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AN ERGONOMIC EVALUATION ON WHOLE-BODY VIBRATION OF LOADING TRACTORS IN TURKISH FORESTRY

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Abstract: *The study presents describe exposure to whole-body vibration during occupational operation of loading tractor. Whole-body vibration was analysed at the seat-operator interface using a tri-axial accelerometer at 145 forestry loading operations in Turkey. The mean total vibration value was found 1.38 ms^{-2} at loading equipment mounted tractors and 1.06 ms^{-2} at original loading machines. The regression analysis was performed in order to determine the most important factors that affect total vibration value transmitted to the tractor operator. The most important factors that affect the total vibration value were machine type, ground roughness condition, ground type, wheel pressure, seat condition and operator weight. In the region, the use of original loading machines should be encouraged. The operator seats having an automatic mass adjustment mechanism should be used. The roughness of the ground should be reduced by covering the ground of forest depots with stabilized material.*

1. Introduction

Modern forestry has confined most of human power to machinery in order to increase the work productivity. Forestry mechanization has great advantages, but it has some problems, too. Unsuitable relations among operator, machine and environment as the components of harvesting systems are the source of these problems and in consequence it has negative effect on operator's health and work productivity.

The ergonomic aspects of the forestry machines with respect to operator exposure to machine vibrations have become primary consideration to enhance operator performance. Loading tractors in various types and dimensions are generally used in forest depots in Turkey for loading and sorting the forest products. In Western Black Sea region, tractors on which loading equipment is mounted (%85) and original loading machines (%15) are used for loading and sorting operations (Melemez and Tunay, 2010).

Whole Body Vibration (WBV) has the most significant influence on productivity and health (Sherwin et al, 2004). The WBV is the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of operators, in particular lower-back morbidity and trauma of spine (Calvo, 2009). Tractors do not have suspensions, and vibration levels in tractors are higher than those in other road vehicles (Kumar et al., 1999). The tire-axle and axle-frame suspensions of the road vehicles are not available on tractors on which the only suspension is between the frame and cabin and the seat. In general, the problem originates from the natural vibration frequencies of the tractor, seat and operator which are the basic vibration characteristics, and very close to each other, and the vibration isolation possibilities are limited (Sabanci, 1999). The design of tractors has changed significantly over recent years; modern tractors tend to have a good seat suspension at least in the vertical plane and in some cases horizontal as well and some models have been manufactured with suspension (Melemez and Tunay, 2009).

The aim of this study is to determine the most important factors that affect WBV transmitted to the loading tractor's operator. WBV was analysed at the seat-operator interface using a tri-axial accelerometer in 145 forestry loading operations in Turkey. The regression analysis was performed in order to determine the most important factors that affect total vibration value. Suggestions are offered to reduce WBV magnitude transmitted to the operator in the region.

2. Materials and Methods

This study was conducted in the forest depots in the Western Black Sea Region, which is one of the regions of Turkey rich in forestry resources. Measurements in the scope of the study were made when operators were working with International, Ford, John Deere, and Massey Ferguson agricultural tractors (on which loading equipment is mounted) and Komatsu and Hidromek original loading machines.

Figure 1-2. Operation of loading equipment mounted tractor and original loading machines.

Vibration measurements were made in accordance with ISO 2631-1 (1997), on the interface between the seat surface and the operator in 145 forestry loading operations. A Bruel and Kjaer 4447 tri-axial vibration level meter is used for measuring vibration levels (Figure 3). Calibrations were done before field measurement. Frequency-weighted rms magnitudes (*a*), in x (back-and-front), y (lateral) and z (vertical) directions were used to describe the vibration conditions (Figure 4).

Figure 3-4. Triaxial accelerometer and measurement axes

The weighted rms acceleration is expressed in ms^{-2} and is calculated by equation 1 (Rehn et al., 2005). Frequency weightings and multiplying factors for health aspects of WBV were specified in international standard 2631-1 for seated persons (correction factors: with respect to health, k_x=1,4, k_y=1,4, k_z=1,0). The vector sum of the root mean square (rms) of frequency-weighted accelerations (a_t) was calculated according to the equation 2.

$$a = \left[\frac{1}{T}\int_0^T a^2(t)dt\right]^{1/2} \quad (1)$$

$$a_t = \left[(1.4 * a_x)^2 + (1.4 * a_y)^2 + (1.0 * a_z)^2\right]^{1/2} \quad (2)$$

The study attempted to find important variables affecting the vibration value to which the operators were exposed. In this scope, regression analysis was performed by designating the measured rms acceleration values (a_t) as the dependent variable and the variables listed below (thought to affect the vibration value) as independent variables. Independent variables are listed as follows:

m_t: Machine type; 1: original and 2: loading equipment mounted
m_d: Machine use duration (year)
s_s: Seat suspension system; 1: useless, 2: medium, 3: effective)
s_d: Seat use duration (year)
s_c: Seat use condition; 1: old, 2: middle, 3: new and usable
w_f: Front wheel pressure (psi)
w_r: Rear wheel pressure (psi)
g_t: Ground type; 1: soil, 2: stabilized
g_r: Ground roughness condition; 1: slightly rough, 2: mildly rough, 3: quite rough
o_w: Operator weight (kg)
a_s: Working area slope (%)
w_a: Working area breadth; 1: narrow, 2: middle, 3: broad

3. Results and Discussion

The mean of the total vibration value was found 1.38 ms^{-2} in loading equipment mounted tractors and 1.06 ms^{-2} in original loading machines. The rms total acceleration values of whole body vibration transmitted to the operator were below the exposure limit value (1.15 ms^{-2}) with 1.06 ms^{-2} for original loading machines and above exposure limit value with 1.38 ms^{-2} for tractors on which loading equipment is mounted.

A lot of researches were carried out about agricultural tractor operators' exposure to high levels of WBV (Lines et al., 1995; Scarlett et al., 2002; Griffin, 2006). Vibration has been proven to result in musculoskeletal disorders of both the hand and arm, the neck, and the back. An epidemiological study indicated that tractor driving was significantly related to an increased risk for low-back symptoms (low-back pain, sciatic pain, etc.) (Bovenzi and Betta, 1994).

Regression analysis was performed to determine the factors affecting the total vibration values transmitted to the operator. Vibration value was classified as a dependent variable, and the variables related to the vibration value were labeled as independent variables for the scope of the analysis.

The coefficient of determination (r^2) of the obtained model was calculated as 0.546. The regression equation (3) obtained at the end of the analysis by using eight variables is as follows:

$$Y = 2.016 - 0.305\, m_t + 0.104\, g_r + 0.009\, w_f - 0.322\, g_t - 0.017\, s_d - 0.135\, s_c + 0.059\, w_a - 0.005\, o_w \quad (3)$$

The dependent variable of the rms acceleration value (a_t) transmitted to the operators while working with loading machines (***Y***) was explained at a 55% rate and by using the independent variables of machine type ($\boldsymbol{m}_t$), ground roughness condition ($\boldsymbol{g}_r$), front wheel pressure ($\boldsymbol{w}_f$), ground type ($\boldsymbol{g}_t$), seat use duration ($\boldsymbol{s}_d$), seat use condition ($\boldsymbol{s}_c$), working area breadth ($\boldsymbol{w}_a$), and operator weight ($\boldsymbol{o}_w$). The regression analysis graphic for the obtained model is shown in Figure 4.

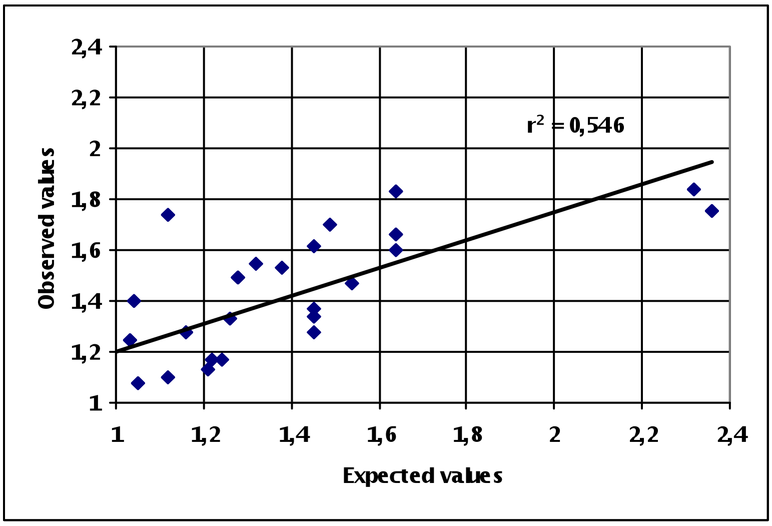

Figure 5. Regression analysis diagram of vibration values

It was observed that the value of vibration transmitted to the operator was lower in original loading machines compared to the agricultural tractors on which loading equipment is mounted. Also, vibration value was lower in the operations carried out on the grounds that were covered with stabilized material and were made smooth. Moreover, in the loading machines having a good suspension system and an automatic mass adjustment mechanism, the vibration values transmitted to the operator were lower compared to the ones lacking these features.

4. Conclusion

The mean of the total vibration value was found 1.38 ms^{-2} in loading equipment mounted tractors and 1.06 ms^{-2} in original loading machines. The regression analysis was performed in order to determine the most important factors affecting total vibration value transmitted to the tractor operator. The most important factors affecting the total vibration value were machine type, ground roughness condition, ground type, wheel pressure, seat condition and operator weight. In the region, the use of original loading machines should be encouraged. The operator seats having an automatic mass adjustment mechanism should be used. The roughness of the ground should be reduced by covering the ground of forest depots with stabilized material.

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