CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216
DOI: 10.3303/CET1758027

A Study of a Barometric Methodology for Assessing the Agricultural and Forestry Machine's Seat Comfort

Marco Pirozzi[a], Venerando Rapisarda[b], Marco Ferri[c], Aldo Calcante[c], Roberto Oberti[c], Elio Romano[d]

[a]INAIL – Dipartimento Innovazioni Tecnologiche e Sicurezza degli Impianti, Prodotti ed Insediamenti Antropici – Laboratorio II – Macchine e attrezzature di lavoro - Via Fontana Candida 1 -00040 - Monte Porzio Catone (RM) ;
[b]University of Catania - Occupational Medicine; Via Santa Sofia 78, 95123 Catania, Italy
[c]Dipartimento di Scienze Agrarie e Ambientali - Produzione, Territorio, Agroenergia – Università di Milano.
[d]Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA)– Unità di Ricerca per l'Ingegneria Agraria (CREA-ING); Laboratorio di Treviglio, via Milano 43, 24047 Treviglio (BG), Italy
m.pirozzi@inail.it

The agricultural operations carried out with machines, require the operator spends a substantial amount of hours in a seated position on a seats often not properly padded therefore the parts of the body in contact with the seat are subject to considerable stresses. In addition, the operator must not only control the task he has done but he must also continually monitor actively with a significant commitment to operate levers, buttons and steering.
Therefore, the operator's body is subject to various twists carried out in dynamic conditions according to the crop processing to perform. The parts of the body in contact with the seat, in particular the buttocks and the back, receive continuously, at irregular intervals, and with different intensity, different mechanical stresses that are translated immediately in pressure to the them tissues.
Often these compressions occur in a concentrated manner, especially if the body is skinny and therefore the pressures could immediately affect the comfort perceived by the operator and at a later time, if repeated by the same operator and with the same machine, they could degenerate into occupational diseases because of the possible an incidence on blood flow.
The purpose of this paper is to propose a new methodology based on barometric mapping, to investigate how forces are applied to the back and buttocks while driving a tractor, under standardized test conditions.
In particular, the experimental tests have been conducted on a smooth surface free of roughness which is the simplest movement a vehicle can do along a road, such as transporting a trailer.
The data were collected through an acquisition system based on a carpet with small pressure sensors. It has been used a carpet of 1024 cells for the sitting and one for the backrest.
Acquisitions between the two sides of the seat were synchronized and the tests were repeated five times in order to develop an adequate analysis.
Statistical analysis was mainly aimed at verifying the variability among datasets in order to study the effect of the seat on the value recorded.
The statistical analysis was mainly aimed at verifying the variability between the data sets to study the effect of the seat on the pressure value recorded.
The results showed, for the observed correlations, this method based on pressure between the seat and the body is a good tool to help the valuation judgment of a seat.

1. Introduction

In all field operations conducted with agricultural machines, the tractor driver is exposed to vibrations. Many of these exposures may exceed regulatory limits so as to consider an increased risk of injury to workers from these operations. The vibrations occur along three translations and three axes of rotation (6-DOF), and can afflict the driver's body at any point of contact with a vibrating surface (Griffin et al., 1990).

Please cite this article as: Pirozzi M., Rapisarda V., Ferri M., Calcante A., Oberti R., Romano E., 2017, A study of a barometric methodology for assessing the agricultural and forestry machine's seat comfort, Chemical Engineering Transactions, 58, 157-162 DOI: 10.3303/CET1758027

The vibration comes, in the operator's body working seated, from the feet resting on the floor, from the seat and from the controls managed by the operator's hands (Mansfield et al., 2005).
The main device of transmission of vibrations from the vehicle frame to the operator is the seat. The manufacturer can implement the type of seat already fitted for a cabin model, with a better one, to prepare a more comfortable cabin. The WBV (whole body vibration) exposure generate discomfort and has been linked to the pain behind the back (Bernard et al., 1997; Lings et al. 1999), and the neck (Rehn et al., 2002). The daily exposure to vibration may compromise the health of the driver, as demonstrated by medical studies (Kumar et al., 2001). In particular, excessive exposure to WBV and awkward working postures are considered the main stress factors that contribute to the development of musculoskeletal disorders among professional drivers (Bovenzi et al., 1994).
So the replacement of the seat as a function of the operations to be performed, as well as the duration and the conditions of the working, could be a very useful option to improve the operator's working conditions. Other factors can affect the attenuation of vibrations, such as tires (Sherwin et al., 2004), wheel suspension (Donati, 2002), driving speed (Malchaire et al., 1996; Rehn et al., 2005) and terrain (Piette et al. 1992).
Modern tractors normally have components capable to reduce vibration, such as new kind of tires; in particular the modern low pressure tires can transmit less vibration (Sam et al. 2006; Schrottmaier et al., 2000). Even the seat suspension system is one of the most effective solutions (Dufner et al. 2002; Melemez et al. 2013). However, even if several advances have been developed, some authors (Scarlett et al. 2007) found in their experiments with modern tractors that the limits established by law (EEC Directive 2002/44/EC) were exceeded when the analyzes were developed in the time intervals corresponding to the actual use of the agricultural machine.
In the automotive industry is used, since the 90s, for the verification of the comfort of the seat, a system based on the reading of the pressure between the tissues of the human body and the seat, called barometric mapping.
Barometric maps have been used in order to study the effects of vibration magnitude and frequency transmitted to the operator as well as the pressure distribution in the ischial areas (Wu et al, 1999). The instrumentation is based on the matrices of pressure sensors that express in real time the pressure variation and the persistence of the pressure in certain areas of the body. Several studies have shown assessments isobars curve distribution of the pressure exerted by operators sitting on a horizontal plane (Schoberth, 1962; Pheasant et al., 1991 e Gross et al., 1994).
The aim of the article is the study of a method able to read the pressure between the operator and the agricultural and forestry machines seat. In particular, the study has focused on the ability of a barometric sensor array to sense differences between seats with anatomical conformations which define different levels of comfort.

2. Material and methods

Tests were conducted at the CREA-ING (Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria) of Treviglio (Bergamo, Italy). Data were recorded on 500 m of standardized asphalt (ISO 2631-1:1997) test track (Figure 1), developing five repetitions for each condition.

Figure 1: The test track of the Laboratory of Treviglio

2.1 Seats and tractors features

The tests have been carried out with the use of three different commercial seats. The three seats were distinguished by the following characteristics: area of the seating surface, the presence of headrest, adjustment options (mechanical, pneumatic) of the seat, size and padding (table 1).
The three seats had the following characteristics: seat A: seat "low range" with reduced (about -10% of the seat B, and about -20% of the seat C) seating surface (measured as a projection on a flat surface), poor cushioning, lack of restraint and poorly adjustable; seat B: seat of "middle range" with a medium seating surface, good padding (about +10% of the seat A), the presence of head restraints and adjustable mechanically; seat C) seat "high-end" with headrest and pneumatic adjustment, wide and adjustable seat, with possible adjustments also in the lower back, in the armrests and head restraints. In the latter case the seat was also able to perform self-calibration according to the operator's weight, while maintaining the possibility of further manual adjustments.

Table 1: Seats' characteristics

	Seat A	Seat B	Seat C
Sitting area (cm^2)	2.068	2.288	2.499
Backrest area (cm^2)	1.634	1.665	2.021
Thickness seat (cm)	4.5	5.0	6.0
Thickness backrest (cm)	4.0	4.0	6.0
Head rest (Y/N)	N	Y	Y
Breathable fabric (Y/N)	N	N	Y
Height adjustment (Y/N)	N	Y	Y
Lumbar adjustment (Y/N)	Y	N	Y
Suspension type	Mechanic	Pneumatic	Pneumatic/Auto

Y= presence; N=absence

2.2 Subjects

The tests were carried out by five subjects, volunteers, healthy, with experience in conducting agricultural machinery. The age range was between 22-50 years old, the mass between 62-106 kg and height between 172-187 cm. All of them were right handed.

2.3 Pressure measurement system

The sensors applied in the tests consisted of a carpet of resistive sensors (32x32) (Figure.2) that instantly generates a matrix of values 1024 (Figure 3). In particular, the instrumental chain constituted of two acquirers Evolution Handle (Tekscan Pressure Measurement System, 1998-2012, South Boston) data with the scanning frequency of 100 Hz.

Figure 2 – The acquisition system

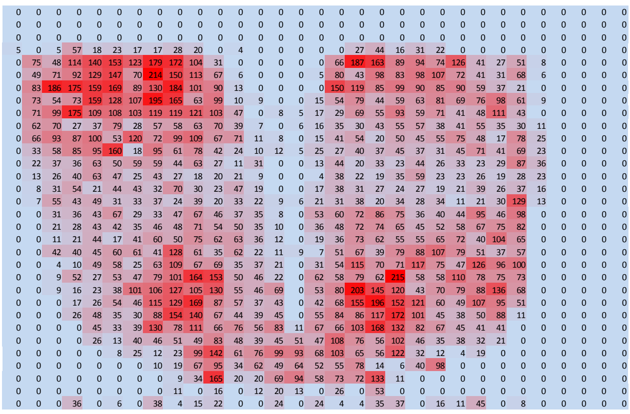

Figure 3 – An array of the pressure (g cm^{-2}) produced from an instantaneous acquisition.

Each sensor is 0.64 mm thick and is able to measure a pressure range between 0 and 1000 g cm^{-2}. From each array, the maximum and mean value can be calculated on 600 frames.
The software used for the reading of the data retrieved by the sensor array is CONFORMat Research ver. 7.60-21C (Tekscan Pressure Measurement System, 1998-2012, South Boston).
The software is also able to provide graphs about: the pressure, the contact area and the distribution of pressures through time. The software can execute the dynamic playback function of two or more signals simultaneously; the system could export data in ASCII.
The acquisition, of variable lenght in function of the speed of travel, was cut away of the entrance phase to the track and the exit phase from the track, characterized by an indicator signal (a bump). From every single test the maximum peak pressure (P^{MAX}) and the average pressure value (P^{AVG}) were obtained.

2.4 Statistical Analysis

The statistical analysis was conducted through the software Comprehensive R Archive Network (CRAN), developed by the Institute for Statistics and Mathematics (Wien-Umgebung, Austria).
The data were reported as means and standard deviations from the mean, and after the first checks the normality of their distribution with the Shapiro Wilk test and their homogeneity of variance test with Fisher's exact test, were subjected to ANOVA variance analysis to obtain an assessment of the factors in the study, constituting the independent variables, with respect to the response selected values representing the dependent variable (P^{MAX}, P^{AVG}).
In addition to the information generated from the analysis of variance were developed post-hoc test for discrimination in classes of the observed variations.

3. Results and discussion

The dataset of the values collected between all compared conditions showed the highest value P^{AVG} of 136.04 g cm^{-2} and the highest value P^{MAX} of 691.00 g cm^{-2} recorded with the use of the seat A.

The summary of the dataset, grouped by seat, is shown in Table 2.

Table 2: P^{AVG} (g cm^{-2}) e P^{MAX}(g cm^{-2}) recorded in the three seats

P^{AVG}	mean	sd	IQR	min	Max
Seat A	136.04*°	36.93	69.56	82.00	184.75
Seat B	122.01	30.07	41.13	84.25	194.38
Seat C	101.39	23.27	27.13	72.75	154.00

P^{MAX}	mean	sd	IQR	min	Max
Seat A	335.80*°	172.29	225.5	143.00	691.00
Seat B	271.20	92.05	91.5	160.00	500.00
Seat C	159.60	57.70	60.0	102.00	303.00

Number of value=75
*Duncan's test significance: *seat A vs. B; °seat A vs. C*

The Shapiro-Wilk test, conducted both on P^{AVG} and P^{MAX}, showed normality of the data distribution.
Levene's test for homogeneity of variance was positive. So it was possible to carry out the analysis of variance (ANOVA) for the effect evaluation of the operator and the seat, on the registered values. The seat type has shown statistically significant influence on the value of P^{MAX} and P^{AVG} with p-value <0.01.
Of the two response values, only P^{AVG} was statistically influenced (p-value <0.05) by the operator sitting on the seat. Instead the P^{MAX} was not significantly influenced by the operator. Both response values showed no statistically significant differences that depend on the repetitions performed, showing a statistically verified repeatability.
Therefore, for the response values dependent on the type of seat has been performed post-hoc Duncan test for the search of the homogeneous medium and the verification of the difference between the seats and the results are reported in table 2, while the distribution of values, grouped by the seat, it is shown in the box plot of Figure 4 and 5.
The same test developed for the research of the difference among the five averages obtained by the operators showed that the P^{MAX} and P^{AVG} were statistically influenced by the operator 1 who had a body mass index (BMI=weight $height^{-2}$) different from the others (Duncan's test at confidence level=0.95). The correlations between BMI and P^{MAX} and P^{AVG} values were positive and significant (p-value<0.05), respectively of 0.68 and

0.72. The correlations between the height of seat padding and the values of P^{MAX} and P^{AVG} were negative and significant (p-value<0.05), respectively of -0.56 and -0.64.

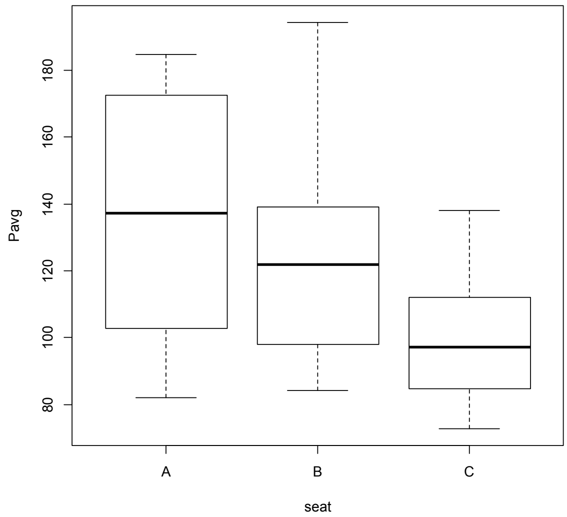

Figure 4 – Median line boxplot of P^{AVG} values (g cm^{-2}).

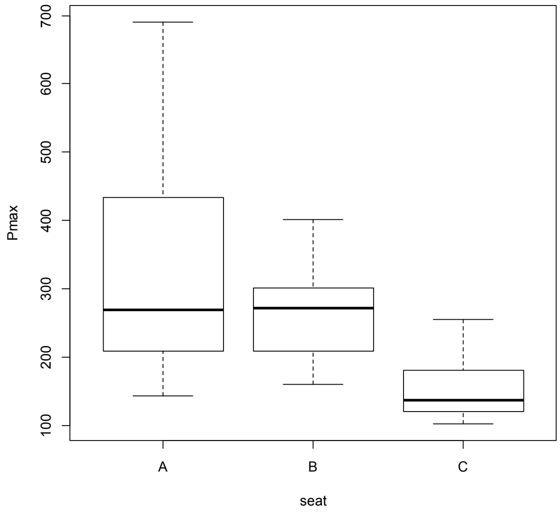

Figure 5 – Median line boxplot of P^{MAX} values (g cm^{-2}).

4. Conclusion

The reading ability of an instrument equipped with sensors has been evaluated for the assessment of the pressures which occur between the seat and the operator ride on seated in an agricultural or forestry machine. The experimental plan was designed to test the differences detected by the barometric instruments with three different types of seats on the market. It was chosen an area of standardized asphalt to avoid the variability coming from the driving surface.

Among the five operators that drove the tractor, only one, the one whose combination of height and body weight has generated a different BMI from the group, has had an effect, together with the type of seat, on the average pressure values (P^{AVG}) registered, probably due to the manifested correlation of BMI with P^{MAX} and P^{AVG}.

The maximum peak values (P^{MAX}) recorded were influenced only by the type of the seat. Further studies should evaluate if the BMI and operators' anthropometric measurements could and how have effect on the reading ability of the proposed methodology. In addition, the investigated method, should be verified during cultivation operations in the field.

This research allows to conclude the methodology applied in this study could be used to describe and compare seats of agricultural and forestry vehicles, with the main objective to highlight the degree of comfort available, assessing the minimum and maximum pressures obtainable in the dynamic situations where the operator can be in the working hours.

The hope is therefore to use the experience gained as a tool for comparing new materials and design and implementation technologies and in the evaluations to improve the quality of the operator's work environment.

Acknowledgments

The authors would like to thank the INAIL (National Institute for Insurance against Accidents at Work) which funded the ERGSEAT project that allowed the useful experiments in this research and they would like to thank also Elia Premoli (CREA-ING Treviglio, Bergamo, Italy), for his technical support in fitting out the sensor array and collecting the experimental data.

Reference

Bernard B.P., 1997, ed. Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for workrelated musculoskeletal disorders of the neck, upper extremity, and low back. Publication No. 97BB141, National Institute for Occupational Safety and Health, Cincinnati, Ohio.

Bovenzi M., Betta A., 1994, Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. Appl. Ergon., 25, 231–241.

Donati P., 2002, Survey of technical preventative measures to reduce whole-body vibration effects when designing mobile machinery. J. Sound Vib.; 253(10): 169.

Dufner D.L., Schick T.E., 2002, John Deere Active Seat™: A New Level of Seat Performance. In Proceedings of the Agricultural Engineering, Halle, Germany, 10–11 October 2002; pp. 43–49.

EEC Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). J. Eur. Commun. 2002, OJL177, 13–20.

Griffin MJ., 1997, Handbook of Human Vibration. New York: Academic Press; 1990. [3] ISO 2631-1. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration – Part 1: General requirements. Geneva Switzerland: International Standards Organization.

Gross C.M., Goonettilleke R.S., Menon K.K., 1994, The biomechanical assessment and prediction of seat comfort. In Lueder R, Noro K (eds): Hard Facts About Soft Machines. London. Taylor & Francis, London: 231-253.

Kumar A., Mahajan P., Mohan D., Varghese M., 2001, IT—Information Technology and the Human Interface: Tractor Vibration Severity and Driver Health: A Study from Rural India. J. Agric. Eng. Res., 80, 313–328.

Lings S., Leboeuf-Yde C., 2000, Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992–1999. International Archives of Occupational and Environmental Health.; 73: 290–297.

Malchaire J, Piette A, Mullier I., 1996, Vibration exposure on fork-lift trucks, Annals of Occupational Hygiene. 40: 79–91.

Mansfield NJ., 2005, Human response to vibration. Boca Raton: CRC Press

Melemez K., Tunay M., Emir T., 2013, The role of seat suspension in whole-body vibration affecting skidding tractor operators. J. Food Agric. Environ. 11, 1211–1215.

Pheasant S., 1991, Ergonomics, Work and Health. London: Macmillan 212-230.

Piette A., Malchaire J., 1992, Technical characteristics of overhead cranes influencing the vibration exposure of the operators. Applied Ergonomics. 23: 121–127.

Rehn B., Bergdhal I., Ahlgren C., From C., Jarvholm B., 2002, Musculoskeletal symptoms among drivers of all-terrain vehicles. J. Sound Vib. 253: 21–29.

Rehn B., Lundstrom R., Nilsson L., Liljelind I., Jarvholm B., 2005, Variation in exposure to whole-body vibration for operators of forwarder vehicles – aspects on measurement strategies and prevention. Journal of Industrial Ergonomics. 35: 831–842.

Sam B., Kathirvel K., 2006, Vibration Characteristics of Walking and Riding Type Power Tillers. Biosyst. Eng. 95, 517–528.

Scarlett A.J., Price J.S., Stayner R.M., 2007, Whole-body vibration: Evaluation of emission and exposure levels arising from agricultural tractors. J. Terramech. 44, 65–73.

Schoberth H., 1962, Sitzhaltung, Sitzschaden. Berlin: Sitzmobel Springer.

Schrottmaier J., Nadlinger M., 2000, Investigation and tuning of the vibration characteristics of tractors with front suspension and cab suspension. In Proceedings of the Agricultural Engineering, Munster, Germany, 10–11 October, pp. 189–194.

Sherwin L., Owende P., Kanali C., Lyons J., Ward S., 2004, Influence of tyre inflation pressure on whole-body vibrations transmitted to the operator in a cut-to-length timber harvester. Applied Ergonomics; 35: 253–261.

Wu X., Rakheja S., Boileau P.E., 1999, Distribution of human-seat interface pressure on a soft automotive seat under vertical vibration. International Journal of Industrial Ergonomics 24, 545-557.