Comparison between ISO 5008 and field whole body vibration tractor values

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(Article begins on next page)

COMPARISON BETWEEN ISO 5008 AND FIELD WBV TRACTOR VALUES

Roberto Deboli, Angela Calvo, Christian Preti[1]

1. Introduction

Tractor drivers are exposed to high levels of whole-body vibration (WBV) during field operations and on/off road transportation [Bovenzi 1994]. Low-frequency vibration consequences, produced by agricultural vehicles, can be extremely severe and depend on different variables: soil type, field operations, tractor mass distribution and forward speed [Lines 1995; Scarlett 2007; Maytona 2008].

To analyze vibration transmitted at the seat of the tractor driver, many studies have been carried out both in controlled and standardized situations [Banfo 1997; Deprez 2005a; Deprez 2005b; Paddan 2002; Scarlett 2007]. Many of these studies have been done on the basis of the international standard ISO 2631-1: this standard defines the whole body vibration measurement simply giving a methodology to calculate the vibration exposure, but doesn't state judgments nor fix limits.

This standard only furnishes measurement and calculus methodology of vibration for general situation, but doesn't give indications how to measure machines vibration in the real workplace.

Standards EN 1032 and EN ISO/TR 25398 try to afford this problem, without offering simple solutions (for example, these standards do not describe surface characteristics and use statistical analysis to obtain vibration values at the driver seat place).

WBV data analysis in agriculture is moreover more complex than in the industrial field, because it is strictly connected to the surface type and condition, other than machine configuration and performed task. These conditions let vibration data many difficult to be comparable in different situations of same agricultural tasks [Deboli 2008].

Homogeneous data may be obtained using normalized tracks.

ISO 5008 standard has been set up to measure driver vibration on normalized tracks: smoother track (100 m long) and rougher track (35 m long). This standard specifies methods to measure and report WBV at the driver's seat on an agricultural wheeled tractor running on an artificial test track at specified forward speeds. The use of an artificial track is useful to limit the variability of some field parameters: followed path, speed fluctuations, weather, temperature, soil conditions.

To have data for comparative purposes, the best results are obtained if all values are acquired attempting to maintain these variables as nearly constant as possible.

ISO 5008, 'in-field' and 'on-farm' tests have been executed to study WBV on agricultural vehicles at the Silsoe Research Institute [Scarlett 2005]. Purpose of this research was to use the artificial track to simulate field and farm tractor operations. Tractor forward speeds on the ISO smoother track were the standardized ones: 10, 12, 13, 14, 15, 16, 18, 20, 24, 30 km/h. The authors obtained WBV emission levels increased in proportion with forward speed, irrespective of the suspension systems present upon the test vehicles. Subsequently, field works were performed (ploughing, plough transport, cultivating, spraying and trailer transport) and corresponding WBV were measured on tractors. Little resemblances were observed between WBV ISO track and field data, because of the high acceleration values measured on tractors running on the ISO track at the above mentioned standardized speeds.

Analyzing the results of this work, the following question arose: 'Does exist a lower travelling speed for a tractor running on the ISO track which can generate the same vibration level for the

[1] *R. Deboli and C. Preti. Researchers at the Italian National Research Council, Institute for Agricultural and Earthmoving Machinery, Strada delle Cacce 73, 10135, Turin, Italy*

A. Calvo. Researcher at the Department of Agricultural, Forestry and Environmental Economics and Engineering - University of Turin, V. Leonardo da Vinci 44, Grugliasco, Italy

Corresponding author: Roberto Deboli, r.deboli@imamoter.cnr.it, Tel. +39 011 3977710, Fax +39 011 3489218

The contribution of this article is to be equally considered among the authors same tractor working in the field?'. Aim of this work is to find an answer to the previous question. For this reason, three new unballast tractors without implements (as requested by ISO 5008) were used to run on ISO smoother track and on different surfaces, typical of agricultural operations, to analyze WBV values and to compare them.

2. Materials and method

2.1. Tractors

Three tractors new of factory and quite commonly used in different agricultural situations, were tested (Tab.1), A category (78/764/EEC Directive), class I (unladen mass < 3600 kg) and class II (3600 kg < unladen mass < 6500 kg). All of them were without cab and axle suspension systems. For this reason, soil asperity was only filtered by tires.

Tractor A was two-wheel drive equipped with radial tires and tractors B and C were four-wheel-drive equipped with low profile tires. All vehicles were fitted with parallelogram-type suspension seats embodying mechanical spring and damper suspension systems.

Tractor	**Class**	**Traction**	**Mass (kg)**	**Tires**			
				Front	***Pressure (10^5 Pa)***	***Rear***	***Pressure (10^5 Pa)***
A	I	2WD	3430	10.00-16	2,03	18.4-34	1.62
B	II	4WD	4080	480/65 R24	1.22	600/65 R34	1.22
C	II	4WD	4390	480/65 R24	1.62	540/65 R38	1.62

TABLE 1 - Tractors characteristics, as furnished by user manual

Tractors were equipped as originally furnished by manufacturers and ballasts or implements were not added (as required by ISO 5008 standard). Concerning tires pressure, machine use and maintenance booklets were referred.

2.2. Track description

All tractors run over typical agricultural surfaces (grass, harrowed clay, unmetalled farm roadway, asphalt road) and on a smoother ISO track.

Tests were conducted at the CNR IMAMOTER testing facilities (Pratofiorito, Turin, Italy).

For the artificial track tests, vibration measurements were carried out when the tractor was driven over a 100 m smoother track. This track consists of two parallel strips suitably spaced for the wheel track of the tractor. The surface of each strip is formed of wooden slats 80 mm wide, each slat separated from the next by a gap of 80 mm. Slats are sited firmly in a base framework. The surface of each track strip has been defined by the ordinates of elevation, with respect to a level base, listed in tables of ISO 5008.

The other test tracks (grass, harrowed clay, asphalt and unmetalled farm road) were present at the IMAMOTER experimental field site: a grass track (1400 m long), a flat and homogeneous harrowed clay track (1200 m long), a asphalt track (1000 m long, without asperity) and a non uniform with random subsidence of different height (2-3 cm maximum) unmetalled farm road (2000 m long).

2.3. Forward speed

On these surfaces, tractors run at forward speeds typical of some agricultural operations (as haymaking and chemical fertilizing) and of some off road transfer, as described in table 2.

For test over the asphalt, machines were driven at their highest forward speed.

Tractor	Test surfaces	Forward speed (km/h)
A, B, C	Grass track	10
A, B, C	Harrowed clay	10
A, B	Asphalt	30
C	Asphalt	41
A	Farm roadway	10
B, C	Farm roadway	14

TABLE 2 - Tractors forward speed on different test surfaces

Over these surfaces, to obtain steady results, data were acquired for quite long time periods (5 minutes or more).

Afterwards, tractors passages on the smoother ISO track (ISO 5008) from 1 until 14 km/h, in step of 0.5 km/h, were observed. Forward speed was monitored by radar (derived from a Doppler radar sensor). For smoother ISO track tests, acquisition times were bind to the machine forward speed (350 seconds for 1 km/h, 24 seconds for 14 km/h).

At least three repetitions for each velocity were executed.

2.4. WBV measures

Acceleration levels were measured on the cab floor of the three tested agricultural tractors. In this first phase only data measured over the platform have been considered, because vibration values measured on the seat were observed changing in previous tests. Infact, in these cases, it was pointed out that seats in some situations showed the resonance phenomenon. This is an hard question which must be deeper analyzed, but this is not a target of the present work.

360 tests were executed: for each test were recorded, and then analyzed, acceleration values concerning both root mean square (RMS) values along the X (longitudinal), Y (transverse) and Z (vertical) axis and 1/3 octave band spectrum, to improve the accuracy of RMS values analysis.

The same operator (70 kg mass and 180 cm height) and the same drive behavior was maintained, all the time.

2.5. Instrument

For data acquisition was used a measuring chain formed by one triaxial accelerometer (Bruel &Kjaer, 4322 type), three charge amplifiers (Bruel &Kjaer, 2635 type) and a digital audio tape recorder (Teac, RD-120 TE type). The triaxial accelerometer was fixed on the cab floor under the driver seat.

A dual channel real-time frequency analyzer (Bruel &Kjaer, 2133 type) was used for data frequency analysis in 0.5-80 Hz band (these range is interesting at hygienist level for WBV exposition, as reported in the ISO 2631-1).

The two whole body weighing filters, Wd for X (longitudinal) and Y (transverse) axis, Wk for Z (vertical) axis, as requested by ISO 2631-1, were applied.

During test over the ISO track, an acoustic device was used, photocells driven. This acoustic signal was recorded on digital recorder to warn the start and stop of data analysis.

2.6. Standards

The International Standard ISO 5008 was used. This standard defines the specification of instruments, measurement procedures, measurement site characteristics and frequency weighting that allow agricultural wheeled tractors WBV measurements to be executed and recorded with an acceptable precision. Vibration were evaluated in accordance with currently standard (ISO 2631-1) which includes means of weighting the vibration levels at different frequencies to consider the frequency sensitivity of the human operator body to WBV.

3. Results

For each tractor, surface and direction (X, Y and Z axis), global acceleration values have been analyzed, as well as acceleration frequency distribution (1/3 octave band). It was observed that ISO 5008 smoother track may sometimes reproduce, at specified speeds, the same vibratory conditions registered over other surfaces, in terms of RMS acceleration values and spectral trend.

Afterward, two case studies have been considered.

3.1. Global acceleration values

Acceleration data analysis was performed along the three axes separately to underline the acceleration behavior along the three directions as a function of the surface type.

In Tables 3, 4 and 5 tractor acceleration source values measured for X, Y and Z axis during all tests are given. Horizontal (X and Y-axis) components are not multiplied by the 1.4 factor.

Each tractor traveled on ISO, grass, harrowed clay, asphalt and unmetalled tracks at the speed reported in the three tables. Concerning ISO smoother track, the speed which generated the weighted RMS accelerations more similar to the weighted RMS values recorded on other examined tracks was considered.

In the case of horizontal components (X and Y axis) the RMS values over the smoother ISO track are higher than the same registered over the other surfaces.

Tractor	Test surfaces	Forward speed (km/h)	RMS value (m/s^2)	Forward speed on ISO track (km/h)	RMS value on ISO track (m/s^2)	Absolute acceleration variation rate (%)
A	Grass track	10	0,20	4,0	0,27	35
B	Grass track	10	0,16	4,5	0,23	44
C	Grass track	10	0,22	4,5	0,24	9
A	Harrowed clay	10	0,31	6,0	0,32	3
B	Harrowed clay	10	0,20	4,5	0,23	15
C	Harrowed clay	10	0,25	4,5	0,24	4
A	Asphalt	30	0,23	6,0	0,32	39
B	Asphalt	30	0,11	4,5	0,23	109
C	Asphalt	41	0,20	4,5	0,24	20
A	Farm roadway	10	0,13	5,0	0,27	108
B	Farm roadway	14	0,12	4,5	0,23	92
C	Farm roadway	14	0,16	4,5	0,28	75

TABLE 3 - X axis. Acceleration RMS values measured on the tractors cab floor (all tracks) at the speeds which generated alike RMS data and their absolute variation rate

RMS differences are remarkably high along X direction, reaching values around 100% in case of asphalt and unmetalled farm roadway (Tab. 3, column 7). These last tracks were not able to create horizontal fluctuation over the tractor cab floor. Also the absence of an agricultural trailer towed by the tractor caused these low acceleration values over asphalt and farm roadway. In the

ISO track, instead, the wooden slats distance and the height difference among them between the two strip tracks caused high horizontal acceleration also at low forward speeds.

Tractor	Test surfaces	Forward speed (km/h)	RMS value (m/s^2)	Forward speed on ISO track (km/h)	RMS value on ISO track (m/s^2)	Absolute acceleration variation rate (%)
A	Grass track	10	0,36	2	0,26	28
B	Grass track	10	0,29	2	0,26	10
C	Grass track	10	0,32	3	0,37	16
A	Harrowed clay	10	0,42	3	0,50	19
B	Harrowed clay	10	0,30	2	0,26	13
C	Harrowed clay	10	0,30	3	0,37	23
A	Asphalt	30	0,13	1	0,15	15
B	Asphalt	30	0,10	1	0,16	60
C	Asphalt	41	0,13	2	0,37	185
A	Farm roadway	10	0,32	2	0,26	19
B	Farm roadway	14	0,25	2	0,26	4
C	Farm roadway	14	0,28	3	0,37	32

TABLE 4 - Y axis. RMS values measured on the tractors cab floor for all track at the speeds which generated alike RMS data and their absolute variation rate

RMS acceleration values on field and on ISO track along the Y direction (Tab. 4) are among them more similar than the RMS measured pairs along the X axis: absolute variation rates are lower, also if tractor C presents a 185% value between the asphalt and the ISO track RMS data. In this case the tractor was running at 41 km/h speed over the asphalt and the low recorded acceleration value (0,13 m/s^2) is due to the absence of subsidence and asperity over the surface, which did not generate significant transversal movements.

Along the vertical direction (Z axis, Tab. 5), tractor passages over the ISO track at a speed range between 3 and 5.5 km/h give out RMS values very similar to the ones measured over other surfaces: in fact, in the worst situation, values are 10% different.

Tractor	Test surfaces	Forward speed (km/h)	RMS value (m/s^2)	Forward speed on ISO track (km/h)	RMS value on ISO track (m/s^2)	Absolute acceleration variation rate (%)
A	Grass track	10	0,75	4,5	0,71	5
B	Grass track	10	0,58	4,5	0,55	5
C	Grass track	10	0,69	4,5	0,62	10
A	Harrowed clay	10	0,91	5,0	0,91	0
B	Harrowed clay	10	0,86	5,5	0,88	2
C	Harrowed clay	10	0,85	4,5	0,90	6
A	Asphalt	30	0,85	5,0	0,91	7
B	Asphalt	30	0,46	4,0	0,47	2
C	Asphalt	41	0,49	3,0	0,50	2
A	Farm roadway	10	0,69	4,5	0,71	3

B	Farm roadway	14	0,57	4,5	0,55	3
C	Farm roadway	14	0,59	4,5	0,62	5

TABLE 5 - Z axis. RMS values measured on the tractors cab floor for all track at the speeds which generated alike RMS data and their absolute variation rate

3.2. Frequency analysis

Aim of this paragraph is to analyze the tractor vibrational behavior in terms of fundamental frequencies obtained in the test conditions presented in paragraph 3.1.

In Figure 1 is reported, for each surface, for each axis and for each forward speed (as in tables 3, 4 and 5) the 1/3 octave band values.

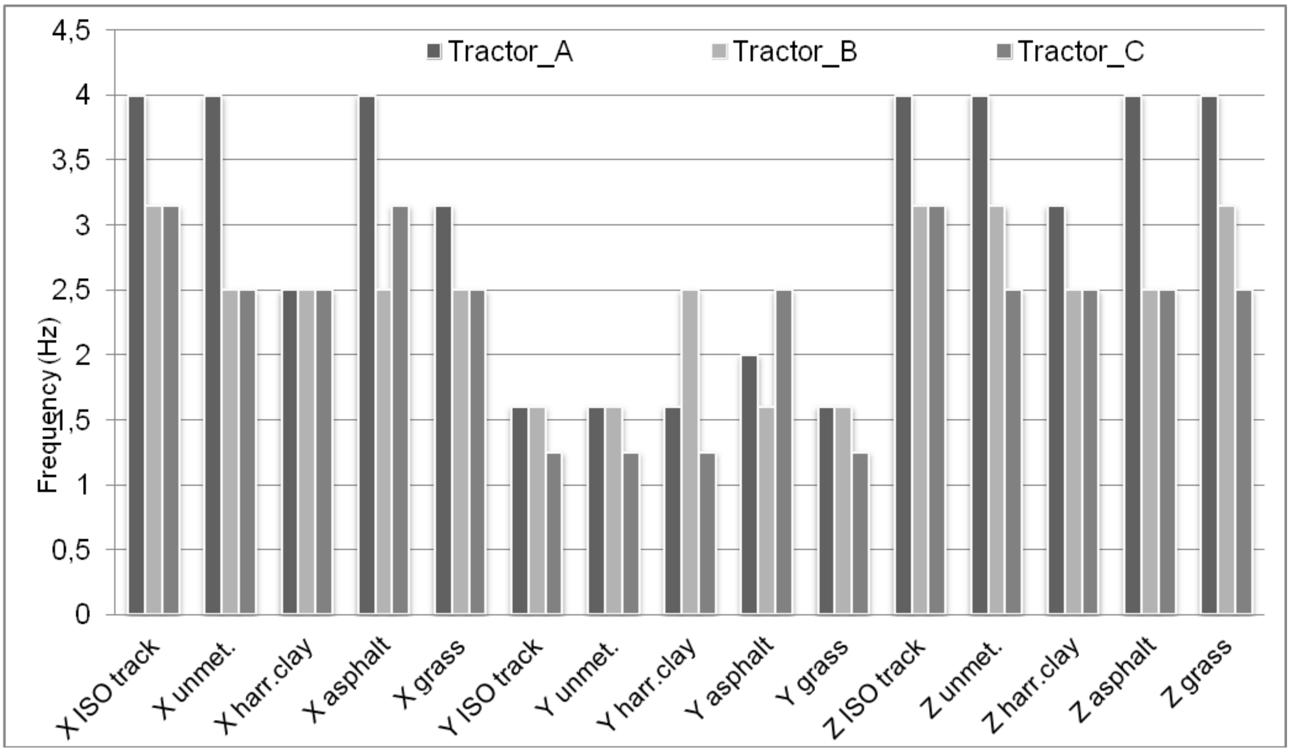

Fig. 1 - 1/3 octave band frequency values for each tractor (A, B and C), in each test condition (ISO smoother track, unmetalled road, harrowed clay, asphalt and grass), along X, Y and Z axis, at the speed reported in tables 3, 4 and 5

Along X direction vibration energy is distributed between 2.5 and 3.15 Hz (for B and C tractors). For ISO track, unmetalled road and asphalt track, tractor A reports also 4 Hz.

Along Y direction, the vibration energy is mainly distributed between 1.25 and 1.6 Hz for all tractors, whereas it is mostly found at 2.5 Hz for C tractor, 3.15 Hz for B tractor and 4 Hz for A tractor along the vertical Z direction. The tractor with lower mass (A, class I, 3430 kg) shows the vibration resonance mainly at 4 Hz, the class II tractor with 4080 kg mass (B) shows a fundamental frequency between 2.5 and 3.15 Hz, while C tractor (class II, 4380 kg) shows values mostly present around 2.5 Hz.

Tractor A presents the resonance frequency at 4 Hz along X and Z axis on almost all surfaces. This frequency goes down to 3.15 and 2.5 Hz when under the tires a deformable surface like harrowed clay or grass is present. In these cases the tire lugs go into the soil, don’t return into the tire and don’t bend the tire sidewalls.

Along X and Z axis the resonance frequency is normally higher when tractors run on the ISO smoother track: this is caused by the interaction of lugs with wooden slats.

An inverse correlation tendency exists between mass and fundamental vibration frequency.

3.3. Frequency analysis and acceleration amplitude: two case studies

Two case studies are described: tractors B and C crossing ISO smoother track, harrowed clay (B) and unmetalled farm roadway (C) along X (C) and Z (B) direction.

As a rule, along Y direction, only the situation where all the tractors run at 30 km/h (or more) on the asphalt track doesn't create crosses with the acceleration measured on the smoother ISO track, always consequence of subsidence and asperity lacks on the crossed surfaces, which doesn't create visible transversal movement on the tractor. For this reason it was not considered interesting to present a case study along Y axis.

In Figure 2, three curves describing acceleration patterns, 1/3 octave band, X axis, of tractor C running on unmetalled farm roadway at 10 km/h (continuous line) and on the ISO smoother track at 2 km/h (dashed line) and 6 km/h (point line) are shown. At 2 km/h, on the ISO track the tractor has the highest longitudinal acceleration at 1 Hz, 0.31 m/s^2 RMS value; at 6 km/h, the RMS value goes down to 0.27 m/s^2 and the energy presents a peak at 3.15 Hz.

Analyzing also other shapes for the same tractor running at higher velocity on the ISO smoother track, this last frequency distribution doesn't change: only the RMS value increases. On ISO track the longitudinal acceleration X shifts in frequency (from 1 to 3.15 Hz) with the increase of machine forward speed: this happens also for the other tractors (with different frequency ranges) and may be caused by the tire radial damping and stiffness variation in function of their angular velocity on the smoother ISO track.

The forward speed rise may produce an increase in the inertia of the vehicle and, as a consequence, the machine is less submitted to the rolling caused by the smoother ISO track geometry.

In this case study, same considerations are not possible for the tractor running on the unmetalled farm roadway, because the tractor forward speed is always 10 km/h over this surface.

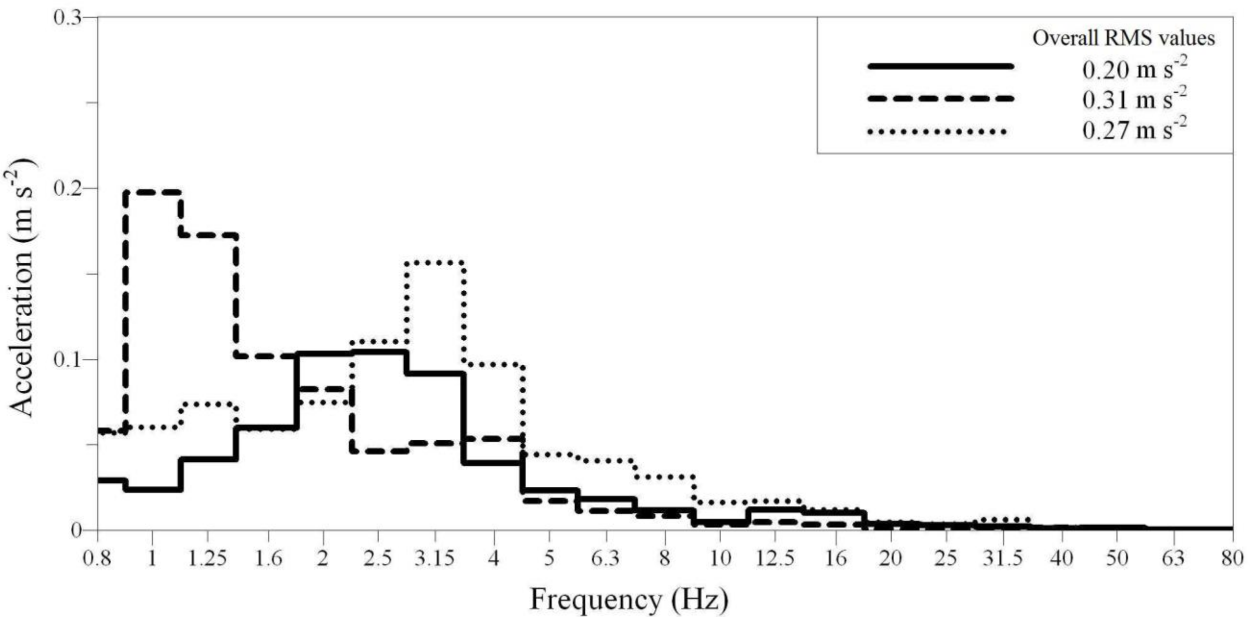

Fig. 2 – Overall RMS values and 1/3 frequency band of tractor C running on unmetalled farm roadway at 10 km/h (continuous line) and on ISO track at 2 km/h (dashed line) and at 6 km/h, (point line), X direction

Considering the Z axis, an interesting result is obtained crossing the ISO track at 5.5 km/h: the energy distribution transmitted to the cab floor of tractor B is quite similar to the one obtained from the harrowed soil tractor passages at 10 km/h (Fig. 3). 1/3 octave band acceleration values are quite the same for the two surfaces at the vertical direction Z and differ only of 2.3% (RMS value is 0.86 m/s^2, for harrowed clay and 0.88 m/s^2 for ISO track).

On the harrowed clay the vibration energy is mainly gathered around 2.5 Hz, while on the ISO track it shifts to 3.15 Hz. This fact happens for all the examined tractors, independently from the mass and tire type and it was probably caused by the energy required to deform the soil surface rather than by the energy dissipated in the tire [Lines 1991a; Lines 1991b; Lines 1992].

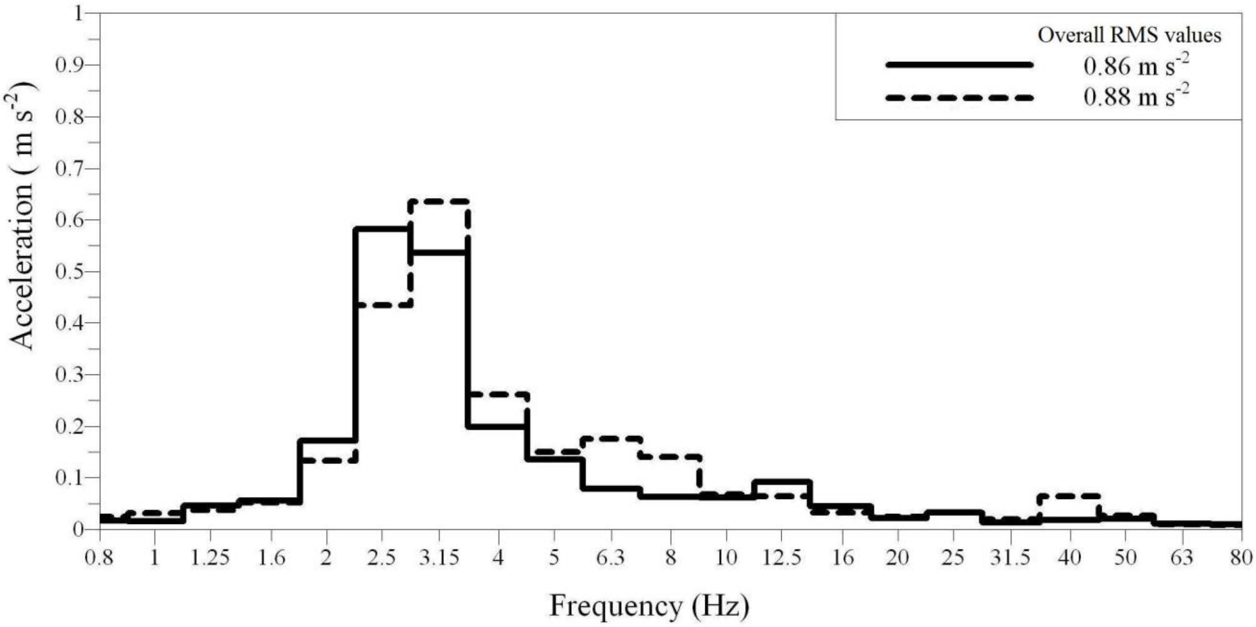

Fig. 3 - Overall RMS values and 1/3 frequency band of tractor B crossing harrowed clay (10 km/h, continuous line) and ISO track (5,5 km/h, dashed line), Z direction

4. Conclusions

Measurement and comparison of vibration levels among tractors running on different surfaces were not aims of this work: the purpose was, indeed, to start to study the vibrational behavior of different tractors running on different surfaces and, thereafter, on the ISO smoother track.

Also considering the difficulties attempting to simplify a complex problem like this, the results obtained in this work with a first comparison of 3 different tractors running on several agricultural surfaces and on an ISO smoother track are hopeful. For example, to declare vibration values of a tractor crossing a grass surface, a manufacturer should simply let the tractor travel on an ISO smoother track at the forward speed of 4.5 km/h to obtain reliable data (especially along Z axis, table 5).

Along Z direction, average RMS acceleration recorded are not only similar in all the situations, but even 1/3 frequencies band are overlapping with negligible differences, also considering the tire reaction over different roughness surfaces [Deboli, 2008].

This work demonstrates that the smoother ISO track may simulate some vibratory situations, as we obtained when the tractor is crossing the grass or unmetalled farm roadway (without trailer).

For agricultural operations with implements other tests are necessary. For tractor movement on the asphalt with or without trailer, different types of artificial tracks are required, which will be further studied.

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Summary

The whole body vibration (WBV) exposure of the operators during field operations with tractors is a never solved problem. WBV values are quite difficult to foresee, because of the high number of variables: mass and geometry of the vehicle, forward speed, tires pressure, ground type, operation cycle, environmental variables.

The use of an artificial track is useful to limit the variability of some field parameters: followed path, speed fluctuations, weather, temperature, soil conditions.

To obtain data for comparative purposes, the best results are obtained if all values are acquired attempting to maintain these variables as nearly constant as possible.

Analyzing the results of works performed by other authors, this question arose: ‘Does a lower forward speed on artificial track exist to generate the same vibration behavior on tractors working in the field?’

In this paper literature is first analyzed, therefore some results of WBV values and frequency analysis of accelerations measured on agricultural tractors travelling on an artificial test track (ISO 5008) and on different grounds are given.

Keywords: WBV, artificial test track, agricultural tractors