels on platform's legs

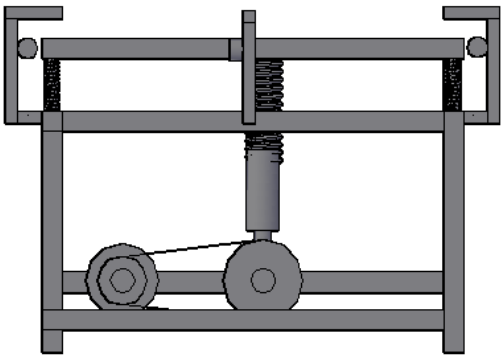

Fig 4. Simulator schema on vertical vibration with springs on platform's legs

Wheels and springs were used on platform legs for focusing vibration to specific direction. Wheels also make horizontal motion smoothly and minimizing friction. If using slider friction will be greater and noisy.

Fig 5. Simulator for translational vibration

4 ANALYSIS

Vibration measurement use accelerometer type of dual channel data collector with magnetic mounting base. Accelerometer is placed on operator's chair which has steel plate on its base to plug the sensor. So vibration that we got is mechanical vibration on operator chair. On every simulation, acceleration was measured twice to get three axis of translational vibration.

Stiffness of springs from steel is higher than stainless steel, using springs with higher stiffness simulator can generate vibration frequency under 50 Hertz. Vibration frequency under 50 hertz is important because human comfort is more sensitive in this range. This simulator has generated vibration like condition on sugar cane factory. Local sugar cane factory in Indonesia have frequency lower than 50 Hz and acceleration 0 up to 7 m/sc2 [4], [19]. Dominance of vibration is variety between vertical direction and horizontal direction (fore-aft and lateral).

Simulator has could focus vibration to specific direction. In condition vertical vibration dominant, average acceleration in horizontal direction is 15% - 55% from vertical vibration and if horizontal vibration dominant, average acceleration in vertical direction is 50% - 63% from horizontal vibration. Next is simulator vibration in average, measured on the chair when it is running with an operator on the chair.

Table 2. Simulator vibration on some conditions

Condition	Vibration Direction	Acceleration (m/sc2)	Frequency (hertz)	% to dominant
v8	Vertical	1.13	40	100%
	fore-aft	0.58	40	52%
	Lateral	0.62	40	55%
v6	Vertical	2.70	36	100%
	fore-aft	1.37	36	51%
	Lateral	1.09	36	40%
v3	Vertical	7.10	46	100%
	fore-aft	3.51	46	49%
	Lateral	1.09	46	15%
h8	fore-aft	1.64	43	100%
	Vertical	1.00	43	61%
	Lateral	0.89	43	54%
h6	fore-aft	2.48	40	100%
	Vertical	1.24	40	50%
	Lateral	1.41	40	57%
h3	fore-aft	7.51	45	100%
	Vertical	4.73	45	63%
	Lateral	3.17	45	42%

This simulator can be used in ergonomic researches about vibration effect to human, can be used on standing or sitting position. Simulator also can use others pulley diameter, to get frequency or acceleration which is desired. Beside vibration, the simulator also generate noisy, so have been considered in the researches.

5 CONCLUSION

Simulator was designed using mechanical concept has generated translational vibration at specific frequency and acceleration. Electrical motor is used as power supply. Rotational motion from electrical motor changed to linier motion at lever. Power is transmitted using pulleys and V belt. Lever motion will pull and push legs of platform, so platform will vibrate in translational vibration. Lever is placed in two difference position, lever in vertical position for vibration in vertical direction dominant and lever in horizontal position for vibration in horizontal direction (lateral and fore-aft) dominant. Vibration direction has could be concentrated. If vibration is dominant in vertical direction, average acceleration on horizontal direction is only 15%-55% than that of vertical. And if vibration is dominant in horizontal direction, average acceleration on vertical direction is only 50%-63% than that of horizontal. Vibration condition is the same as sugar cane factory which be criterion. Acceleration is from 0 until 7 m/sc^2 when it is running and frequency dominant lower than 50 hertz. Vibration with frequency under 50 hertz is sensitive to human discomfort.

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