Research article

Investigation of Vibration Characteristics of a Hand Tractor using MEMS Sensor

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Abstract The increase of agricultural mechanization, especially hand tractors has been remarkably emerged in the last decade. It is known as well that agricultural mechanization not only facilitated timely completion of operations but also increased production, labor savings, energy efficiency, productivity, and profitability. With high degree of hand tractor use, providing a safe and comfortable working environment to operators became an important consideration, specifically vibration that is a main cause of early fatigues. In this study focus on measuring translational acceleration and rotational angular velocity at various locations of hand-tractor under stationary and driving modes. Root-mean-squares (RMS) and power-spectrum-density (PSD) were used to investigate vibration magnitude and dominant frequencies, and effective measurements were finally suggested. Results showed that under stationary mode largest vibration acceleration appeared at handgrip in vertical axis of about 8.5m/s^2 followed by engine top, gearbox and chassis, respectively. In driving mode, the main vibration magnitude occurs in vertical axis at about 11.8 m/s^2. Within 50Hz frequencies, predominant acceleration occurred in longitudinal axis at about 10Hz frequencies at first peak and about 18Hz frequencies at next peak at engine top. Whereas, at handgrip predominant acceleration appeared hugely in vertical axis at about 10Hz frequencies, and at the same frequency was found in pitch axis of rotational angular velocity under stationary mode. However, it appears clearly at about 9Hz frequencies in vertical axis in driving mode. Both conditions, vibration exposures are much higher than that in health risk limitation standard that operators should be prevented effectively; otherwise, to suffer from early fatigue.

Keywords agricultural tools, vibration magnitude of translational acceleration and rotational angular velocity, hand-arm vibration, and future development

INTRODUCTION

Agriculture employs almost 80% of Cambodian rural labor forces. It is considered to strongly support Cambodian people in ensuring food security (Ngo and Chan, 2010) and constitutes a main source of income (Ros et al., 2011). It is the main driver of poverty reduction (Ngo and Chan, 2010), and it has a 29% contribution to the GDP (Chao, 2009; Chan, 2013).

The enhancement of agricultural production through agricultural tools, the use of agricultural mechanization has gradually increased, specifically over the last decade (Chan, 2013). It is evident that the agricultural mechanization not only facilitated timely completion of operations but also increased production, labor savings, energy efficiency, productivity, and profitability (Singh et al., 2011). In Cambodia; therefore, many farmers sold animals to buy mechanized tools for field operations, especially hand tractors (Chao, 2009). Multipurpose uses of mechanization meant that time operation to hold handgrip became longer that induce to vibrated discomfort known as early fatigue. Tiwari et al., (2006) explained that machine vibration was detrimental to agricultural users. Many researchers also confirmed that vibration would be very harmful to health induced such as early fatigues that may cause physical, physiological and musculoskeletal disorders after long-time exposure over months and years (Salokhe et al., 1995, Sam et al., 2006).

This study measures vibration magnitude and vibration transmissibility at various locations of hand tractors such as engine top, chassis, gearbox and handgrip, hand-arm vibration exposure and suggests effective intervention for future development.

METHODOLOGY

Experimental Hand Tractor

A 12Hp hand tractor as shown in Fig. 1, under stationary and driving modes in a duration of 30 seconds with the idling speed (5 km/h) was employed in these experiments using MEMS sensor.

Fig. 1 Transportation-type hand tractor

Experimental Instrumentation

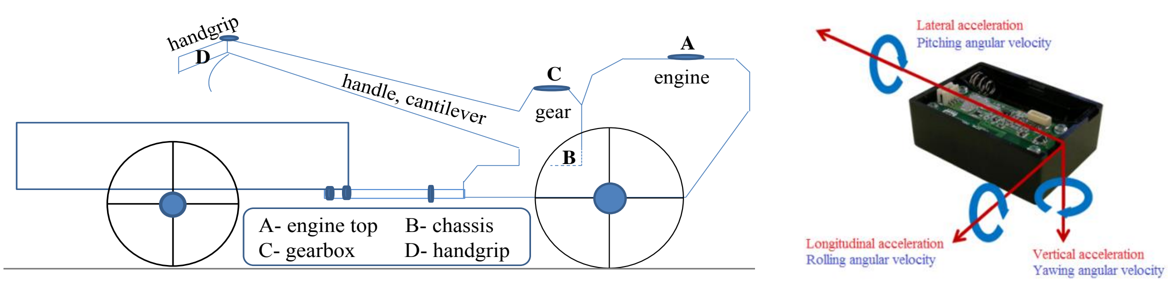

Fig. 2 Locations of experiment specification and MEMS sensor

Vibration transmission measurement at various locations of hand tractor had been carried out by many researchers, and strain gage were mostly employed for the experiments (Salokhe et al., 1995, Taghizadeh et al., 2007). However, strain gage were complicate in manipulation such as Strain Amplifier, Chanel-Data-Tape Recorder, Autonomous Data Acquisition Unit and Microcomputer with a limited connected cord. In a modern society; however, a MEMS sensor is very compact, light and easy to use. So it was chosen for this study. The wireless sensor can detect signal within 50 meters, and the output is easy to convert and calculate (Choe et al., 2013).

Data Outputting and Processing

The characteristics of hand tractor vibration are described in RMS, PSD and dominant frequencies, derived from output generation equations, Eq. (1) and Eq. (2). Vibration transmission is a proportion between engine top, main source of vibration, and connecting parts.

$$G = \frac{(V-1.65)\times 9.8}{0.19} \qquad (1)$$

$$W = \frac{V-1.35}{5.6\times 0.00067} \qquad (2)$$

Where V: voltage output when translational acceleration and rotational angular velocity are in G and W, respectively (Choe et al., 2013).

Root Mean Square and Power Spectrum Density

The RMS was used to obtain vibration magnitudes, and the PSD was employed using Fast Fourier Transform (FFT) function of mathematical computation and signal processing software package to obtain frequency domain (Salokhe et al., 1995). The PSD was plotted against frequency of the signal; therefore, the dominant frequency of vibration was received from the plot.

Hand-arm vibration exposures

A quantity of three combination axes was recommended by ANSI S2.70-2006 to evaluate hand-arm vibration exposures as expressed in Eq. (3) and Eq. (4).

$$a_{hw(rms)} = \sqrt{\textstyle\sum_i (W_{hi} a_{hi(rms)})^2} \qquad (3)$$

$$a_{hv(rms)} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (4)$$

Where $a_{hw(rms)}$: vibration in each direction $a_{hv(rms)}$: vibration combined value, W_{hi}: correction coefficient,$a_{hwx}, a_{hwy}, a_{hwz}$: each direction value.

RESULTS AND DISCUSSION

RMS of Stationary Hand Tractor

Vibration magnitudes of the 12Hp hand tractor using MEMS sensor are described in Fig. 3. It can be seen that RMS values at handgrip in vertical axis was the biggest followed by those at gearbox, engine top and chassis, respectively. The high vibration magnitude at handgrip in vertical axis was given that handle acts like a cantilever beam (Salokhe et al., 1995, Bahareh et al., 2013).

At engine top, magnitude is observed higher in longitudinal axis given that it responses to the corresponding of engine power stroke. The excitation of power stroke induces the rotating engines to vibrate in the same direction (Mehta et al., 2000). At the same location, extreme vibration signals predominantly in roll axis. It would be reasonably that engine is the main source of vibration excitation that vibration is movably parallel to the displacement of piston.

As engine is a main source of vibration, the relationship between engine top and other connecting parts were observed. It revealed that engine transmitted vibration slightly to chassis of 0.4 m/s^2, and gearbox of about 0.4 m/s^2, but largely to handgrip 1.1 m/s^2.

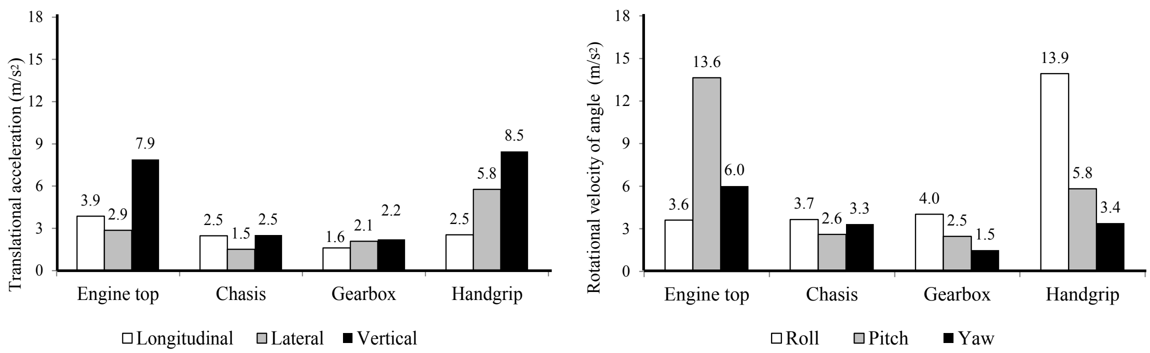

Fig. 3 RMS of translational acceleration and rotational angular velocity (stationary)

RMS of Driving Hand Tractor

Figure 4 represents the RMS of translational acceleration and rotational angular velocity at idling speed. Of the translational acceleration, peak magnitude appears in vertical axis of around 12 m/s^2, and it as well occurred hugely at roll axis of about 11 m/s^2. The predominant vibration may be caused by cantilever beam the hand tractor acts (Salokhe et al., 1995, Bahareh et al., 2013).

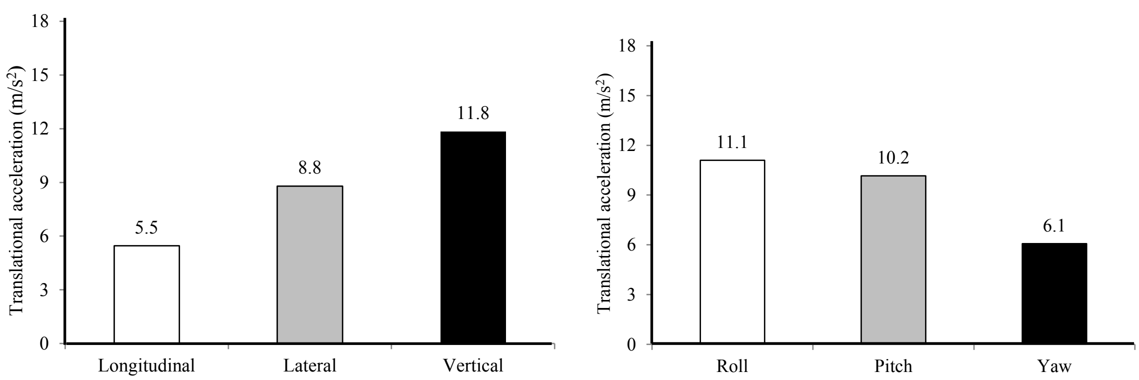

Fig. 4 RMS of driving hand tractor at handgrip

Power Spectrum Density at Stationary and Driving Modes

The results of PSD on the engine top and handgrip were partly represented in Figs. 5 and 6. The sensitivity vibration at 2, 5 or 20Hz may cause severe discomfort or injury but will not produce the nausea, vomiting and color changes so characteristic of motion sickness (M. J. Griffin, 1990).

It is seen in stationary condition that predominant magnitude at the engine top occurred largely at about 10Hz frequencies in longitudinal axis while at about 11Hz frequencies dominantly emerged at handgrip in vertical axis. These may be due to the corresponding to the movement of engine piston and movement of cantilever beam that the handle acts (Salokhe et al., 1995).

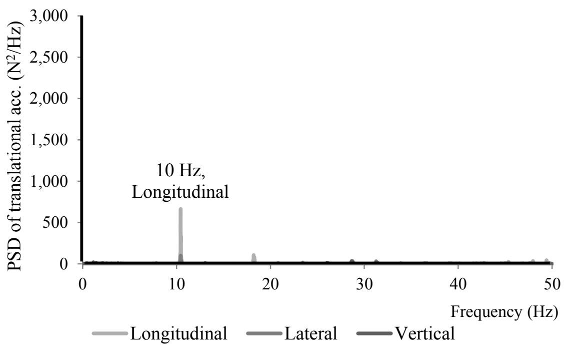

Fig.5 PSD at engine top (stationary)

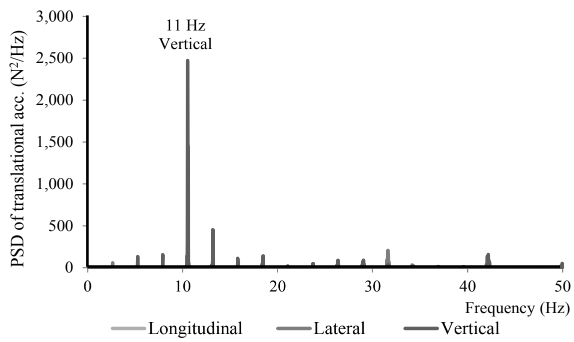

Fig.6 PSD at handgrip (stationary)

In driving mode, dominant frequency is found at about 3Hz frequencies first in longitudinal axis and about 9Hz frequencies next in vertical axis. The first frequencies would cause by movement of engine piston and the second peak would cause by cantilever beam that these results also confirmed by Salokhe (1995) and Bahareh et al., (2013).

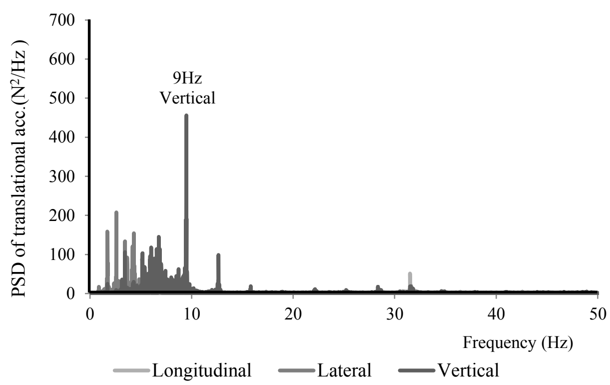

Fig. 7 PSD at handgrip (driving)

Hand-arm Vibration Exposures

The hand-arm vibration exposures were conducted based on RMS of engine vibration magnitude under hand-gripped modes to observe the severity of vibration from hand tractor to the operators, and a picked up frequencies were experimentally needed to compute exposure.

Results appeared that in stationary and driving modes the RMS of hand-arm vibration exposures were extremely higher than those stated in health guidance zone. This means that operators shall be technically advised to stop their operation; otherwise, it would be longer-sooner risky to health.

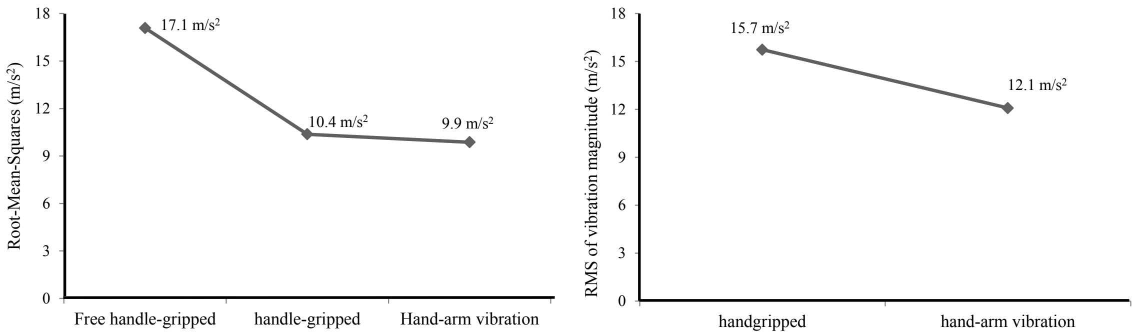

Fig.8 RMS of hand-arm vibration exposure in stationary and driving modes

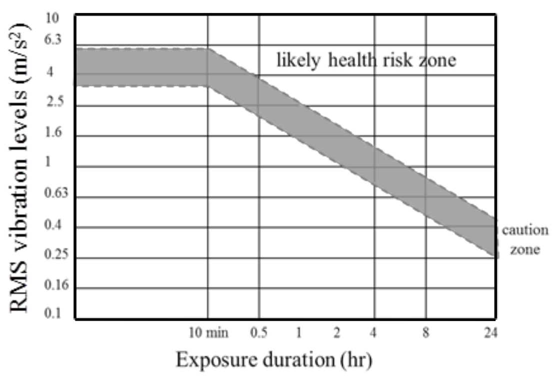

Fig.9 Health Guidance Zones (Sayed M.E. *et al*., 2012)

Future Development

To prevent from health risky, an effective interventions such as isolator dampening sleeves, splitting handle arm installed on some locations in between engine and base frame and between handle and gearbox. Some researchers applied successfully with isolators dampening sleeves, splitting handle arm on some locations (Chavan et al., 2013, Charturvedi et al., 2012).

CONCLUSION

The demand to improve agricultural production through enhancing agricultural mechanization was important for country development, Cambodia. However, with multipurpose uses of mechanization, especially hand tractors, long-time operation would cause discomfort to operator through handgrip vibration. Experiment results showed that the large vibration occurred at the handgrips in vertical axes. The RMS of hand-arm vibrations exposure at the handgrip of the 12Hp hand tractor were much higher than that in health risk limitation standard. Therefore effective intervention should be developed to prevent operator's health.

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