CONSIDERATIONS REGARDING THE VIBRATIONS TRANSMITTED TO THE OPERATOR BY AN AXIAL FLOW HARVESTER COMBINE
/
CONSIDERAŢII PRIVIND VIBRAŢIILE TRANSMISE OPERATORULUI DE O COMBINĂ CU FLUX AXIAL

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ABSTRACT

Vibrations are dynamic phenomena occurring in elastic or quasi-elastic media after a local excitation and becoming manifested by propagating the excitation within the medium in the form of some elastic oscillations. Thus, depending on the phenomenon dynamics, there can be met vibrations with low variation frequencies, characteristic to the mechanical structures, structures in constructions and earthquake waves, as well as vibrations with high variation frequencies. The vibration measuring is performed on a straw cereal harvesting machine with an axial threshing apparatus ("CASE IH") in two conditions: in a stationary position and during work, by using transducers for each of the main working parts of the harvester: thresher, header (stripper), chassis and operator's chair. On the basis of the values of longitudinal, cross and vertical accelerations, measured at various frequencies in the two operating conditions of the harvester (at stationary and during work), the effect of the vibrations is established on each of these parts and, finally, cumulated, the vibrations sent to the operator's chair, the nomograms following to be traced and to be established the range with the limits up to which these are not dangerous for the operator's health.

REZUMAT

Vibraţiile sunt fenomene dinamice care iau naştere în medii elastice sau cvasielastice în urma unei excitaţii locale şi care se manifestă prin propagarea excitaţiei în interiorul mediului sub forma unor oscilaţii elastice. Astfel, în funcţie de dinamica fenomenului se întâlnesc vibraţii cu frecvenţe de variaţie scăzute, caracteristice structurilor mecanice, structurilor din construcţii şi undelor seismice, precum şi vibraţii cu frecvenţe mari de variaţie. Măsurarea vibraţiilor se realizează pe o combină de recoltat cereale păioase cu aparat de treier axial (CASE IH), în două condiţii: la staţionar şi în lucru, utilizându-se traductori pentru fiecare din principalele organe de lucru ale combinei: batoză, heder, şasiu şi scaunul operatorului. Pe baza valorilor acceleraţiilor longitudinale, transversale şi verticale măsurate la diferite frecvenţe în cele două condiţii de funcţionare a combinei (la staţionar şi în lucru) se stabileşte efectul vibraţiilor asupra fiecărui dintre aceste organe şi în final, cumulat, vibraţiile transmise la scaunul operatorului, urmând să se traseze nomogramele şi să se stabilească domeniul cu limitele până la care acestea nu sunt periculoase pentru sănătatea operatorului.

INTRODUCTION

Agriculture provides food, raw materials for other industries and employment opportunities. As a consequence, given the key role of agriculture in global economy, safety and health of its employees are regarded to be of major importance (*Benos L. et al, 2020*).

Vibrations are dynamic phenomena that arise in elastic or quasi-elastic environments following a local excitation and which are manifested by the propagation of the excitation inside the environment in the form of elastic oscillations (*Brăcăcescu C. et al., 2017; Postelnicu et al., 2017; Vlădut V. et al, 2013; Vlădut V. et al, 2014; Vlădut V. et al, 2021*) and they can produce a wide variety of different effects to the machine operators. The effects on the operator exposed to a high vibration level for a longer period of time are usually permanent in character and are therefore considered to be an occupational disease leading to invalidity (*Goglia V. et al, 2006*). Vibration is a complicated movement for the human body to react to, and some factors including vibration magnitude, frequency, duration time, input position, etc., are especially significant to the effects. It appears that some environmental elements, including light, heat and noise, are also relative to the effects of vibration (British Standards 6481, 1987; *ISO 2631/1, 1985; Brüel & Kjaer, 1984*; *Liang X.C. et al, 2018*).

Frequent exposure to vehicle-and equipment-induced whole body vibration (WBV) is common in agriculture, mining, construction and many other heavy industries. In agriculture, specifically, WBV exposure is highly prevalent during operation of machinery and transport vehicles (*Yung M. et al, 2018*).

Combine harvesters have been playing an important role in modern agricultural production in recent years, their working process is divided into the cutting of the crop and recovering grains from the field, separating grains from the greater crop parts such as straw and separating grains from material-other-than grain (MOG), then collecting cleaned grains in a tank for temporary storage or directly in a bags (*Hamed A.R., 2016*).

Whole-body vibration (WBV) is defined as vibration occurring when a greater part of the body weight is supported on a vibrating surface. WBV principally occurs in vehicles and wheeled working machines, such as combine harvesters. In most cases exposure to WBV occurs in a sitting position and the vibration is then primarily transmitted through the seat pan, but also through the seatback (*Rahmatalla S. et al, 2011*).

Biodynamics of seated human subjects has been a topic of interest over the years, and a number of mathematical models have been established. The concept of absorbed energy was discussed in the mid-1960's by a group of scientists who presented results from investigations which indicated that the subjective experience of vibration is related to the amount of vibration energy absorbed by the body (*Szczepaniak J. et al, 2014*).

Whole body vibration is a reflection of the comfort limitations of agricultural machinery and is subjectively assessed by their drivers or passengers. The effects of mechanical vibration are determined by the frequency of vibrations, magnitude, directions and duration of time. Humans have different sensations of vibration and different parts of the human body resonate at different frequencies. Whole body vibration (WBV) exposures are often predominant in the fore-aft (x) or lateral (y) axis among off-road agricultural vehicles. However, as the current industry standard seats are designed to reduce mainly vertical (z) axis WBV exposures, they may be less effective in reducing drivers' exposure to multi-axial WBV (*Kim H. et al, 2018*).

The European Directive 2002/44/CE on the minimum health and safety requirements regarding the exposure of workers to the risks arising from vibrations impose specific requirements for the safety of workers exposed to mechanical vibrations (*Matache M.G. et al, 2020*). Through this directive two exposure indicators for whole-body vibration have been defined:

- the daily exposure limit value standardised to an eight-hour reference period shall be 1.15 m/s^2 or, at the choice of the Member State concerned, a vibration dose value of 21 m/s1.75;
- the daily exposure action value standardised to an eighthour reference period shall be 0.5 m/s^2 or, at the choice of the Member State concerned, a vibration dose value of 9.1 m/s1.75.

Fig.1 - The ortogonal measuring directions that effect driver WBW, (*Vlăduţ V. et al, 2021*)

Long-term exposure to WBV can be connected with an increased risk of numerous diseases affecting the back, digestive, circulatory and nervous systems, sexual and urinary systems. The exposure to WBVs at work clearly relates also to the increased risk of lumbar pains, the pain of the sciatic nerve and disorders of lumbar intervertebral discs as well as musculoskeletal symptoms in the area of the neck and shoulders. WBV can also cause the loss of tenderness in the limbs as well as skeletal and gastrointestinal disorders. Some symptoms of disorders may also appear in the form of fatigue, insomnia and tremor.

Apart from health effects, exposure to vibrations may impair the performance of operators, particularly in activities with high demands on accuracy that are characteristic of the operation of forest machines as well as harvesters (*Luboš S. and Václav M., 2022*).

MATERIALS AND METHODS

In order to measure the vibrations occurring at the stationary and during the working process on the combine, the longitudinal, transverse and vertical accelerations are measured, corresponding to the three directions of measurement: *x*, *y* and *z*. These accelerations (their size), as well as the frequencies at which they manifest, are measured by means of accelerometers glued to the main parts of the combines that produce vibrations, such as: the threshing apparatus, the chassis and the header to those with axial flow. Subsequently, the vibrations transmitted by these working parts to the seat of the combine and thus to the operator who leads the combine are measured, in order to be able to determine how and the value with which they affect his health.

The establishment of the main requirements and of the measurement points is made taking into account the work conditions, the interaction between the working parts and the field as well as between the constructive elements of the combine, its operating regime, or other requirements. The measurement points where the transducers (accelerometers) are to be placed shall be established either by analytical methods or by using modeling (the finite element method).

Transducers (accelerometers) are mounted on flat surfaces, if possible without inclinations, as close as possible to the working part whose vibrations are intended to be measured. They are not mounted directly on these working parts because most of the working parts of the combine that produce vibrations are in motion: the central conveyor, the cleaning system, the rotor, etc.

The main purpose of the measurements is to determine to what extent the vibrations produced by the main parts of the combine affect the health of the person serving it. For this purpose, the vibrations transmitted to the support of the combine seat are measured (figure 2).

Fig. 2 - Transducers mounted on the combine seat

In order to measure the vibrations produced by the CASE-IH 2388 axial flow harvester (figure 3, 4), the vibrations transmitted by its main working parts to the operator's seat were determined.

The vibrations transmitted to the operator's seat represent the vibrations produced by the threshing cylinder, the header and the other parts of the harvester, transmitted through the chassis to the operator's cab and then from the platform to the seat.

The measurements were done using Bruel & Kjaer type accelerometers, an analog amplifier device, DAP 2400 data acquisition system (*Broch J.T, 1980*), and a laptop, measuring longitudinal, transverse and vertical accelerations for the two operating conditions in which significant vibrations occur: at stationary and at work (when harvesting wheat).

Fig.3 - CASE-IH combine, front view

Fig.4 – CASE-IH combine, perspective view

RESULTS

Vibrations were measured on the chassis, header and thresher on the three orthogonal (x, y, z) axes, during motion and in stationary position. It was found that the level of vibrations transmitted did not endanger the health of the human operator.

The following accelerations were measured for the thresher:

Table 1

Acceleration values measured for the thresher

f [Hz]			1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	*40*	50	63	80
CASE - IH	thresher *s*	L	0.011	0.006	0	0	0	0	0.016	0.04	0.03	0.02	0.02	0.02	0.008	0.02	0.02	0.07	0.03	0.06	0.17	***0.68***
		T	0	0	0	0	0	0	0	0	0	0.03	0.15	0.16	0.03	0	0.04	0.33	0.1	0.46	2.89	***3.12***
		V	0	0	0	0	0	0	0.05	0.05	0.05	0.03	0.06	0.07	0.05	0.04	0	0.73	0.08	0.18	0.96	***2.75***
	thresher *w*	L	0.06	0.05	0.03	0.02	0.02	0.016	0	0.04	0.14	0.016	0.02	0.03	0.01	0.02	0.02	0.02	0.06	0.03	0.06	***0.16***
		T	0.08	0.08	0.03	0.03	0.03	0.02	0	0	0.02	0.05	0.18	0.08	0.04	0.05	0.12	0.21	0.16	0.55	***2.32***	2.21
		V	0.06	0.08	0.05	0.07	0.08	0.08	0.05	0.05	0.03	0.05	0.06	0.06	0.06	0.08	0.03	0.25	0.08	0.21	0.88	***1.75***

**s - stationary position, w - while working*

Figure 5 shows the longitudinal accelerations-a_x, the range of dangerous frequencies being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 0.68 m/s at 80 Hz > 24h;
- CASE-IH combine while working: 0.16 m/s at 80 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

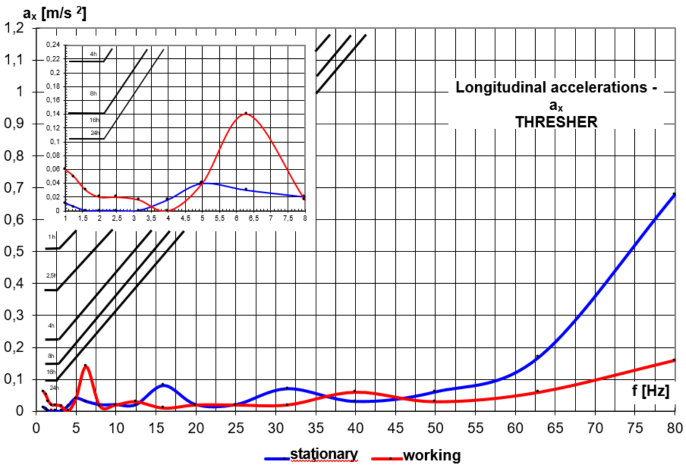

Fig. 5 - Thresher longitudinal accelerations, CASE-IH combine in stationary position and while working

Figure 6 shows the transverse accelerations - a_y, the range of dangerous frequencies being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 3.12 m/s^2 at 80 Hz > 24h;
- CASE-IH combine while working: 2.32 m/s^2 at 63 Hz > 24h;

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

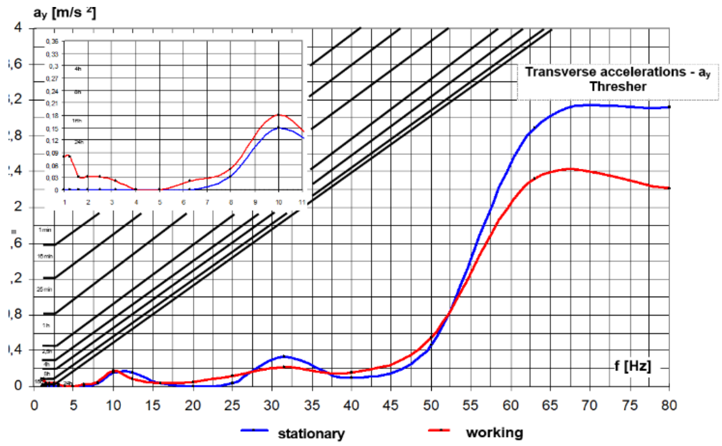

Fig. 6 - Thresher transverse accelerations, CASE-IH combine in stationary position and while working

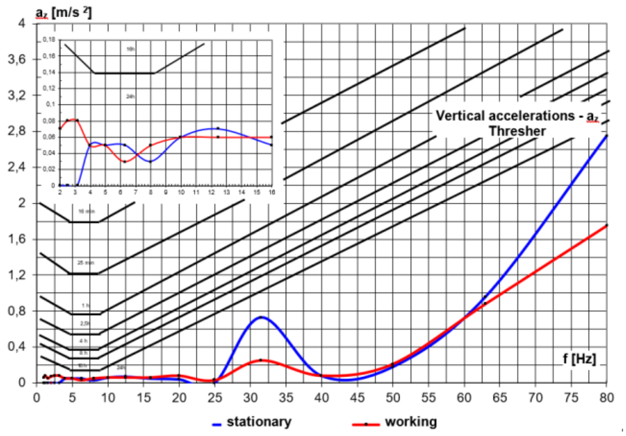

Fig. 7 - Thresher transverse accelerations, CASE-IH combine in stationary position and while working

Figure 7 shows the vertical accelerations – a_z, the range of dangerous frequencies being between 2.5 and 10 Hz. The maximum accelerations were:

- CASE-IH combine in stationary position: 2.75 m/s^2 at 80 Hz > 24h;
- CASE-IH combine while working: 1.75 m/s^2 at 80 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

For the **CHASSIS**, the following accelerations were measured:

Table 2

Acceleration values measured for the chassis

f [Hz]			1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	*40*	50	63	80
CASE - IH	Chassi	L	0	0	0.005	0.007	0.007	0.008	0.017	0.028	0.03	0.012	0.014	0.014	0.014	0.034	0.029	0.037	0.033	0.047	0.10	*0.21*
		T	0	0	0	0	0	0	0	0	0	0	0	0	0.018	0.018	0	0.23	0.06	0.31	0.71	*2.04*
		V	0	0	0	0	0	0.008	0.03	0.037	0.03	0	0.034	0.034	0.034	0.034	0.037	0.22	0.06	0.34	0.22	*0.97*
	Chassi	L	0.07	0.066	0.044	0.051	0.058	0.025	0	0.045	0.018	0.026	0.028	0.03	0.035	0.028	0.03	0.04	0.03	0.07	0.12	*0.28*
		T	0.09	0.065	0.065	0.065	0.038	0.038	0.038	0.021	0	0	0.19	0.08	0.06	0.13	0.04	0.12	0.12	0.49	1.0	*2.37*
		V	0.09	0.08	0.10	0.18	0.24	0.11	0.06	0.05	0.04	0.06	0.11	0.07	0.07	0.13	0.05	0.18	0.05	0.12	0.28	*0.45*

**s - stationary position, w - while working*

Figure 8 shows the longitudinal accelerations - a_x. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 0.21 m/s^2 at 80 Hz > 24h;
- CASE-IH combine while working: 0.28 m/s^2 at 80 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

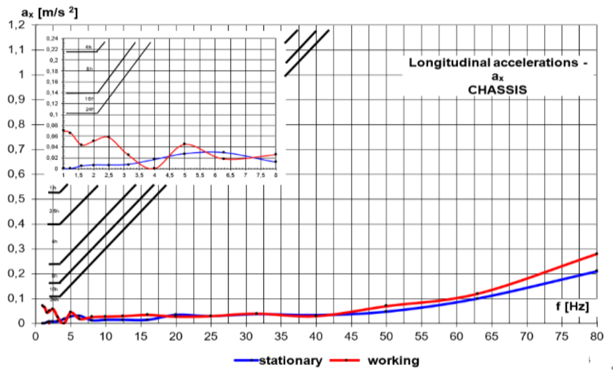

Fig. 8 - Chassis longitudinal accelerations, CASE-IH combine in stationary position and while working

Figure 9 shows the transverse accelerations - a_y, the range of dangerous frequencies being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 2.04 m/s^2 at 10 Hz > 24h;
- CASE-IH combine while working: 2.37 m/s^2 at 10 Hz > 24h;

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

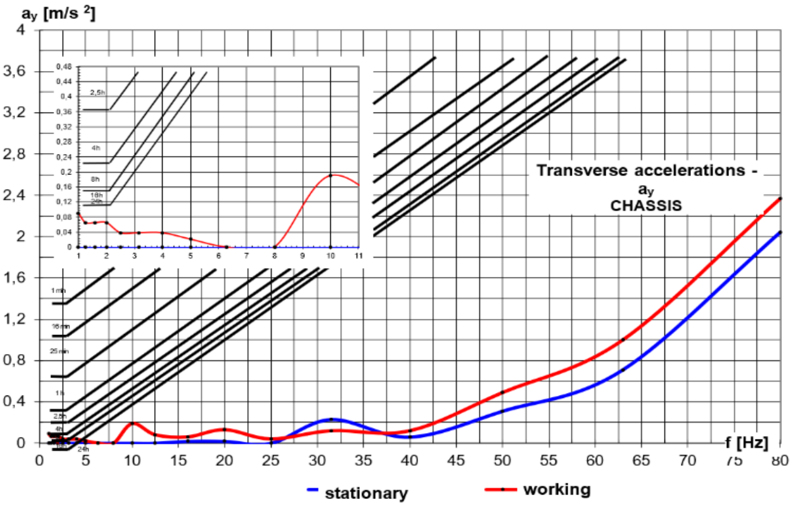

Fig. 9 - Chassis transverse accelerations, CASE-IH combine in stationary position and while working

Figure 10 shows the vertical accelerations - a_z, the range of dangerous frequencies being between 2.5 and 10 Hz. The maximum accelerations were:

- CASE-IH combine in stationary position: 0.97 m/s^2 at 80 Hz > 24h;
- CASE-IH combine while working: 0.24 m/s^2 at 2.5 Hz ≤ 16h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

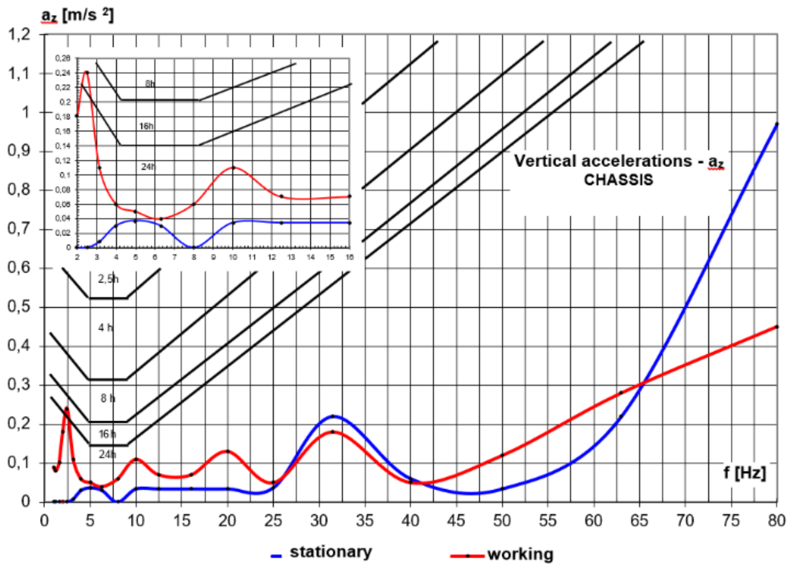

Fig. 10 - Chassis vertical accelerations, CASE-IH combine in stationary position and while working

For the **HEADER,** the following accelerations were measured:

Table 3

Acceleration values measured for the header

f [Hz]			1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	*40*	50	63	80
CASE - IH	Header s	L	0	0	0	0	0	0.01	0.03	0.025	0.03	0.02	0.02	0.02	0.01	0.02	0.023	0.06	0.05	0.09	0.12	*0.32*
		T	0	0	0	0	0	0	0.01	0.02	0.025	0.037	0.2	0.2	0.03	0.07	0.08	0.24	0.11	0.22	0.31	*0.53*
		V	0	0	0	0	0	0.023	0.08	0.02	0.02	0.06	0.22	*0.25*	0.05	0.08	0.08	0.34	0.15	0.3	0.3	*0.51*
	Header w	L	0.06	0.06	0.04	0.03	0.05	0.03	0.05	0.02	0.03	0.02	0	0.02	0.02	0.02	0.02	0.04	0.06	0.09	0.21	*0.27*
		T	0.05	0.07	0.10	0.07	0.05	0	0	0.04	0.04	0.04	0.15	0.05	0.05	0.17	0.08	0.43	0.13	0.41	0.34	*0.62*
		V	0.13	0.15	0.14	0.11	0.11	0.07	0.08	0.06	0	0.07	0.16	0.07	0.08	0.19	0.08	0.22	0.21	0.43	0.47	*0.59*

**s -stationary position, w - while working*

Figure 11 shows the longitudinal accelerations - a_x, the range of dangerous frequencies for this type of acceleration being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 0.32 m/s^2 at 80 Hz > 24h;
- CASE-IH combine while working: 0.27 m/s^2 at 80 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

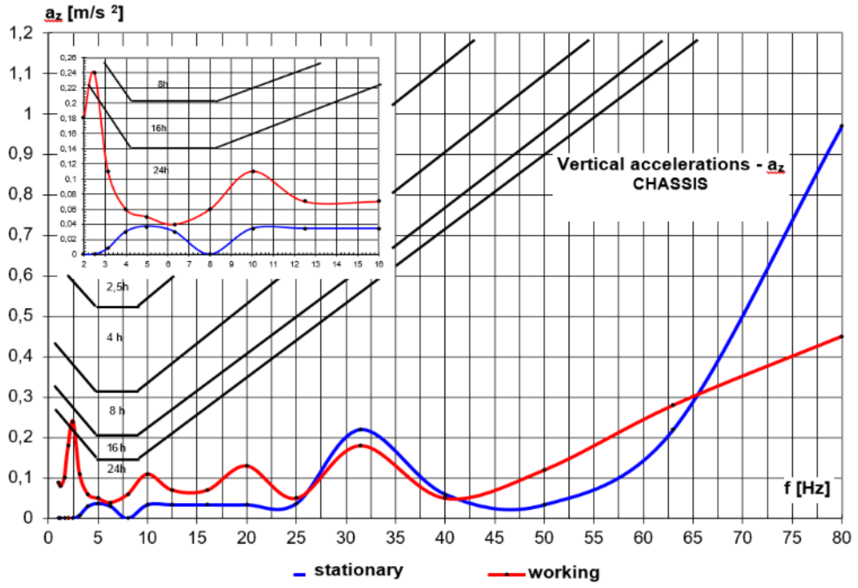

Fig. 11 - Chassis vertical accelerations, CASE-IH combine in stationary position and while working

Figure 12 shows the transverse accelerations - *ay*, the range of dangerous frequencies being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 0.53 m/s^2 at 80 Hz > 24h;
- CASE-IH combine while working: 0.62 m/s^2 at 80 Hz > 24h;

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

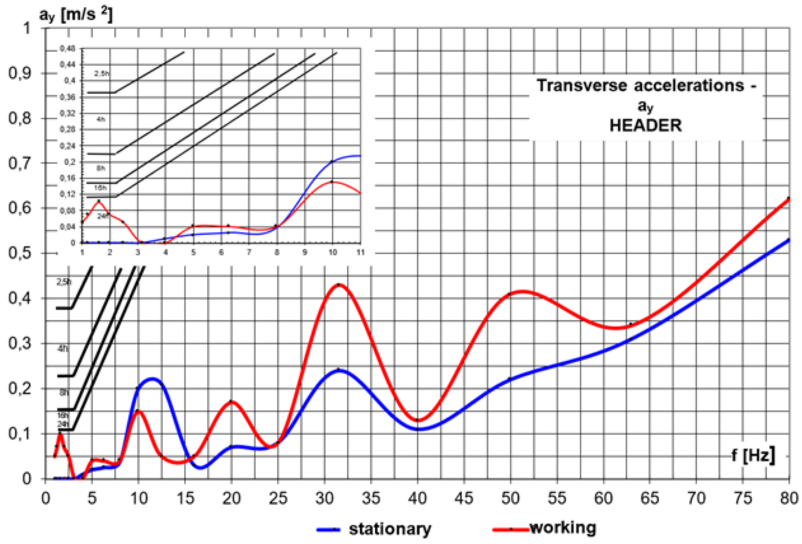

Fig.12 - Header transverse accelerations, CASE-IH combine in stationary position and while working

Figure 13 shows the vertical accelerations - a_z, the range of dangerous frequencies being between 2.5 and 10 Hz. The maximum accelerations were:

- CASE-IH combine in stationary position: 0.25 m/s^2 at 12.5 Hz ≤ 16h;
- CASE-IH combine while working: 0.59 m/s^2 at 80 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

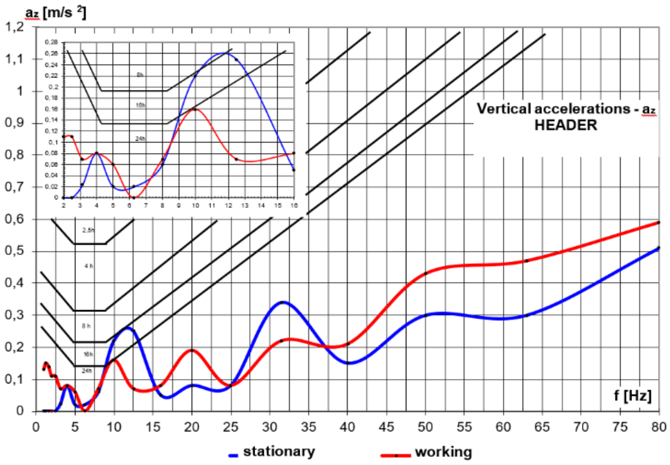

Fig.13 - Header vertical accelerations, CASE-IH combine in stationary position and while working

For the **SEAT**, the following accelerations were measured:

Table 4

Acceleration values measured for the seat

f [Hz]			1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	*40*	50	63	80
CASE-IH	Seat	s L	0.007	0.007	0.008	0.008	0.011	0.015	0.016	0.018	0.019	0.018	0.036	0.036	0.036	0.04	0.05	0.21	0.08	*0.42*	0.07	0.08
		T	0.007	0.008	0.01	0.012	0.012	0.014	0.014	0.026	0.058	0.07	0.022	0.031	0.17	0.16	0.11	*0.23*	0.08	0.09	0.07	0.11
		V	0.023	0.028	0.026	0.029	0.03	0.05	0.05	0.05	0.06	0.06	0.10	0.09	0.08	0.09	0.11	0.32	0.13	*0.43*	0.17	0.24
	Seat	w L	0.09	0.09	0.06	0.04	0.05	0.04	0.05	0.04	0.04	0.06	0.06	0.07	0.05	0.07	0.07	0.13	0.08	*0.47*	0.08	0.11
		T	0.10	0.10	0.07	0.04	0.04	0.06	0.14	0.08	0.10	0.09	*0.28*	0.13	0.22	0.28	0.21	0.16	0.08	0.10	0.12	0.11
		V	0.17	0.18	0.17	0.014	0.16	0.16	0.09	0.07	0.07	0.09	0.11	0.10	0.12	0.14	0.13	0.18	0.12	*0.34*	0.16	0.19

**s - stationary position, w - while working*

Figure 14 shows the longitudinal accelerations - a_x, the range of dangerous frequencies for this type of acceleration being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 0.42 m/s^2 at 50 Hz > 24h;
- CASE-IH combine while working: 0.47 m/s^2 at 50 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

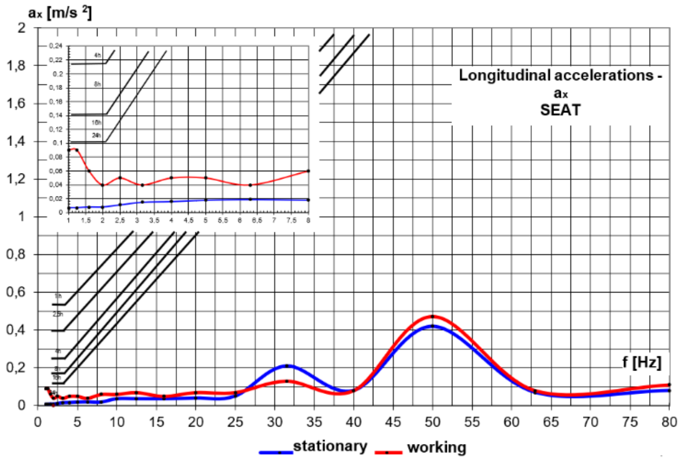

Fig. 14 - Seat longitudinal accelerations, CASE-IH combine in stationary position and while working

Figure 15 shows the transverse accelerations - a_y, the range of dangerous frequencies being between 1 and 3.15 Hz. The maximum measured accelerations were:

- CASE-IH combine in stationary position: 0.23 m/s^2 at 31.5 Hz > 24h;
- CASE-IH combine while working: 0.28 m/s^2 at 10 Hz > 24h;

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

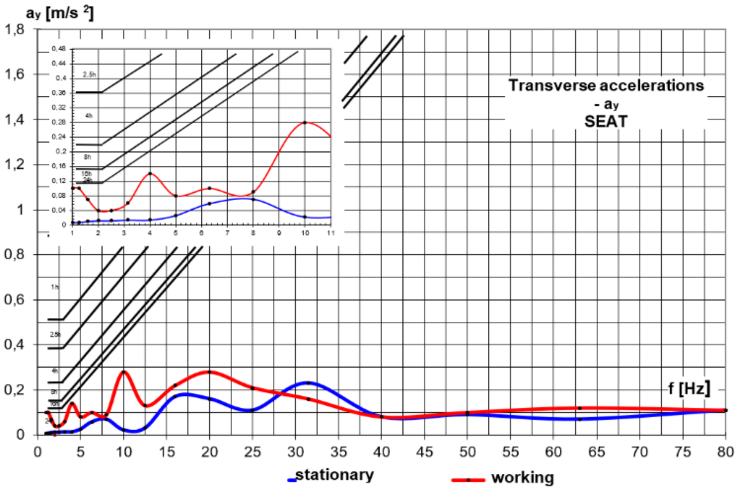

Fig. 15 - Seat transverse accelerations, CASE-IH combine in stationary position and while working

Figure 16 shows the vertical accelerations - a_z, the range of dangerous frequencies being between 2.5 and 10 Hz. The maximum accelerations were:

- CASE-IH combine in stationary position: 0.43 m/s^2 at 50 Hz > 24h;
- CASE-IH combine while working 0.34 m/s^2 at 50 Hz > 24h,

which means that the operator can work without his health being affected, while the combine is working or in stationary position, for 24 hours.

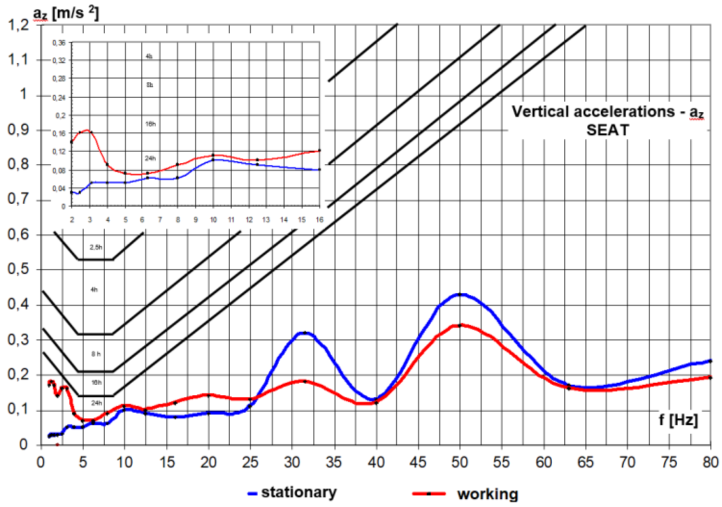

Fig.16 - Seat vertical accelerations, CASE-IH combine in stationary position and while working

CONCLUSIONS

The final value of the vibrations is represented by the value of the vibrations transmitted by the thresher, chassis, and header parts to the seat, because those vibrations directly affect the operator's health.

Following the graphs corresponding to the values of the accelerations on the nomograms, for the SEAT, it results:

- longitudinal accelerations maximum values– a_x (fig.14), were:
  - stationary: 0.42 m/s^2 at 50 Hz;
  - working: 0.47 m/s^2 at 50 Hz,
- transverse accelerations maximum values– a_y (fig.15), were:
  - stationary: 0.23 m/s^2 at 31.5 Hz;
  - working: 0.28 m/s^2 at 10 Hz,
- vertical accelerations maximum values– a_z (fig.16), were:
  - stationary: 1.10 m/s^2 at 40 Hz;
  - working: 0.34 m/s^2 at 50 Hz.

From the nomograms and measurements, it results that for the CASE-IH combine it is possible to work without issues for over 24 hours, continuously, without the vibrations affecting the health of the operator.

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