Computers and Electronics in Agriculture 141 (2017) 160–170

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Analysis of annoying shocks transferred from tractor seat using vibration signals and statistical methods

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ARTICLE INFO

Article history:
Received 5 December 2016
Received in revised form 3 July 2017
Accepted 26 July 2017

Keywords:
Whole-body vibration (WBV)
Tractor
Shock detection
Kurtosis

ABSTRACT

In many developing countries, agricultural tractors are employed for different field operations and transportation along rural roads where the operator is exposed to high levels of harmful vibrations from the tractor seat. In case of the vibrations transferred to the operator's body, the vibration signal form and the number and type of the shocks have been neglected in related literature. This article is focused on modern approaches to analyze tractor and car seats vibrations which have been ignored in many standards guidelines. For this purpose, examining a case study, kurtosis and skewness approaches were used to evaluate the vibration signals generated by a tractor seat. Further, an innovative model was developed to evaluate the effect of the vibrations, in terms of vibration intensity and signal form, on the operator. Average percentage of vibration transfer from the engine to feet platform was estimated at 31%. It could be concluded that, ground roughness generates vibrations within the frequency range of 0–30 Hz, while the engine causes vibrations at some frequency ranging within 50–200 Hz. Kurtosis could better present the difference between the two signals. The results indicated that, when considered independently, the values of RMS, VDV and kurtosis cannot well represent differences in vibration signals parametrically. However, the novel approach, when used as a benchmark for comparison, showed the differences between the signals at high accuracy.

1. Introduction

Being used in a wide range of engineering sciences, vibration analysis techniques are examined based on different aspects. One aspect is related to various types of rotating and reciprocating engines of industrial and agricultural equipment. In the internal combustion engines used in industrial and agricultural fields, the combustion and engine structure tend to generate some vibration (Taghizadeh-Alisaraei et al., 2012) which are important given that, in the field work, fatigue and discomfort are incurred by not only the physical work, but also the vibrations (Kang and Kaizu, 2011). In tractors and combines, vibrations generated from engine operation and ground roughness can be transferred to the driver's body through the seat and cabin floor (Langer et al., 2015; Prasad et al., 1995).

In Iran and many other countries in the Middle East and Africa, old fashion tractors are widely used in agricultural fields and for daily transportations along rural roads, and so, farmers are exposed to their harmful vibrations. For agricultural tractors, the vibrations caused by high forward speed and uneven ground tend to reduce driving efficiency while disturbing the driver, putting him/her at the risk of spinal diseases, as studied during 1960s (Servadio et al., 2007). Long-term vibration stresses can contribute to degenerative changes within the joints of the human body, especially in the lumbar spine. The forces transmitted through the joints serve as the main reason for these diseases. A simulation of the human body in standing and sitting postures as a biomechanical mode for measuring these forces was done by Fritz et al. (2005).

The frequency range of 2–6 Hz has been observed to be the most harmful for the operator because of the resonance. For this reason, the seat must be well designed to prevent vibrations within this range. Further reduction in the level of riding vibrations appear to be necessary and some possible methods for achieving significant improvements have been outlined (Prasad et al., 1995). Whole-body vibration (WBV) depends critically on operator's body anatomy, vehicle mass, weight distributions, tire inflation pressures and ground (Scarlett et al., 2007). Transferred vibrations through a seat depend on the impedance of the seat and the apparent mass of the seat occupant (Toward and Griffin, 2011).

Numerous studies have been done on the vibrations transferred to operator's body. In a study, vibrations transmitted from the ground to a driver's seat were analyzed using ISO standard meth-

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http://dx.doi.org/10.1016/j.compag.2017.07.020
0168-1699/

ods for a tractor equipped with a front suspension axle and a suspended cabin operating at speeds of 11.1 and 13.9 m s^{-1}. Accordingly, it was observed that accelerations along *y*- and *z*-axes decreased by 27% and 44%, respectively at increased forward speed (Scarlett et al., 2007). In another study, several factors affecting the apparent mass of the body such as age, gender, physical characteristics, backrest contact, and magnitude of vibration were evaluated for seat transmissibility. The resonance frequency of the seat was observed to decrease the vibration magnitude increased (Toward and Griffin, 2011).

Vibration magnitude, tractor forward speed, tire inflation pressure, and soil moisture content are involved throughout the design of seat. In a research, Cuong et al. evaluated the effect of different tire inflation pressures, soil moisture contents, and forward speeds on tractor vibration in the paddy on a two-wheel-drive unsuspended tractor. The results showed that, the tractor vibrations were strongly dependent on forward speed and rear tire inflation pressure (Cuong et al., 2013).

In a study, seat vibrations were evaluated in 100 vehicles and compared by the BS 6841 and ISO 2631 standard criteria (Paddan and Griffin, 2002). Shibata et al. considered different body postures when evaluating WBV. They showed that, compared to a standing operator, a sit operator tends to respond more sensitively and severely to fore-aft and lateral vibrations; it was while the standing operator responds more sensitively and severely to vibrations in vertical direction (Shibata, 2015) .

Jiao et al. evaluated the effects of different vibration frequencies on heart rate variability and driving fatigue. They showed that different vibration frequencies tend to impose distinctive effects on autonomic nerve activities (Jiao et al., 2004).

Nawayseh showed that sitting condition and body posture affect the vibration transmissibility via the car seat. According to hime, increase backrest angle enhanced the Vibration Dose Value (VDV) long *x*-direction while reducing that along *z*-direction. At increased backrest angle, total VDV at the backrest was higher than on the seat surface. On the other hand, VDV values were insensitive to feet position and headrest contact (Nawayseh, 2015).

Boshuizen et al. demonstrated that the prevalence of back pain is approximately 10% higher in tractor drivers than workers not exposed to tractor vibrations. Being mainly reported in the lower back, the pain was lasted over several days (Boshuizen et al., 1990).

Zheng et al. examined apparent mass and transmissibility of human body in terms of vertical and fore-aft excitations and the relation between the apparent mass and body transmissibility. The results showed the non-linearity of vertical apparent mass of the human body. An increase in the vibration magnitude was seen to lower the main resonance frequency (Zheng et al., 2012). Hostens and Ramon performed vibration tests on the cabin and seat of combines. In these studies, vibrations of significantly higher frequencies were observed in the cabin when driving on an asphalt road at 20 km/h, as compared to driving on a farm road at slower speeds. The results showed that, compared to seat with mechanical suspension system, a suspension-equipped seat reduces frequencies higher than 4 Hz, making it a more comfortable place for the driver to sit (Hostens and Ramon, 2003).

Another study conducted by Goglia et al. on 4WD tractor steering obtained a weighted acceleration-frequency in no-load and fully-loaded modes of 4.26 m s^{-2} and 17.91 m s^{-2}, respectively. In this test, it was observed that, after less than two years, 10 percent of the users exposed to vibrations had finger blanching problems (Goglia et al., 2003).

Toward and Griffin analyzed effectiveness of the factors related to apparent mass such as "age, gender, physical properties, backrest and seat vibration" on the capabilities of the seat. According to them, vertical vibration transmission through the seat at 12 Hz depended on the age, body mass index and gender. Although the weight was correlated with the apparent mass, it was ineffective when it came to vibration transmission to the seat. The resonant frequency of the seat was seen to reduce by increasing the stimulation vibration. Moreover, the resonant frequency decreased by increasing the contact between the operator's back and the backrest (Toward and Griffin, 2011).

As was shown, most of previous research has been concerned with low-frequency vibrations and their effect on humans' body, failing to examine the effect of the shock and type of shock on humans' body. So, this paper is focused on modern approaches for analyzing tractors and cars seat vibrations, which have been widely ignored in many standards guidelines. Two cases are compared here, namely the one without shock (stationary) and the one with a high level of shocks (transportation). For this purpose, the amount of transferred vibrations from the engine and road roughness to a MF399 tractor seat in stationary and driving states (along an uneven rural road) were measured by accelerometers and recorder devices. Then, the amount of the transferred shock was determined using innovative methods such as kurtosis and proposed statistical analysis. Accordingly analyzed were some shortcomings of ISO 2631 and ISO 4859 when it came to shock diagnosis in the vibration transmitted through the body.

2. Materials and methods

2.1. MF 399 tractor

In this study, a single differential tractor MF399 manufactured in the Iran Tractor Manufacturing Company (Tabriz, Iran) was used. Table 1 shows technical specifications of the tractor.

Tractor vibrations are mainly caused by its engine and uneven road roughness before being transmitted to the seat and then the driver. Car and tractor seats are considered as integrated systems including mass, spring, and damper, where the system is subjected to the movements of the base.

Table 1
Specifications of MF 399 tractor, accelerometers, and A/D converter.

Tractor		
Weight & dimensions	**Engine**	Front axle width, 1365–1975 mm
With full fuel, oil and water	Model 1006-6 Perkins	Rear axle width, 1530–2230 mm
Mass on the front axle, 1303 kg	Diesel with direct injection	**Power Take-off Shaft**
Mass on the rear axle, 2014 kg	Number of cylinders, 6	Independent hydraulic clutch with hand lever
The total mass 3317 kg	The compression ratio of 16:1	The type of PTO, two speed of 540 and 1000 rpm at 1000 and 1900 engine rpm, respectively.
Length: 4330 mm, width: 1973 mm, Height: 1906 mm	Fuel injection timing, 22 degrees before top dead center	
The distance between the front and rear wheel axles, 2580 mm	Maximum power 2200 rpm, kW 82	
	Maximum torque 1200 rpm, 431 N·m	
	Maximum no-load speed, 2310 rpm	
Accelerometers		
Multi-Purpose Accelerometers, CTC AC102-1A, Frequency Response (±3 dB) 0.5–15000 Hz, Dynamic Range ± 50 g peak, Resonant Frequency 23000 Hz		
A/D converter		
Advantech USB-4711A, 16 Single input channels A/D, Converting 12 bit A/D, Maximum sampling frequency of 150 kHz		