Skidder operator vibration exposure

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Abstract

The exposure of workers to vibration is expressed as energy equivalent A(8), which is determined by the procedure clearly described in the international standard ISO 5349-1-2001. A(8) is a value that depends not only on the vibration level in certain operating procedures, but also on the duration of exposure. Research was conducted on Ecotrac 120 V and Ecotrac 140 V, the most used skidders in Croatian forestry. Vibration on the steering wheel and seat of the skidders was measured by vibrometer with triaxial accelerometer. Measurements were performed at three characteristic engine operating modes: idling, at maximum torque and full throttle. Daily exposure to vibration of a skidder operator A(8) is calculated based on structural data of daily working times in different working conditions as well as distribution of three characteristic engine operating modes of effective time. The results show differences in vibration levels between different types of tractors and working conditions. The research was carried out within the project "Development of hybrid skidder – HiSkid" co-financed by European Regional Fund in the scope of European Union Operational Program „Competitiveness and Cohesion" 2014-2020 (2014HR16M1OP00-1.2).

Keywords: *skidder, daily vibration exposure, A(8), WBV, HAV, engine operating modes*

1. Introduction

The ergonomic aspects of forestry machines with respect to operator exposure to machine vibrations have become the primary consideration for enhancing operator performance in recent decades. In mechanized forest operations, whole-body vibration may have considerable influence on machine productivity and the health of the operator [1]. Whole-body vibration is a problem with forestry machines and often causes discomfort and injury. The Directive 2002/44/EC [2] defines the minimum health and protection requirements for the workers exposed to vibrations that are transmitted to the hand-arm system (HAV – *hand-arm vibrations*) and to the whole body of the operator (WBV – *whole-body vibrations*). Directive 2002/44/EC unambiguously sets daily exposure action value of 2.5 m/s^2 (HAV) and 0.5 m/s^2 (WBV) as a warning level above which protective measures must be applied and daily exposure limit value of 5 m/s^2

(HAV) and 1.15 m/s^2 (WBV) above which work must be stopped. The A(8) value does not only depend on the vibration level in certain operating procedures, but also on the duration of exposure, i.e. on the duration of each skidder operating procedure [3]. In the forestry field, previous studies have shown that forestry vehicle operators are exposed to high levels of WBV. Limit values could be exceeded with a large number of modern farming tractors [4]. One study measured operator exposure to whole-body vibration in timber extraction with grapple skidder when comparing the values of the weighted acceleration and VDV (*vibration dose value*) with the limits established by the European Directive, it is verified that the measured values are higher than the one expected by the respective regulation [5]. Factors such as vehicle speed, driving style, machine design and geometry, belt and chain type, suspension type, power transmission to the wheels, mass distribution, position of the driver's seat, and the seat features affect the exposure of operators of forestry machinery to WBV [6]. Measured vibrations on steering handles of the one-axle farming tractor during driving and soil processing at three tractor speeds indicate the highest vibrations at the lowest tractor speed and during soil processing, and actually higher vibrations were measured during soil processing [7]. Worker`s exposure to whole-body vibration is the highest during the skidding operations and for operations where a cable skidder was moving with no load (1.31 m/s^2) and ramping (1.22 m/s^2), and the lowest with the full load (0.91 m/s^2) [8]. These exposure levels increase with increases in driving speed, the roughness of the terrain, and decreases in driving with a load, as seen in forestry skidders [9]. In harvesters the vibration level is affected by the characteristics of the vehicle (engine speed, engine fitted with shock-absorbers), terrain characteristics (surface obstacles), methods of wood processing (processing of trees), seat characteristics, physical condition and sitting position of the operator and soil characteristics (dry, frozen, wet soil). The same authors conclude that the air pressure in tires has a considerable impact on the level of vibrations that are transmitted through the seat to the whole body of the operator while the harvester is moving on uneven terrain [10]. Vehicle speed and the type of terrain on which it moves highly affect the level of vibrations that are transmitted through the seat to the whole body of the operator [11]. Technical factors that could be used to help minimize operator WBV exposures such as: seat suspension systems, seat cushioning, cab/chassis, and axel/chassis suspension systems, and the vehicle tires inflation pressure are presented in one study [12]. Higher WBV operator exposures are detected during tractor skidding than the limit values specified by international standards. But when a skidding tractor has a seat suspension system with springs, significant reductions is noticed in the total WBV accelerations [1]. Aside from technical upgrades of machines, reduction of exposure to WBV, while simultaneously maintaining high productivity, requires careful selection of worksites and adapted work organization [13]. With the methodology of determining 8-hour energy equivalent of the total value of the estimated accelerations A(8), an accurate picture of the working day should first be made and whole day shooting of the operator's work with the film camera is one of the ways to get such a picture. The same authors state that, in practice, it is practically impossible to measure the levels of vibrations for each activity, and for this reason, it is necessary to make initial measurements in the test polygon under controlled conditions [14]. The vibration exposures measured on these test tracks do not necessarily represent actual field exposures. Exposures measured on

ISO 5008 test tracks overestimate those found during field tasks [15]. On the other hand, one should be aware that studies tracking exposures over an entire work cycle may underestimate the acceleration levels for specific work tasks. This is due to the different vibration exposures for the individual work tasks as well as the fact that periods, where the vehicle is stationary, are often incorporated into the exposure average [16]. The aim of the research is to determine the level of vibration of a skidder in controlled test conditions, and modeling the total value of the exposure to vibration of a skidder driver on a daily basis A(8). The research results are used to investigate vibration exposure in real working conditions and represent the baseline values for future future research within the project "Development of hybrid skidder – HiSkid".

2. Material and Methods

The research was done on the skidders Ecotrac 120 V and Ecotrac 140 V, which are the most used skidders in Croatian forestry. The measurements were carried out on the skidders Ecotrac 120 V, whose mass is approximately 7,5 tons, and on the Ecotrac 140 V, whose mass is approximately 8 tons. Ecotrac 120 V is powered by a 6-cylinder air-cooled engine with a nominal power of 86 kW and the Ecotrac 140 V is powered by a 4-cylinder liquid-cooled engine with a nominal power of 104 kW. The skidders are fitted with an air suspension seat whose sensitivity can be regulated manually. For the data obtained from measurements in three modes at all measuring points, the triaxial vibrometer calculated the weighted vibration values for time records in the direction of all three axes, in accordance with the recommendations of the standard HRN EN ISO 5349:2008 [17,18]. Vibration on the steering wheel and seat of the skidders was measured using vibrometer Brüel & Kjaer type 4447 and triaxial accelerometer type 4520-002 with UA 3017 mount on the steering wheel and triaxial accelerometer type 4524-B fitted in the rubber protective cover on the seat of the researched skidders (Figure 1). Measurements were performed at three characteristic engine operating modes: idling (900 rpm), at maximum torque (1500 rpm), and full throttle (2200 rpm). Weighted acceleration levels in all three axes (a_{hwx}, a_{hwy} and a_{hwz}) were obtained. From the weighted acceleration levels in all three axes, the vibration total value (a_{hv}) for three modes according to the following relation was determined (Eq. 1):

$$a_{hv} = \sqrt{{a_{hwx}}^2 \cdot {a_{hwy}}^2 \cdot {a_{hwz}}^2} \quad (1)$$

a_{hwi} – weighted effective acceleration levels (m/s^2)

The exposure to vibration of a skidder driver on a daily basis A(8) is calculated based on data of the structure daily working times (effective time and allowance time) in different working conditions (hilly terrain for Ecotrac 120 V, and mountainous terrain for Ecotrac 140 V) as well as the distribution of three characteristic engine operating modes of effective time. The mentioned data are taken from previous scientific research on the work of skidders [19]. Based on the measured acceleration values on the seat and steering wheel, and the calculated vibration total values, a model for estimating the daily exposure value A(8) was calculated according to the relation (Eq. 2):

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{N} a_{hvi}^2 \cdot T_i} \tag{2}$$

T_0 – daily working time of 8 h or 28800 s
a_{hvi} – vibration total value for i operation
T_i – duration of i operation
N – total number of operations

a. b.

Figure 1 : a. Measuring of vibrations on the steering wheel
b. Measuring of vibrations on the seat

Additional time represents the non-productive part of the total working time related to preparatory time, mealtime, resting time, and other interruptions. Research on the productivity of Ecotrac 120 skidder determined an additional time factor of 1.22 for a site on mountain terrain, and a factor of 1.31 for a site on hilly terrain (Table 1) [19]. Based on these data, it is concluded that the additional time does not depend so much on stand and exploitation factors as on the organization and supervision of the execution of work in skidding wood. For the same skidder, in another study, in the hilly conditions of central Croatia the additional time factor is 1.34, and in the mountainous conditions of selective forests 1.18 [20]. In research [3], engine speed data are sorted during skidder normal work in the 2 working day period (Table 2). All data of engine speeds were obtained by the use of the FMS (*fleet management system)*. All engine speeds less than 1200 rpm represent idle operating mode, engine speeds from 1200 rpm to 1800 represent normal operating mode near the maximum torque, and engine speeds higher than 1800 rpm represent full throttle operating mode.

Table 1. Structure of daily working times

		%	**min**
ECOTRAC 120 V hilly terrain	Total effective time	**69**	**330**
	<1200 rpm	6,9	33
	1200 - 1800 rpm	55,2	265
	> 1800 rpm	6,9	33
	Allowance time	**31**	**150**
	Total time	**100**	**480**
ECOTRAC 140 V mountainous terrain	Total effective time	**78**	**374**
	<1200 rpm	7,8	38
	1200 - 1800 rpm	62,4	298
	> 1800 rpm	7,8	38
	Allowance time	**22**	**106**
	Total time	**100**	**480**

3. Research results

Table 2. Daily vibration exposure

ECOTRAC 120 V	**Seat - WBV**	a_{hv} [m/s^2]	*T* [min]	A(8)
	Off	*0*	149	**0,65**
	Idle (900 rpm)	1,17	33	
	Max torque (1500 rpm)	0,74	265	
	Full throttle (2200 rpm)	0,65	33	
	Total		480	
	Steering wheel - HAV	a_{hv} [m/s^2]	*T* [min]	A(8)
	Off	0	149	**0,73**
	Idle (900 rpm)	0,63	33	
	Max torque (1500 rpm)	0,84	265	
	Full throttle (2200 rpm)	1,27	33	
	Total		480	
ECOTRAC 140 V	**Seat - WBV**	a_{hv} [m/s^2]	*T* [min]	A(8)

	Off	*0*	106	**1,12**
	Idle (900 rpm)	0,89	38	
	Max torque (1500 rpm)	1,38	298	
	Full throttle (2200 rpm)	0,24	38	
	Total		480	
	Steering wheel - HAV	a_{hv} [m/s^2]	T [min]	A(8)
	Off	0	106	**1,23**
	Idle (900 rpm)	1,13	38	
	Max torque (1500 rpm)	1,32	298	
	Full throttle (2200 rpm)	2,05	38	
	Total		480	

Obtained results show that HAV values measured on the steering wheel do not even exceed the action value of 2.5 m/s2. However, WBV values on the seat exceed action value in both observed skidders. Especially concerning is how close is Ecotrac 140 to exceeding the daily limit value for WBV of 1.15 m/s2. The reason for that could be the different propulsion engine in Ecotrac 140. Ecotrac 140 and Ecotrac 120 are very similar in build, and both have pneumatic seats, so the reason for higher vibrations on the seat of the Ecotrac 140 could be the liquid-cooled, 4-cylinder, turbodiesel engine. On the other hand, Ecotrac 120 is propelled with an air-cooled, 6-cylinder, naturally aspirated diesel engine which is perhaps more balanced, and thus produces fewer vibrations.

4. Conclusions

Both of the observed skidders are designed very similar and with the same intention, to skid wood. Since the vibration exposure was measured in a controlled environment, and obtained vibration values do not take into account the terrain characteristics and other working factors, the main reason for the significant difference in WBV values is the propulsion engine. Winching makes a significant amount of work time in skidding during which the engine must operate in order to propel the winch. If the skidder would be fitted with batteries and electric powered winch, the total engine operating time would be reduced, and thus WBV would be lower. Electric motors are far more balanced than ICE (*internal combustion engine*) and also produce fewer vibrations. Regarding the latter, hybrid technology is already used in forestry and it is the logical step to ensuring better results in many fields including work ergonomics.

5. References

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