Whole Body Vibration (WBV) transmitted to the operator by tractors equipped with radial tires

Deboli R.[1], Calvo A.[2], Preti C.[1], Paletto G.
[1] *IMAMOTER-CNR, Strada delle Cacce 73, 10135 Torino, Italy, Tel. 0039 0113977710, Fax 011 3489218, r.deboli@imamoter.cnr.it*
[2] *DEIAFA, Sez. Meccanica, Facoltà di Agraria, V. Leonardo da Vinci 44, 10095 Grugliasco (TO), Italy, angela.calvo@unito.it*

Abstract

Other than the tractor components technological development, in the last decennia the interest for the driver comfort increased. Noise and vibration control priority increased too. Especially for vibration the tires quality plays a great role.
Modern tractors are often equipped without any type of suspension and the tires task is to reduce vibration caused by the uneven ground where these machines travel.
When the tractor moves, it is solicited by a vibrational excitation that, through the vehicle, reaches the driver causing to him a stressing and tiring situation.
To verify the vibrational comfort value given by these radial-ply tires, tests have been carried out using a 93 kW tractor. The tests have been executed with two different tractor speeds (12 and 7 km/h) and using both an artificial test track (ISO 5008) and an asphalt road.
Four different types of tires have been used (from three different manufacturers): for each test cycle the inflation pressure has been changed.
The acceleration values have always been revealed over the cabin platform to make irrelevant the running in of the seat.
In this way it was possible to extract the tires parameters which most influence the dynamical behaviour of the tractor and therefore the operator's comfort.
192 test have been conducted, using four different tires at two different pressure, 3 different track type, 2 different speed, and repeating each test three times.

Keywords: vibration, WBV, tractor tires.

Introduction

Low-frequency vibrations, produced by the agricultural vehicles, can be extremely severe, depending upon the terrain that the agricultural vehicle is crossing and the forward speed of the vehicle (Lines et al., 1995, Scarlett et al., 2007). By comparison with the progress achieved over the past decades in improving the performance of agricultural tractors (power, transmission, electronics…), the protection of the driver from vibration remains very inadequate. This is due to the fact that, in general, agricultural tractors do not have chassis suspension and the tires, which are relatively flexible and weakly damped, are the only suspension system (Cutini et al., 2007, Servadio et al., 2007). This explains why the tractor driver is subjected to low frequency, high amplitude vibration that are an important risk factor for low back pain disorder (Bovenzi et al., 1994).

In order to reduce the health risks and the discomfort to the driver and to enable the driver to work at a faster pace, it is important to isolate the driver from the machine vibration as much as possible.

Agricultural machinery construction companies play an important role in the production and implementation of all features that can reduce the WBV driver level: for this reason tyres producers are heavily involved (Stayner 2001, Sherwina et al., 2004) .

Aim of this investigation is to indicate likely variations in WBV from four different types of tires (from three different manufacturers). 192 test have been conducted, using four different tires at two different pressure, 3 different track type, 2 different speed, and repeating each test three times.

Materials and methods

To verify the vibrational comfort value given by the radial-ply tires, tests have been carried out using a 4WD tractor (table 1) equipped with four different types of tires, from three different manufacturers.

Table 1. Main features of tractors

Item	Measure unit	Value
Tractor power	kW	93
Cylinders	n	6
Displacement	cm^3	6720
Wheel base,	mm	2661
Trackwith front	mm	1407
Trackwith rear	mm	1426
Mass front	kg	2044
Mass rear	kg	3066
Cab suspension		silent-blocks
Axles suspension		any
Ballast		any

<u>*Tire characteristic*</u>
Four different types of tires have been tested (table 2). All tires were new. Tires A, C and D were at low aspect ratio.

Table2. Tire characteristics

Tire	A		B		C		D	
	front	rear	front	rear	front	rear	front	rear
Tire size	480/65 R28	600/65 R38	380/85 R28	460/85 R38	480/65 R28	600/65 R38	480/65 R28	600/65 R38
Number of lugs	22	23	20	21	19	20	20	22
Lugs height, mm	41	46	48	52	41	50	42	49
Average area of a lug, cm^2	108	175	77	112	130	213	114	171

Tests have been carried out on three different surfaces:

- The smoother ISO, 100 m track (from standard ISO 5008: 2001), which represents an unmetalled farm roadway, designed to test the fitness for validity of tractor seats. This track provides an acceleration input which, at the cab floor, is dominated by the vertical component (figure 1);

- ISO track and asphalt (1/2 ISO in the following). For this test tractor was driven with two wheels on the track and two on the asphalt. Aim of the test was to improve the lateral force on the tires (figure 2);
- Asphalt. Tractor vibration were tested on a conglomerate bituminous rectilinear plane tract of 400 m length. These type of tests gave us information about the tires behaviour during transfer on the road.

Use of ISO 5008 ride vibration track tests provides a reasonable basis for comparison of tires under tests for the high repeatability and reproducibility of vibration data.

Operative condition

In order to maintain the test programme within reasonable limits we have carried out the test at 12 km/h and 7,5 km/h. Forward speed was monitored by a Peiseler wheel.

For the forward speed of 12 km/h each test was executed with three different tire pressures (1.6, 1.2 and 0.8 bar), while for 7.5 km/h the pressure was only 0.8 bar (table 3).

Three test replicates were performed for each test speed and pressure (192 test have been conducted).

The same driver was used for all tests.

Table 3. Operative conditions

Speed (km/h)	12	12	12	7.5
Pressure (bar)	1.6	1.2	0.8	0.8
Test track	ISO ½ ISO Asphalt	ISO ½ ISO Asphalt	ISO ½ ISO Asphalt	ISO ½ ISO Asphalt

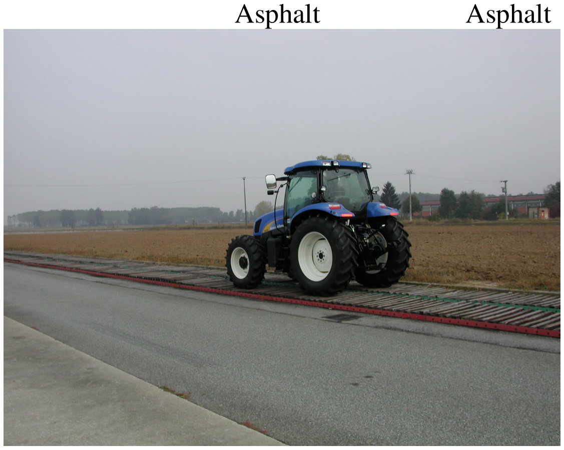

Figure 1. ISO test track

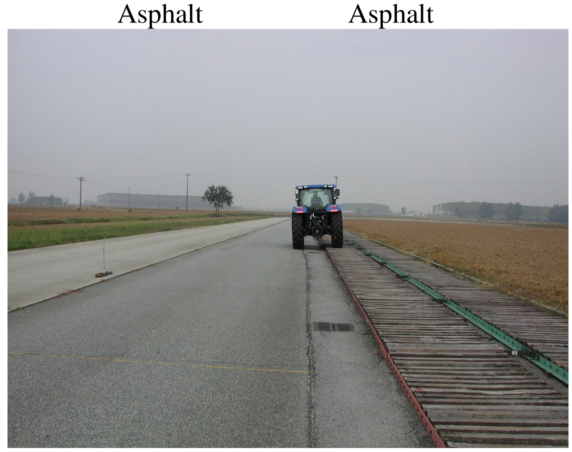

Figure 2. ½ ISO test track

Test instruments

A Larson Davis Human Vibration Meter type HVM100 (serial No 292) was used to condition the cab floor accelerometer. A tri-axial accelerometer ICP® (Integrate Current Preamplifier) from PCB, type SEN020 (serial No. P 51694) with sensitivity of 1mV/g, was connected to the human vibration meter HVM 100. The accelerometer was fixed on the cab floor, close to the seat mounting point.

The acceleration records were frequency-weighted, using the weighting factors *wd* and *wk* specified in ISO 2631-1 for the horizontal and vertical axes respectively, before calculation of root mean- square (r.m.s.) acceleration values. The horizontal (X and Y-axis) components were multiplied by a factor of 1.4, as also specified in ISO 2631-1. Combined (vector-sum) three-axis acceleration values were obtained for the cab floor by calculating the root-sum-of-squares (RSS) of the combined orthogonal axes components.

As the tractor seat was new of factory, in order to avoid any effect of the seat running in, the measurements of vibration were executed only on cab floor.

Test type

Each test has been repeated three times for each configuration. In table 4 the RSS measured and the averages for 7.5 km/h speed at the pressure of 0.8 bar are reported.

Table 4. RSS values (m/s^2) obtained at the speed of 7.5 km/h, 0.8 bar pressure

A		B		C		D	
	RSS		RSS		RSS		RSS
ISO	1.16	ISO	1.07	ISO	1.03	ISO	1.16
ISO	1.15	ISO	1.09	ISO	1.03	ISO	1.14
ISO	1.21	ISO	1.09	ISO	1.03	ISO	1.15
average	**1.17**	**average**	**1.08**	**average**	**1.03**	**average**	**1.15**
1/2 ISO outward	1.03	1/2 ISO outward	0.95	1/2 ISO outward	0.87	1/2 ISO outward	0.88
1/2 ISO back	1.01	1/2 ISO back	1.02	1/2 ISO back	0.88	1/2 ISO back	0.96
1/2 ISO outward	1.00	1/2 ISO outward	0.93	1/2 ISO outward	0.85	1/2 ISO outward	0.91
1/2 ISO back	1.05	1/2 ISO back	1.01	1/2 ISO back	0.84	1/2 ISO back	0.98
1/2 ISO outward	1.02	1/2 ISO outward	0.96	1/2 ISO outward	0.84	1/2 ISO outward	0.92
1/2 ISO back	1.00	1/2 ISO back	1.00	1/2 ISO back	0.87	1/2 ISO back	0.98
average	**1.02**	**average**	**0.98**	**average**	**0.86**	**average**	**0.94**
asphalt	0.15	asphalt	0.16	asphalt	0.13	asphalt	0.21
asphalt	0.16	asphalt	0.15	asphalt	0.14	asphalt	0.19
asphalt	0.14	asphalt	0.16	asphalt	0.16	asphalt	0.21
average	**0.15**	**average**	**0.15**	**average**	**0.14**	**average**	**0.20**

To better understand the possible influence of track type, speed, tire pressure and tire type over the measure vibration, data have been grouped in different ways (by tire type, by speed, etc.). All data have been written in Excel and therefore elaborated using the SPSS software to verify differences among speed, pressure and tire type, using the ANOVA procedure, considering the normality of the data distribution. This has been possible because an high repeatability has been revealed during each test phase: in fact, the obtained result in each test are very homogeneous to demonstrate the high accuracy level used during the test.

Results

First of all, no statistical analysis has been carried out to verify if vibration differences existed among the different test tracks because it was obvious looking at the collected data.

The asphalt registers the lowest values, while the highest accelerations are reported in the ISO track.

Vibration in function of speed and pressure

Considering the speed and the pressure, the different test track have been evaluated. In all the cases, the 0.8 bar pressure registered the lowest vibration values for all the tire type.

12 km/h speed. ISO track

The 12 km/h speed has been initially considered. For the ISO track, the vibration averages at different pressure level at the speed of 12 km/h are reported in figure 3. At the pressure of 1.6 and 1.2 bar the vibrations are between 2 and 2.5 m/s^2, while at 0.8 bar they don't exceed 1.84 m/s^2.

Also if the differences are very low, the highest vibration values are always due to the A and D tires. Because of the high repeatability, the two-way ANOVA (with a confidence level of 95%) reports the main difference factor as the pressure, while a lower difference is for the tire type. In all the cases the tires are different among them.

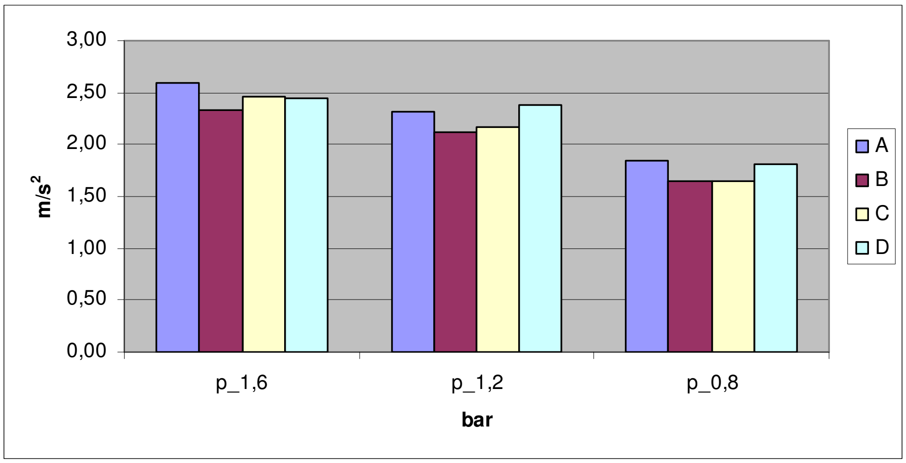

Figure 3. Average vibration values on the ISO track, 12 km/h speed

With a one-way ANOVA analysis ($p<0.05$) it has been possible to better evaluate possible tire statistical homogeneity at the different pressure levels. The results are in table 5.

Table 5. Statistical vibration analysis among tires on the ISO track, speed 12 km/h

1.6 bar	1.2 bar	0.8 bar
C and D have the same vibration behaviour	B and C are statistically equivalent for the WBV	WBV are statistically equal for B and C tyre. The same is for A and D

12 km/h speed. ½ ISO track

Analysing data for this track type (figure 4), we immediately notice that the accelerations are lower than the ISO track (figure 3). Also in this case, the two-way ANOVA ($p<0.05$) reports the highest differences for the pressure and it is not possible to group the tire vibration values. Only the one-way ANOVA permits to couple the vibration obtained by the tires at the different pressure level (table 6). In this case the differences are more underlined, at the point that only at the 1.2 bar it is possible to consider statistically equivalent tires B and C.

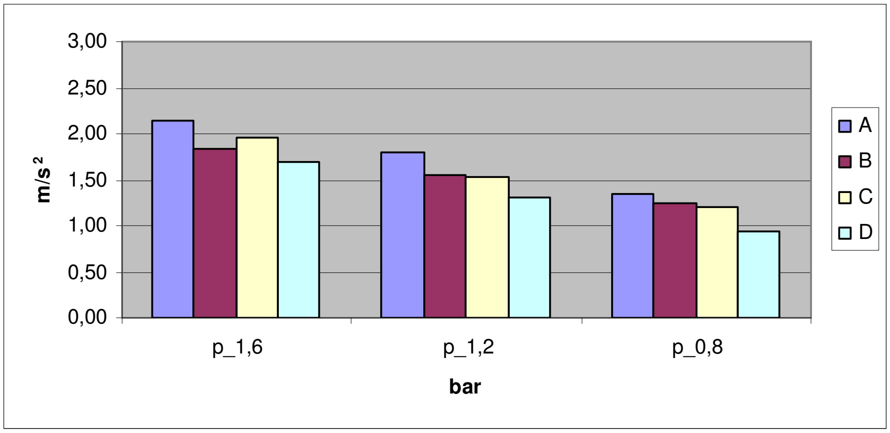

Figure 4. Average vibration values measured on the ½ ISO track, 12 km/h speed

Table 6. Statistical analysis among vibration tires on the ½ ISO track, speed 12 km/h

1.6 bar	1.2 bar	0.8 bar
All tires are different among them	B and C have the same vibration behaviour	B and C are statistically different for $p<0.05$, equal for $p<0.01$

12 km/h speed. Asphalt track

Because the measured vibrations on this track are very low, here it is not possible to represent the averages with the same scale of the other tracks (figure 5): in fact the highest vibration value in this case is 0.42 m/s^2 for the C tire. It is also curious that in the asphalt the tire A registers the lowest vibration values, whereas in the ISO and in the ½ ISO it had the highest values.

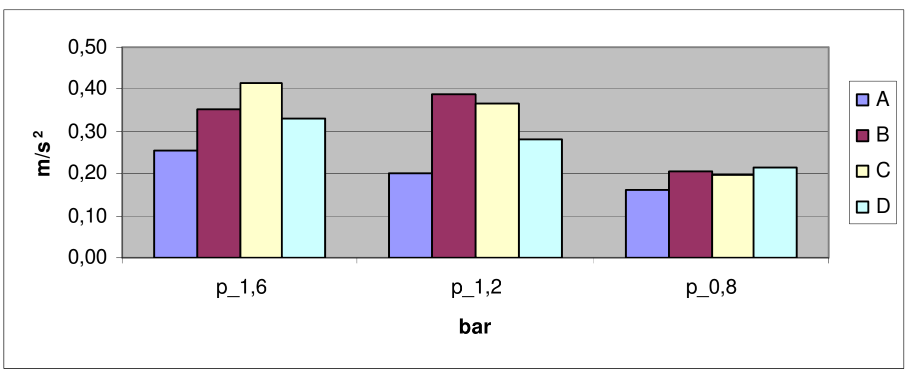

Figure 5. Average vibration values measured on the asphalt track, 12 km/h speed

From a statistical point of view, because the values are smaller and are between 0.16 and 0.42 m/s^2, it is not possible to group the tires among each pressure level: only the one-way ANOVA ($p<0.05$) permits to group them inside each pressure level (table 7).

Table 7. Statistical analysis among vibration tires on the asphalt track, speed 12 km/h

1.6 bar	1.2 bar	0.8 bar
B and D are statistically equal from the vibration point of view	B and C transmit the same WBV	B, C and D are statistically equivalent

7.5 km/h speed. All the test tracks

At the 7,5 km/h speed, only the 0.8 bar pressure has been tested for all the tracks. Because of the very high repeatability, none statistical equivalence has been detected: all the tires are different for vibration emission, also if the averages are very close to each other (figure 6). Only for the asphalt, the vibration equivalence among A, B and C tires has been statistically obtained.

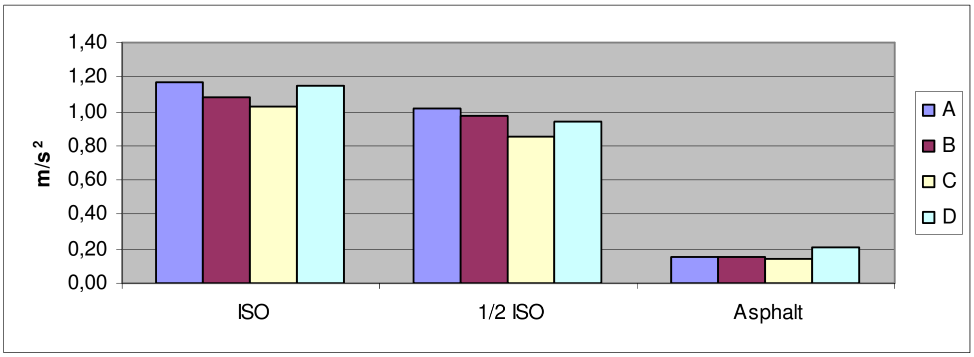

Figure 6. Average vibration values measured over different tracks, 7.5 km/h speed, 0.8 bar tire pressure

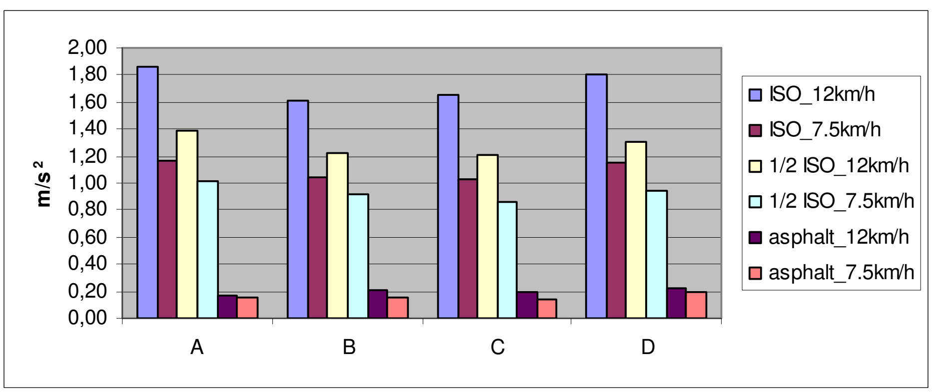

Figure 7. Average vibration values at the 0.8 bar pressure

The comparison of the average vibration values in the same conditions between the 7.5 km/h speed and the 12 km/h (figure 7) reveals that the acceleration is higher at the highest speed: the difference is more evident for the ISO and the ½ ISO track, while it is softer over the asphalt.

Conclusions

Under the vibrational aspect the behavior of tire B (with different structural elements) is similar to the other ones and there are not statistical differences.

In this work, however, there are statistical differences among the vertical (Z direction) vibration measured over the different tires inside each test condition (same track, same speed and same pressure), but it is difficult to say if a tire is 'better' than another, especially when the vibration differences are very low, as in the case of the asphalt. More differences are revealed in the ISO track, where also the measured vibration are higher. Concerning tires behaviour, the tire A reports the highest vibration values in the ISO and in the ½ ISO track, while in the asphalt it registers the lowest vibration data: effectively, there are tires which are more adapt to smooth surfaces (as the asphalt is) and others which are better over irregular soils (as the ISO track).

In all the cases, lower is the speed, lowest are the vibration measured, independently by the soil and tire characteristics.

For longitudinal (Y) and lateral (X) direction no differences have been found among tires.

Also for tests carried out on the ½ ISO tack no valuable results were found, probably because the difference in height between ISO track and asphalt was little and insufficient to generate a lateral dynamic charge.

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