Possibility of Determination of Daily Exposure to Vibration of Skidder Drivers Using Fleet Manager System

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Abstract – Nacrtak

This paper describes an indirect method of determining exposure to vibration of skidder drivers using the Fleet Manager System. The hand-arm exposure of workers to vibration is expressed as energy equivalent A(8), which is determined by the procedure clearly described in the international standards ISO 5349-1-2001 and ISO 2631-1-1997. A(8) is a value that depends not only on the vibration level in certain operating procedures, but also on the duration of exposure (duration of each skidder working procedure).

Research was done on the skidder Ecotrac 120V equipped with the Fleet Manager System (FMS). The role of the FMS is to measure engine speed and duration of a certain engine speed during the working day. The analysis of the working days was performed in the aim to connect skidder working elements (driving, winching, pulling out of winch rope, etc.) with engine speeds.

Vibration on the steering wheel and seat of the skidder Ecotrac 120V was measured by vibrometer with triaxial accelerometer (Brüel and Kjaer 4447) at different engine rotational speeds. The exposure to vibration of a skidder driver on a daily basis A(8) was calculated using data of the summarized durations at certain skidder engine rotational speeds measured by the FMS and the measured level of vibrations at specific engine rotational speeds.

Keywords: vibrations, A(8), engine rotational speed, Fleet Manager System, skidder

1. Introduction – *Uvod*

Field scientific research, such as the research of some exploitation characteristics of forest vehicles during extraction of different forest products, the impact of extraction on some soil characteristics aimed at determining the environmental viability and its impact on ergonomic conditions in the operator's cabin, requires a lot of time spent in the field and is hence very expensive. The Fleet Manager System (hereinafter FMS) is a system of remote monitoring and control of the vehicle operation, which enables gathering of data without disturbing the vehicle operation, i.e. it provides the possibility to research in almost uncontrollable exploitation conditions. The FMS is a very useful tool for the control and organization of the complex system of production and supply of wood chips from the place of chipping to the buyer (Holzleitner et al. 2013.) as well as during the time study.

The use of FMS as the tool in the process of data gathering from the vehicle aimed at measuring and determining some ergonomic parameters such as vibrations transmitted through the steering wheel on the hands and through the seat to the whole body of the operator, is not known in the literature. Goglia et al. (2012) consider that, 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.

Measuring vibrations on chain saws, Rottensteiner et al. (2012) conclude that the level of vibrations is considerably affected by wood density and that it should, therefore, be one of the basic parameters in calculating the worker's daily exposure to vibrations A(8).

Goglia et al. (2003) measure vibrations on the steering wheel of the small farming tractor while idling and under full load, and then they calculate the daily exposure to vibrations A(8), which amounts to 14.28 m/s^2. According to ISO 5349-1-2001, it means that in less than two years adverse effects of vibrations can be expected with 10% of tractor drivers.

Dewangan and Tewari (2009) measure vibrations on steering handles of one-axle farming tractor during driving and soil processing at three tractor speeds. The highest vibrations were measured at the lowest tractor speed and during soil processing, and actually higher vibrations were measured during soil processing.

Poje (2011) concluded that the worker`s exposure to whole-body vibration were 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).

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. Therefore the FMS, as the system for monitoring and control of the vehicle operation, is highly suitable for determining the A(8) values, because the analysis of data gathered from the vehicle (time, engine rotational speed, winch/crane operation, position/moving, vehicle speed, etc.) can easily show the duration of individual operations at specific engine rotational speed. By subsequent measurement of vibrations (a_{hv}) at characteristic engine speeds, the A(8) value can be simply calculated, as specified by the standard ISO 5349-1-2001.

$$a_{\mathrm{hv}} = \sqrt{a_{\mathrm{hwx}}^2 + a_{\mathrm{hwy}}^2 + a_{\mathrm{hwz}}^2} \qquad (1)$$

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

Where:

T_0 = available time of 8 h or 28 800 s,

a_{hvi} = total exposure to vibrations for i operation,

T_{i} = duration of this operation,

N = the total number of operations.

Sherwin et al. (2004) state that with harvesters the vibration level is affected by the characteristics of the vehicle (engine rotational 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. Kumar (2004) concludes that the 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.

The Directive 2002/44/EC 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). According to this Directive, the upper limit of the worker's daily exposure to hand-arm vibrations is 5 m/s^2, while the daily warning value is 2.5 m/s^2. The worker's exposure through hand-arm system is measured in accordance with the specifications described in the standard ISO 5349-2:2002.

According to the Directive 2002/44/EC, the upper limit of the worker's daily exposure to vibrations that are transmitted to the whole body is 1.15 m/s^2, while the daily warning value is 0.5 m/s^2 (8-hour working time). Scarlett et al. (2002) agree that these limit values could be exceeded with a large number of modern farming tractors. Workers' exposure to vibrations that are transmitted to the whole body is measured by the method specified by the standard ISO 2631-1:1997.

2. Material and Methods – *Materijal i metode*

Engine rotational speed obtained by the use of the FMS was divided into classes of 100 min^{-1}, ranging between 800 and 2 100 min^{-1}. As in the FMS report the engine rotational speed is shown in the dependence of time, the duration of engine operation at specific engine rotational speed was determined by further analysis.

Subsequent measurement of vibrations at the same engine rotational speed classes was performed with the help of vibrometer Brüel & Kjaer, type 4447 and triaxial accelerometer, type 4520-002, on the steering wheel and triaxial accelerometer, type 4524-B, fitted in the rubber protective cover on the seat and seatback of the researched skidder.

The measurements were carried out on the skidder Ecotrac 120V whose mass is approximately 7.5 tons. The researched skidder is powered by a 6-cylinder air-

Fig. 1 Measuring of vibrations on the steering wheel
Slika 1. *Mjerenje vibracija na kolu upravljača*

Fig. 2 Measuring of vibrations on the seat
Slika 2. *Mjerenje vibracija na sjedištu*

Table 1 Time consumption per classes of engine rotational speed
Tablica 1. *Prikaz utrošenoga vremena prema razredima brzine vrtnje pogonskoga motora*

Revolution per minute, rpm *Broj okretaja u minuti*	Duration *Trajanje*	Duration – T_i *Trajanje* – T_i
min^{-1}	hh:mm:ss	s
850 (800–899)	00:07:27	447
950 (900–999)	00:01:03	63
1050 (1000–1099)	00:03:05	185
1150 (1100–1199)	00:26:39	1599
1250 (1200–1299)	02:39:06	9366
1350 (1300–1399)	02:19:23	8363
1450 (1400–1499)	02:22:56	8576
1550 (1500–1599)	00:44:17	2657
1650 (1600–1699)	00:32:40	1960
1750 (1700–1799)	00:31:41	1901
1850 (1800–1899)	00:28:52	1732
1950 (1900–1999)	00:29:02	1742
2050 (2000–2099)	00:12:17	737
Total time – T_0 *Ukupno vrijeme* – T_0	10:58:28	39328

cooled engine of the nominal power of 86 kW. The skidder is fitted with an air suspension seat whose sensitivity can be regulated manually.

3. Results – *Rezultati*

Based on the analysis of the working day of vehicles through the engine rotational speeds and their duration obtained by the use of the FMS and subsequent measurement of the total exposure to vibrations (the resulting vector) a_{hvi} on the steering wheel (Fig. 1), seat (Fig. 2) and seatback of the skidder Ecotrac 120V, the operator's daily exposure to vibrations A(8) was calculated.

Total working time, obtained by the use of the FMS and by subsequent analysis of the engine speed, amounted to 10:58:28 hours (39 328 s), meaning that the work was organized in two-shifts with two operators. The highest share of time (more than two hours) was measured in three rotational classes: 1 250, 1 350 and 1 450 min^{-1} (Table 1).

The diagram in Fig. 4 shows that the highest values of the total exposure to vibrations a_{hv} at all three measuring points were measured when the engine was idling, and in the engine rotational speed class of 850 min^{-1}. According to the presented curves, the highest vibrations were measured on the steering wheel, somewhat lower on the seatback, and the lowest vibrations were measured on the seat in the whole range of the engine rotational speeds.

According to the diagram in Fig. 5, with the skidder in question the daily exposure to vibrations A(8) through the steering wheel on the hand-arm system is 2.12 m/s^2. According to the Directive 2002/44/EC this is below the daily warning value of 2.5 m/s^2.

The daily exposure to vibrations A(8) calculated for the seat exceeds the daily warning value for the allowed vibrations that are transmitted to the whole

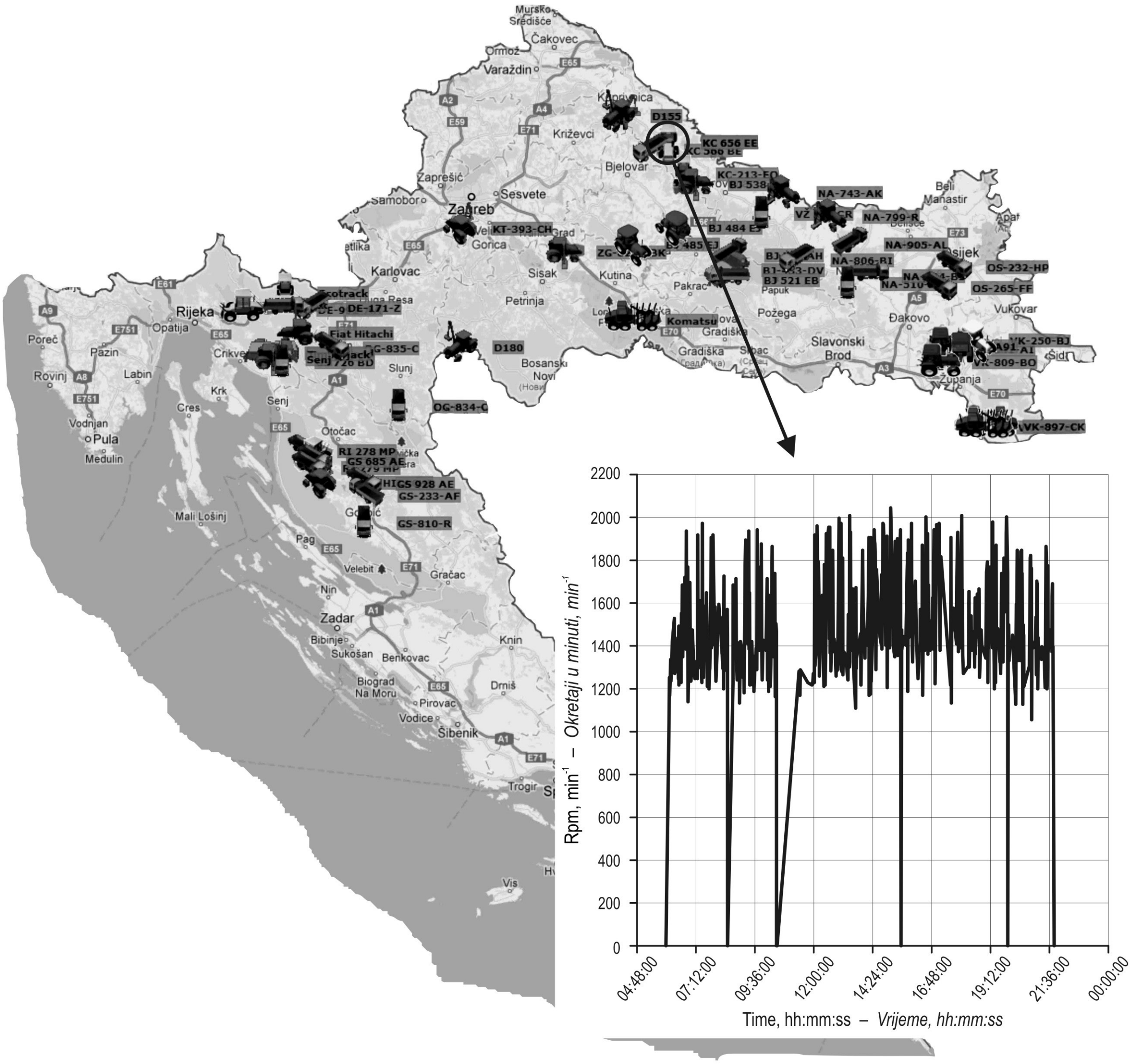

Fig. 3 Position of the researched skidder on the map with the diagram showing engine rotational speeds during a working day

Slika 3. *Položaj istraživanoga skidera na karti s dijagramom prikaza brzine vrtnje motora tokom jednoga radnoga dana*

body (0.5 m/s^2) amounting to 0.99 m/s^2, while A(8) calculated on the seatback exceeds the upper limit value of the worker's daily exposure to vibrations (1.15 m/s^2) amounting to 1.73 m/s^2.

4. Discussion – *Rasprava*

The FMS proved to be a highly suitable system for gathering data on engine rotational speed aimed at determining the worker's daily exposure to vibrations A(8). It is very easy to deduct the duration of engine operation in individual classes of rotational speed from the report generated by the FMS control center.

The measured values a_{hv} on the steering wheel as well as on the seat and seatback show that the highest vibrations occur when the engine is idling. Regarding these results, it should be noted that all measured values a_{hv} are mostly below 1 m/s^2, which is very satisfying.

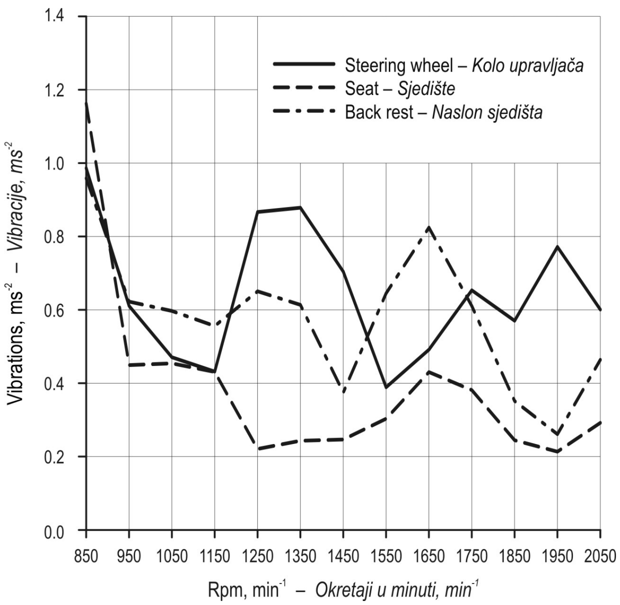

Fig. 4 Evaluated vibration accelerations ahv according to the engine rotational speed for all three measuring points on the skidder Ecotrac 120V

Slika 4. *Prikaz vrednovanih ubrzanja vibracija ahv prema brzini vrtnje motora za tri mjerna mjesta na skideru Ecotrac 120V*

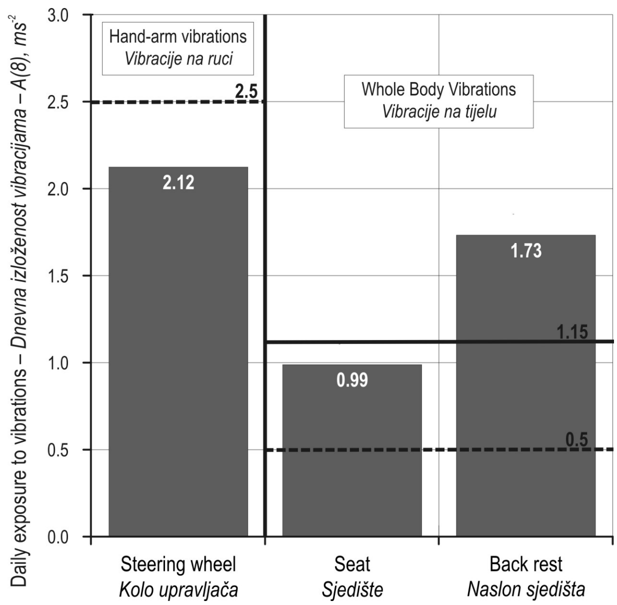

Fig. 5 Daily exposure to vibrations A(8) for all three research points

Slika 5. *Dnevna izloženost vibracijama A(8) za sva tri istraživana mjesta*

The calculated value of the worker's daily exposure to vibrations A(8) for the recorded working time of 10:58:28 hours in accordance with the Directive 2002/44/EC shows that on the steering wheel it does not exceed the daily warning value of 2.5 m/s^2 for the arm-hand system. The calculated A(8) value on the seat exceeds the warning value of 0.5 m/s^2, while the calculated A(8) value on the seatback exceeds the upper limit value of the daily exposure to vibrations of 1.15 m/s^2. Since the work was organized in two shifts with two operators in one working day, the exposure to vibrations A(8) of one worker was in fact half of the calculated values, and according to the Directive 2002/44/EC, the A(8) value exceeds the daily warning value of 0.5 m/s^2 only on the seatback.

The aim of further research is to divide the skidder working day not only by engine rotational speed but also by operating procedures and by vehicle speed, and based on these parameters, obtained with the help of the FMS, to calculate the worker's daily exposure to vibrations A(8).

The further research will also include the impact of terrain characteristics (surface obstacles), methods of tree processing, seat characteristics, physical condition and sitting position of the operator and also soil characteristics for determining the worker's daily exposure to vibrations A(8).

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Sažetak

Mogućnost određivanja dnevne izloženosti vibracijama vozača skidera upotrebom sustava Fleet Manager

U radu je opisana indirektna metoda određivanja izloženosti vibracijama vozača skidera upotrebom sustava daljinskoga praćenja vozila (Fleet Manager System ili FMS). Izloženost radnika vibracijama iskazuje se kao energijski ekvivalent A(8), koji je određen i jasno opisan u međunarodnim standardima ISO 5349-1-2001 i ISO 2631-1-1997. A(8) je vrijednost koja ne ovisi samo o razini vibracija pri određenom radu nego i o vremenskom trajanju vibracija (trajanje svakoga radnoga zahvata skidera).

Istraživanje je provedeno na skideru Ecotrac 120V opremljenim sustavom za daljinsko praćenje vozila (FMS). Zadaća je FMS-a bila mjerenje brzine vrtnje motora te vremensko trajanje pojedinih brzina vrtnje tokom radnoga dana. Napravljena je analiza radnoga dana skidera po pojedinim radnim elementima (vožnja, privitlavanje, izvlačenje užeta itd.) kako bi se određeni radni element mogao povezati sa specifičnom brzinom vrtnje motora.

Vibracije na kolu upravljača i sjedištu skidera Ecotrac 120V mjerene su vibrometrom s troosnim akcelerometrom (Brüel and Kjaer 4447) pri različitim brzinama vrtnje. Dnevna izloženost vibracijama A(8) vozača skidera izračunata je na temelju podataka o ukupnom trajanju brzine vrtnje motora u pojedinim razredima brzine vrtnje izmjerenih pomoću FMS-a te pomoću vrijednosti vibracija pri istim razredima.

Ključne riječi: vibracije, A(8), brzina vrtnje motora, sustav Fleet Manager, skider

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