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CONSIDERATIONS REGARDING VIBRATIONS LEVEL OF A SICKLE BAR MOWER DURING WORK

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Abstract: Hand operated equipment usually generates vibrations which in time could endanger the operator's health. In order to assure operator's safety, the vibration level which is generated has to be under the safety limits. Thus, the vibrations usually are measured according to applicable standards, and if they exceed the limits, there has to be adopted measures in order to mitigate the negative effects by vibrations absorption or insulation. Within this paper are presented the vibration measured results for a 6 kW sickle bar mower during mowing works. The researches were done in order to assess the vibration level and to identify a way to reduce those vibrations. The experiments were performed on the experimental plots from INMA Bucharest. The raw accelerations data were recorded and processed in order to obtained the vibrations RMS values. Furthermore, there were made changes on the structural design of the mower in order to reduce de vibration level and the measurements were repeated.
Keywords: vibration level, sickle bar mower, vibration absorption

1. INTRODUCTION

Vibrations level produced by many handheld equipment is largely enough to cause lesions occurrence when used for a long-time during work program. Vibrations could be transmitted to the body through an arm or both arms simultaneously, causing discomfort al inferior level and reducing work efficiency. Gravity of biological effects of hand-arm transmitted vibrations, is influenced by many factors such as: exposure time, working process, daily exposure rate, vibrations direction as also the direction of the force applied by the worker to the used tool's handles: angles of the fingers, hand, fist, elbow and shoulder joints (Antonov et al. 2013).

Agricultural equipment which is usually handled by hand such as rototillers, trimmers, chainsaws, mowers etc. are usually powered by a thermal engine (gasoline or diesel) which represents the main source of vibrations together with the transmission system. In case of sickle bar mower, the engine's vibration is amplified by the sickle bar movement during work, which is on a perpendicular direction with the forward moving direction. This causes a high amount of vibration to be felt by the worker, almost in every case exceeding the imposed limits through European directives and standards (Monarca et al. 2008, D 2002/44/EC; Postelnicu et al., 2013).

In order to reduce the vibration level, there are some theoretical measures which could be used to modify the structural design of the machines like adding additional auxiliary mass or using a dynamic damping system (Ene and Pavel 2008, Harris and Crede 1968). However, theory assumes some initial simplifying hypothesis which in real-life situations couldn't be applied.

Usually, vibration isolation or absorption issues are tackled in a more empirical way, applying trial and error algorithms in order to mitigate vibrations effects. After every structural change the engineer checks whether the change really lowered the vibration level. Thus, vibration measurement is a powerful instrument to assess the design of agricultural equipment and its dynamic response during simulation and real-life tests (Sfîru et al. 2014; Biriş et al., 2016a; Biriş et al., 2016b; Pruteanu et al., 2015; Stoica et al., 2015; Vlăduţ et al., 2014; Vlăduţ et al., 2015). There are researchers which assessed handheld equipment compliance with regulations regarding vibration effect on the operator (Monarca et al. 2008, Sorica et al. 2017; Vlăduţ et al., 2006; Vlăduţ et al., 2009; Vlăduţ et al., 2013) which used the measuring method mentioned in (EN ISO 5341-2 Mechanical vibration). After making structural changes whether the structural changes really lowered the vibration level.

Within this paper are presented researches done on a 6 kW sickle bar mower before and after some structural changes made in order to lower the vibration level during mowing work, applying a theoretical-empirical method for identifying the principal vibrations source and adding auxiliary damping mass. The vibrations were then assessed from the worker's exposure level to hand transmitted vibrations (EN ISO 5341-1 Mechanical vibration).

2. MATERIALS AND METHODS

For experiments we used a 138 kg sickle bar mower configured with a 115 cm wide, centrally mounted cutterbar, for semi-professional users. The model was used mainly for cutting grass and field cleaning. It was powered by a 9 HP gasoline engine, with a maximum speed of 3600 rpm. The mower was fitted with height-adjustable handlebars which were fixed in middle position.

Vibration measurements were performed on both handlebars near the worker's hand and near the cutterbar, on the eccentric actuating mechanism of the cutterbar using three triaxial accelerometers from PCB, model 356B10, using mounting methods provided in [8]. The Ox axis was parallel with the longitudinal direction of the mower, the Oy axis corresponded to the movement of the cutterbar and Oz direction was perpendicular on the soil.

Figure 1. Sickle bar mower

Figure 2. Accelerometer mounting positions – left handlebar, right handlebar, cutterbar

The data acquisition system used was Sirius provided by DEWESOFT with dedicated conditioning and data acquisition software. The accelerometers calibration was performed using a Type 4294 Calibration Exciter with 10 m/s^2 r.m.s. acceleration at 159.2 Hz. It was used a 10 kHz sample rate for continuously data acquisition, the recorded data being saved in ASCII files.

Experiments were performed on the experimental field from INMA Bucharest, cutting grass with height between 0.7 and 1 m, on 50 m long tracks. One worker was handling the mower while the researcher was carrying the data acquisition system and the laptop for measurements. The measurements were performed with the mower standing still and the cutterbar working, and with the mower shifted in first and second gear, and the cutterbar working, trying for the throttle lever to be fixed in almost the same position.

Figure 3. Aspects during experiments

Vibrations were measured by measurements of acceleration. The unit of measurement was m/s^2. The weighted accelerations on the three perpendicular directions of the orthogonal measuring system: a_{hwx}, a_{hwy}, a_{hwz} were calculated for both right and left handlebars. The total vibration value, a_{hv} was calculated for each handlebar of the sickle bar mower.

$$a_{hv} = \left[\left(a_{hwx}{}^2 + a_{hwy}{}^2 + a_{hwz}{}^2\right)\right]^{\frac{1}{2}} \quad (1)$$

In order to obtain the weighted vibration data for each channel, the method from annex A, part 2 was used, the weighted vibration being computed as in relation 2:

$$a_{hw} = \left[\sum_i (W_{hi} a_{hi})^2\right]^{\frac{1}{2}} \quad (2)$$

where: W_{hi} represents the weighing factor for third octave band i, as in table A.2 from [5].
a_{hi} represents the r.m.s. acceleration measured in the i – th third octave band.

In figure 4 is presented the calculus sheet made in Glyphworks which allowed for each third octave band to compute the weighted vibration as in relation (2). Afterwards, the obtained data for each axis of both accelerometers used on the handlebars were computed in Excel to obtain the total vibration values according to relation (1).

The vibration values for the third accelerometer placed near the cutterbar were computed only as r.m.s using the same calculus sheet as in figure 4.

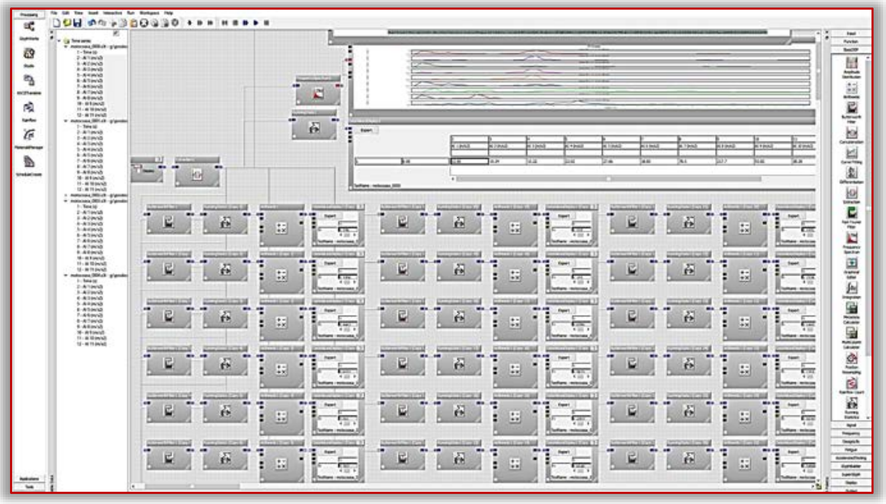

Figure 4. Weighted vibration data calculus sheet

In order to reduce the vibration level, the cutterbar was identified as the main vibration source. As mean for vibration damping it was chosen the auxiliary mass method. For this to be achieved, there were realized several additional weights to be mounted on top of the cutterbar through means of rubber supports and the experiments were repeated. The main goal was to reduce the vibration level without affecting the mowing performance.

3. RESULTS

In figure 5 are presented the raw vibrations evolution in time measured by all three accelerometers, on the left handlebar (AI1 - Ox axis, AI2 -Oy axis, AI3 - Oz axis), right handlebar (AI4 - Ox axis, AI5 -Oy axis, AI6 - Oz axis) and on the cutterbar (AI7 - Ox axis, AI8 -Oy axis, AI9 - Oz axis.

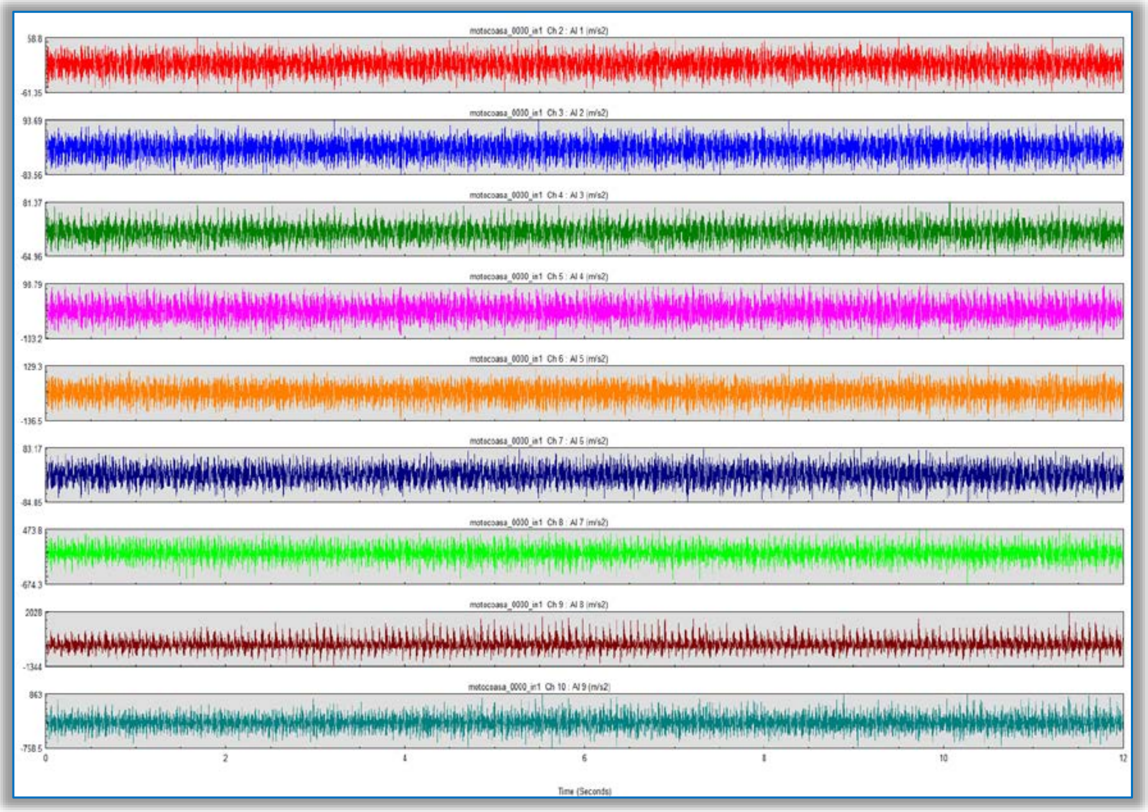

Figure 5. Raw vibrations measured on the sickle bar mower functioning but not moving

It can be observed the high difference between the handlebars vibrations amplitudes and the ones of the cutterbar, especially on Oy direction which corresponds to the bar movement, fact which concludes that the main source of vibrations is the cutterbar. However, all vibrations are extremely high for a human operator to handle, even after application of weighing filter. In table 1 are presented the r.m.s. values obtained for vibration during experiments. The total vibration was computed using relation (1) for the handlebars and cutterbar with the mention that for the later were used the unweighted values of vibration obtained for all three axes.

Table 1. R.M.S. Values of measured vibrations without auxiliary weights

	Left handlebar weighted vibration			Right handlebar weighted vibration			Cutterbar unweighted vibration		
Experiment	Ox (m/s^2)	Oy (m/s^2)	Oz (m/s^2)	Ox (m/s^2)	Oy (m/s^2)	Oz (m/s^2)	Ox (m/s^2)	Oy (m/s^2)	Oz (m/s^2)
Standing still	6.72	6.06	12.01	8.52	7.08	14.49	78.5	217.7	93.82
Total vibration	15.03			18.24			249.71		
First gear	7.02	6.85	12.65	8.94	7.54	14.89	81.43	275.2	110.2
Total vibration	16.00			18.93			307.42		
Second gear	6.88	6.42	12.32	8.57	6.99	14.78	73.11	264.3	92.32
Total vibration	15.50			18.46			289.35		

In all observed cases (standing, first and second gear moving), the r.m.s. values are high and although they depend on the throttle lever's position, the achieved engine speeds were sufficient for functioning in real life exploitation conditions. As observed, the weighted total vibration values are exceeding the limit imposed by Directive 2002/44/EC and means for vibration reduction were sought afterwards. Also, it can be noticed that the movement of the mower through the grass field has a very small impact on the total weighted vibration value as the difference between the standing still case and the first and second gear movement cases are below 7%, fact which allowed for the vibration reduction experiments to be performed only on the standing still mower.

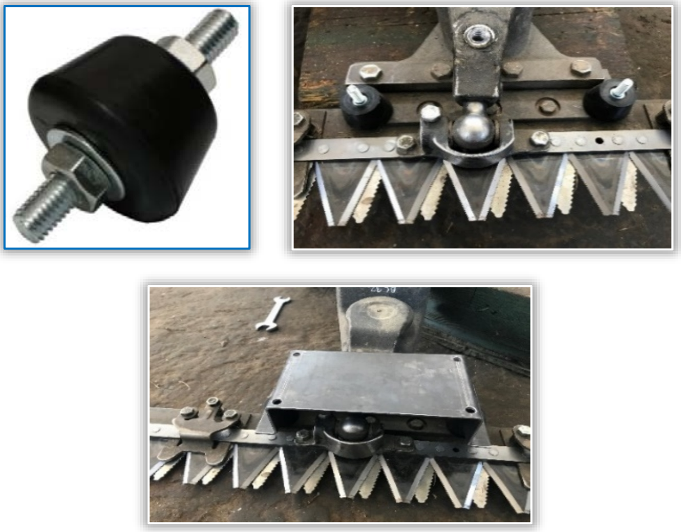

Figure 6. Rubber absorber and mounting of the support plate for the auxiliary weights

Figure 7. Auxiliary weights placement on the sickle bar

There were identified on the cutterbar two points on which some rubber vibration absorbers could be mounted and on top of them was designed a metal sheet support for the auxiliary weights to be added.

The following experiments were performed on the standing still mower, only with the sickle bar actuated. Were added additional auxiliary weights of 20, 40 and respectively 60 kg. It was used the same methodology for vibration assessment.

In table 2 are presented the obtained results as r.m.s values for the measured vibrations.

Table 2. R.M.S. Values of measured vibrations with auxiliary weights

	Left handlebar weighted vibration			Right handlebar weighted vibration			Cutterbar unweighted vibration		
Auxiliary weight experiment	Ox (m/s^2)	Oy (m/s^2)	Oz (m/s^2)	Ox (m/s^2)	Oy (m/s^2)	Oz (m/s^2)	Ox (m/s^2)	Oy (m/s^2)	Oz (m/s^2)
20 kg	6.44	5.76	10.04	7.54	6.68	12.34	74.43	200.42	84.52
Total vibration	13.24			15.93			229.89		
40 kg	5.88	4.98	8.87	7.01	6.14	10.87	70.24	189.21	82.36
Total vibration	11.75			14.32			217.98		
60 kg	5.31	4.67	6.44	6.43	5.32	8.84	67.34	170.34	76.29
Total vibration	9.56			12.16			198.42		

4. CONCLUSIONS

The paper presented measurements performed for assessment of vibrations level of a sickle bar mower during work and a method for reducing these vibrations.

In the first phase, the measured values exceeded the limits imposed by European Directive 2002/44/EC, meaning that the operator's health was endangered.

After applying the auxiliary mass method in order to reduce vibrations, the new measured results on the handlebars were reduce with about 35% with the sickle bar loaded with 60 kg of auxiliary weight. The main vibration reduction was on the Oy axe, due to the positioning of the auxiliary weight alongside this axis. Also was observed a significant reduction on the Oz axis due to the auxiliary G force exerted by the auxiliary mass. However, the auxiliary weight was only distributed on top of the sickle bar, fact which will hinder the mower to function properly. In future researches there will be identified a way to spread the weight over the entire structure of the mower.

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