DEVELOPMENT OF AGRICULTURAL EQUIPMENT SEAT SUSPENSION SYSTEM UNIT TO REDUCE WBV TRANSMITTED TO AGRICULTURAL EQUIPMENT OPERATORS

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ABSTRACT

Suspension seats are designed to isolate vehicle operators from potentially hazardous vertical whole-body vibration. Off-road vehicles are subjected to vibration and shock that can be severe enough to cause seat suspensions to exceed their range of travel, causing end-stop impacts that may increase the hazard to operators. The objective of this study was to develop the agricultural equipment seat suspension system unit to reduce WBV transmitted to agricultural equipment operators. For this a survey conducted in nine farm machinery-servicing stations belong to the Ministry of Agriculture (MOA), Farm machinery station in Gemiza, Egyptian Project for improving the main crops production in Sakha, and the local sector of farm machinery during the years of 2008-2009 through periodic visits. Vibration measurements were performed according to ISO 2631-1, 1997.

The results revealed that the tractor (Nasr model) which has no suspended seat and range of 60-65 horse power in the sample under study considers the highest equipment gives WBV data the frequency weighted RMS acceleration magnitude of the largest single orthogonal axis is in the vertical axis (Z) and also for VDV of weighted RMS acceleration. This constitutes a high risk on the labor body, followed by UTB tractor and rice combine. The results revealed that the highest number of labors postures adopt was (65.7%) for other constrained posture where the labors move in every directions randomly,

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followed by (19.9%) for twisted, and (14.4%) for bent forward and the highest number of tractors distribution by types in the sample was about (26.6 %) for tractor Nasr, followed by (15.6 %) for tractor Kubota, (13.9 %) for tractor UTB, (12.1 %) for tractor John Deere, (11 %) for tractor Fiat new Holland , (8.1 %) for tractor Lamborghini, (6.9 %) for tractor Massy Ferguson, and (5.8 %) for tractor Ford.

Results showed that there are significant differences between the different types of equipment during the variation of farm operations, significant correlation, and significant relationship between the whole body vibration factors.

KEYWORDS: Human factor engineering (HFE), whole body vibration (WBV), mechanical springs, suspension seats, and agricultural equipment features.

INTRODUCTION

Suspension seats are designed to isolate vehicle operators from potentially hazardous vertical whole-body vibration. Off-road vehicles are subjected to vibration and shock that can be severe enough to cause seat suspensions to exceed their range of travel, causing end-stop impacts that may increase the hazard to operators **Scarlett et al. (2005).**

Gunstona *et al.* (2004) stated that many off-road machines are equipped with a suspension seat intended to minimize the vibration exposure of the operator to vertical vibration. The optimization of the isolation characteristics of a suspension seat involves consideration of the dynamic responses of the various components of the seat.

Hamed (2011) conducted a study to revealed that the Nasr tractor is the most dangerous and accidents source among other farm equipment. This tractor was selected to be considered as an example of modification towards safe performance, friendly relation with worker and real benefit of studying anthropomology and whole body vibration.

Blüthner *et al.* (2006) stated that seats with horizontal suspensions can help to reduce detrimental effects of whole-body vibration (WBV) on health, comfort and performance.

Bouazara *et al.* (2006) demonstrated the performance of the optimal seat algorithm to reduce the vibration transmitted to drivers. A general model for a suspension seat had been formulated to analyze the vibration isolation effectiveness of the passive and active damped suspensions. The performance characteristics of one passive and one semi-active suspension seat have been measured in a laboratory under sinusoidal and random excitation. The measured data revealed that the passive suspension performance is strongly dependent upon the height adjustment.

Schust *et al.* (2006) stated that the optimal design of driver seats with horizontal suspension requires knowledge of human response with respect to the perception of the vibration intensity and seat comfort or of the performance in motor tasks.

Wang *et al.* (2006) mentioned that a well-designed tractor seat should be able to accommodate conveniently operators of various sizes and shapes. It should provide adequate body support and geometric parameters of seat with respect to anthropometric data of seating users. The design of a tractor seat should give due consideration to static and dynamic performance requirements.

Mehta *et al.* (2008) mentioned that tractor driving imposes a lot of physical and mental stress upon the operator. If the operator's seat is not comfortable, his work performance may be poor and there is also a possibility of accidents. The optimal design of tractor seat may be achieved by integrating anthropometric data with other technical features of the design.

Patra *et al.* (2008) stated that the biodynamic response of human body seated without a back support and exposed to vertical whole-body vibration have been standardized in ISO 5982 and DIN 45676 in terms of driving-point mechanical impedance and apparent mass. A comparison of ranges defined in two standards; however, revealed considerable differences in both the magnitude and phase. Greater differences were more evident for the three body mass groups, which suggested the lack of adequate reference values of biodynamic responses of seated human subjects of different body masses.

Stein ***et al.*** **(2008)** stated that two horizontal driver's seat suspension configurations, a high friction one and a low friction one, were measured in laboratory. The vibration mitigation performance was compared to that one simulated using a simple seat suspension model loaded with a rigid mass, including the influence of the friction. The vibration mitigation performance was also compared with the performance of a seat with no suspension fitted.

Subashi ***et al.*** **(2009)** stated that the effect of the magnitude of fore-and-aft and lateral vibration on the subjective and mechanical responses of seated subjects has been investigated experimentally using simultaneous measurements of relative discomfort and apparent mass. Twelve male subjects were exposed to sinusoidal vibration at nine frequencies (between1.6and10Hz) at four magnitudes (in therange0.125–1.0ms^{-2} RMS) in both horizontal directions (fore-and-aft and lateral).The method of magnitude estimation was used to estimate discomfort relative to that caused by a 4Hz reference vibration in the same axis.

The objective of this study was to develop the agricultural equipment seat suspension system unit to reduce WBV transmitted to agricultural equipment operators.

MATERIAL AND METHODS

To reduce WBV transmitted to agricultural equipment operators by developing of agricultural equipment seat suspension system unit, a survey was conducted to collect data and information on such incidents specially back pain that happened from farm equipment operating during the years 2008-2009 through periodic visits in nine selected farm machinery-servicing stations and the local sector belong to the ministry of agriculture (MOA), from five governorate; Sharkia, Kafer ElShiekh, Kalubia, Gharbia, and Ismaellia and Egyptian project for improving the main crops production in Sakha, and the local station in Gemeza. The governorates were selected on the basis of highest number of labors who had back pain related to equipment and farm machines and the highest tractors and farm machines density in the region (Equipment and farm machinery bulletin, 2008). The selected farm machinery-servicing stations for the surveys were; Elkasasin, Kafer Sakr, Hehya, Abokaber, Sakha, Kellen, Kotour, Toukh, and Benha.

The collected data were divided in two major categories:

1- Data of the whole body vibration and occupational history related to equipment and farm machines measurements were taken for 245 labors that operate different types of equipment and machines (Nasr, UTB, Massy Ferguson, Ford, John Deere, Kubota, Lamborghini, Fiat New Holland, Kubota & Yanmer combine, and Wheat combine) included with high vibrating mechanism, in different types of farm operations (Primary tillage, Secondary tillage, Harvesting with tractor and mower, Harvesting with rice combine, Transportation off/on road, Land leveling, Precision land leveling (Laser), Ditching, and Harvesting with wheat combine), chosen randomly among farm machines, and equipment operators. Data were collected by interviewing persons using a questionnaire format. Stop watch, and Human vibration analyzer type 4447 were used for the measurements.

2- Data of features of the most dangerous equipment and machines which cause injury were taken for 220 equipment and machines chosen randomly among tractor drivers, combine operators, and machines operators. 173 tractor drivers, 18 wheat combines operators, and 29 rice combines operators were asked some questions according to a questionnaire format.

A suspended seat was designed and manufactured in a local workshop using locally manufactured material as follows (Steel helical coil spring, Steel leaf spring, Rubber spring by casting, Flat iron sheet for the seat, Sponge and leather)

According to Hook's law of modulus of elasticity the materials were selected based on the large deflections within their elastic range and the mechanical properties according to its stiffness, the steel helical coil spring and the steel leaf spring consist of spring steel 52, the template molding by casting consists of cast steel 32, the rubber spring by casting is a mix of granules and used rubber, other factors to be considered are costs, availability, formability, and stress relaxation.

The suspended seat components had the following details and dimensions as shown in figures from Fig. (1) through (6).

A universal testing machine was used to measure the stiffness of modified springs. Then the field experiments of the tractor Nasr model was carried out through the agricultural season (October – November 2010) in the Egyptian project for improving the main crops production farm to test the performance of with developed seat the tractor Nasr model seat to perform safely after and before development.

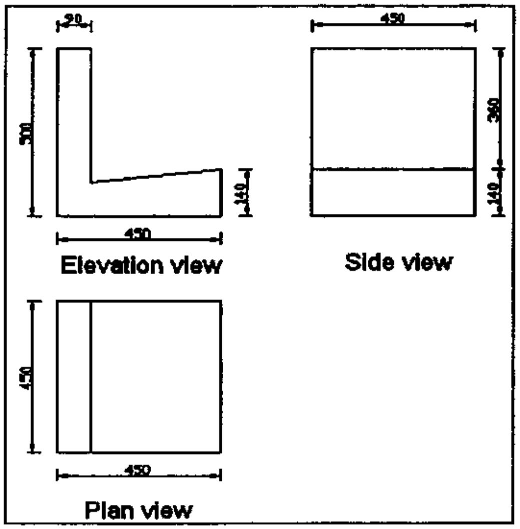


Fig. 1. Layout of the modified suspended seat for tractor Nasr model. Dims in mm

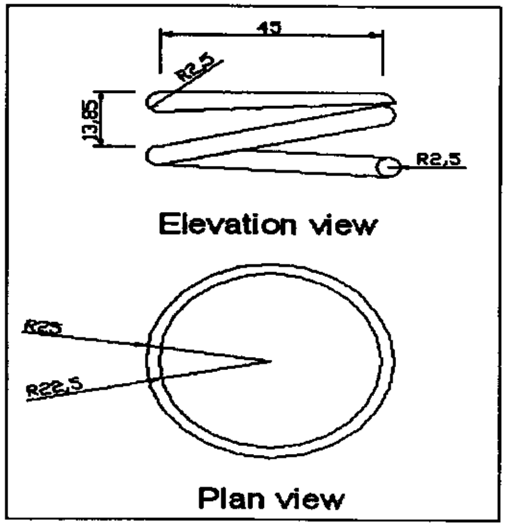


Fig. 2. Layout of the steel helical coil spring.

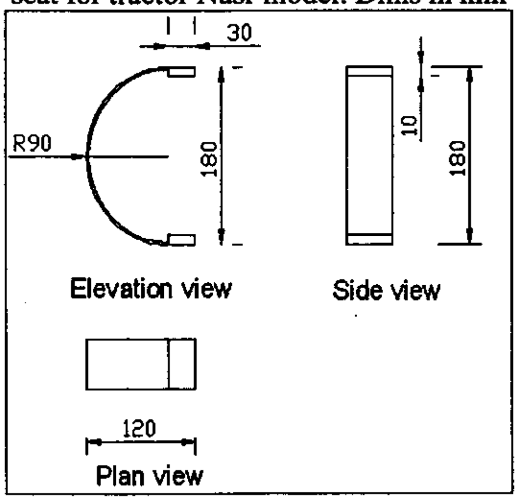


Fig. 3. Layout of the steel leaf spring.

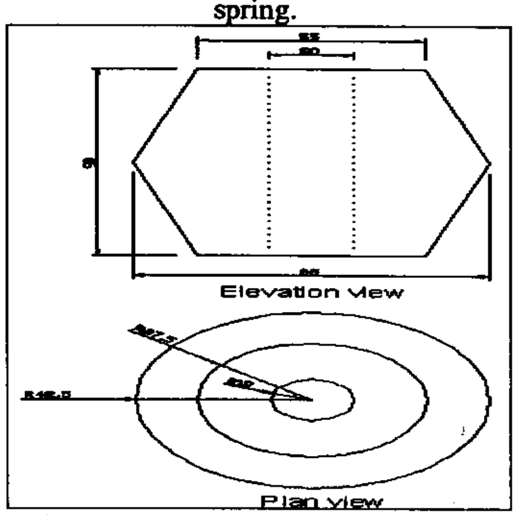


Fig. 4. Layout of the rubber spring by casting.

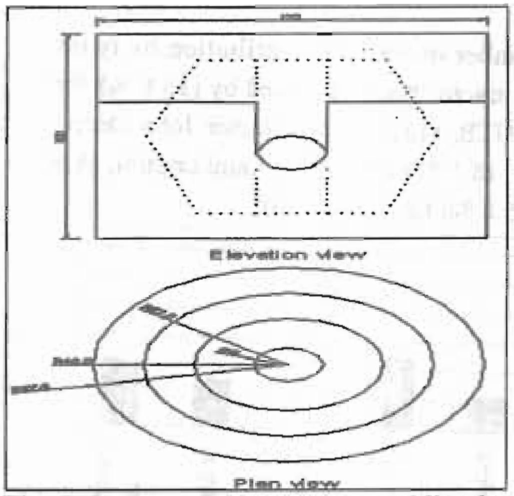


Fig. 5. Layout of the template molding by casting.

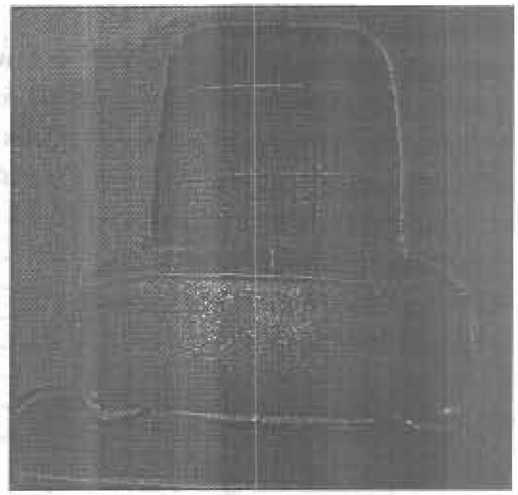


Fig. 6. The modified seat.

RESULTS AND DISCUSSION

Data obtained from the survey were statistically analyzed and plotted in the following figures from fig. (7) and fig. (8). The whole body vibration and occupational history related to equipment and farm machines survey data were classified according to postures adopt, kind of transportation, long to get to work, type of ground, days a week to work, weeks a year to work, and job includes recurrent work done with labor back Fig. (7) showed that the highest number of labors postures adopt was (65.7%) for other constrained posture where the labors move in every directions randomly, followed by (19.9%) for twisted, and (14.4%) for bent forward.

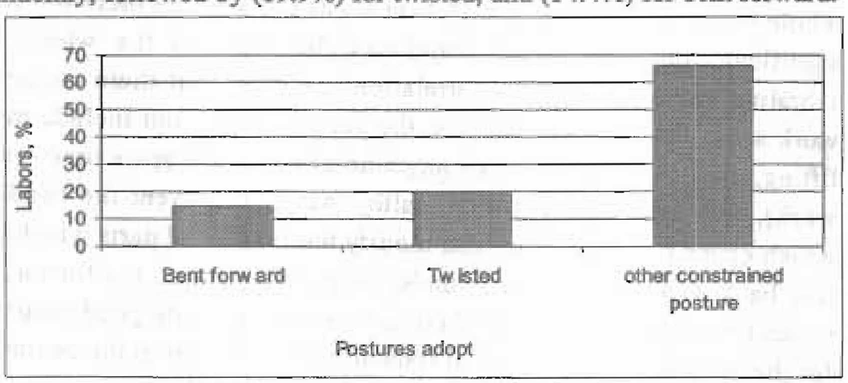


Fig. 7. The postures adopt by labors when driving.

Fig. (8) showed that the highest number of tractors distribution by types in the sample was about (26.6 %) for tractor Nasr, followed by (15.6 %) for tractor Kubota, (13.9 %) for tractor UTB, (12.1 %) for tractor John Deere, (11 %) for tractor Fiat new Holland , (8.1 %) for tractor Lamborghini, (6.9 %) for tractor Massy Ferguson, and (5.8 %) for tractor Ford.

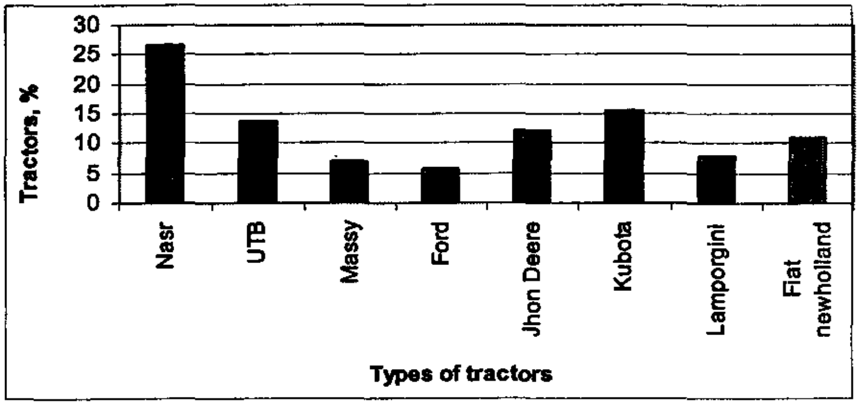


Fig. 8. Tractors distribution by types.

Statistical analysis was thoroughly and in details performed to test the significance of all the whole body vibration factors. The results of significant relationships of chi-square tests revealed that there is a need to provide good suspension for the seat (which get the final transmitted force then to the operator) to ensure operating in safe conditions. Table (1) concluded the statistical analysis for correlation matrix of all the whole body vibration factors. Data analysis showed that there was highly significant and significant correlation between all the whole body vibration factors. All these correlations revealed that there are need to work some days not excessive in the year, job must not include manual lifting, drive on a regular basis any kind of vehicle in spare time (outside work), and take care with the healthy status to prevent the conditions which cause low back pain, and modify the functional parts which cause low back pain in the sample under study (the seat of the tractor, Nasr model) during operating. So there is a need to provide good suspension for the seat (which get the final transmitted force then to the operator) to ensure operating in safe conditions.

Table 1. The correlation matrix of all the whole body vibration factors.

whole body vibration factors	postures adopt	kind of transpo-rtation	long to get to work	type of ground	vehicle jerk or jolt	days a week to work
postures adopt	1					
kind of transportation	.002	1				
long to get to work	.151**	.536**	1			
type of ground	.106	.120*	0.053	1		
vehicle jerk or jolt	.066	.127*	0.01	.584**	1	
days a week to work	.168**	0.081	.253**	.219**	.197**	1
weeks a year to work	.168**	0.081	.253**	.219**	.197**	1.000**
job include manual lifting	.493**	.162**	.297**	0.014	.348**	.292**
job include recurrent work done with labor back	1.00**	0.002	.151**	0.106	0.066	.168**
drive on a regular basis any kind of vehicle in spare time (outside work)	.243**	.169**	.196**	0.111	.273**	0.027
LBP degree	.034	.381**	.238**	0.082	0.1	0.008

Table (2) concludes the results of the statistical analysis of ANOVA for the primary tillage operation of different types of tractors. Data analysis showed that there was highly significant difference on the mean of VDVZ for the different types of tractors; on the other hand, there was insignificant difference on the mean of RMSX, RMSY, RMSZ, VDVX, and VDVY. So it was clear that the vibration measurement parameters for tractor Nasr during measuring time and during twelve hours in primary tillage; the mean of VDVZ, which cause low back pain were between (43.9176 and 73.4593) $m/s^{1.75}$, is more than the threshold limit. However, the values exceeded both of exposure action value and exposure limit value proposed by ISO 2631-1-1997, especially in vertical (Z) axis. So there is a need to provide good suspension for the seat (which get the final transmitted force then to the operator) to ensure operating in safe conditions.

Table 2. The results of the statistical analysis of ANOVA for the primary tillage operation of different types of tractors.

Vibration axes	Tractor	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	F Value	Sig.
RMSX	Nasr	0.45	.008	0.47	0.84	0.24	2.09	1.85	0.133
	UTB	0.25	.007	0.33	0.65	0.18	0.9		
	massy	0.23	.008	0.22	0.65	0.1	0.88		
	ford	0.16	.007	0.14	0.54	0.21	0.53		
	kubota	0.14	.007	0.17	0.47	0.14	0.47		
RMSY	Nasr	0.36	.007	0.44	0.73	0.21	1.75	0.91	0.464
	UTB	0.26	.007	0.33	0.67	0.14	0.94		
	massy	0.23	.008	0.30	0.74	0.17	0.85		
	ford	0.23	0.10	.005	0.64	0.14	0.65		
	kubota	0.25	0.10	0.12	0.67	0.14	0.78		
RMSZ	Nasr	0.43	.008	0.90	1.25	0.38	2.45	1.22	0.311
	UTB	0.46	0.13	0.65	1.24	0.34	1.78		
	massy	0.49	0.18	0.58	1.51	0.22	1.48		
	ford	0.52	0.23	0.15	1.44	0.27	1.37		
	kubota	0.30	0.12	0.36	1.00	0.33	1.13		
VDVX	Nasr	34.7	6.81	13.3	41.4	7.77	194	1.39	0.248
	UTB	5.18	1.49	11.0	17.6	7.33	24.2		
	massy	4.73	1.78	6.38	15.1	6	18.9		
	ford	1.46	0.65	10.3	13.9	10	13.5		
	kubota	3.98	1.62	5.23	13.5	3.1	15.2		
VDVY	Nasr	25.8	5.07	13.6	34.5	11.4	148	1.31	0.277
	UTB	6.59	1.90	10.5	18.9	6.6	23.9		
	massy	4.28	1.62	9.22	17.1	4.9	16.5		
	ford	3.60	1.61	6.97	15.9	5.9	15.6		
	kubota	4.63	1.89	5.51	15.2	2.7	15.6		
VDVZ	Nasr	36.5	7.17	43.9	73.4	38.6	220	5.82	0.001**
	UTB	0.63	0.18	32.3	33.1	31.9	33.9		
	massy	0.003	.001	23.7	23.8	23.7	23.8		
	ford	0.16	.007	23.0	23.4	23.0	23.4		
	kubota	0.174	.007	19.6	20.0	19.6	20.0		

**. ANOVA is significant at the 0.01 level (one-way).

Modification to increase safety considerations

In the tractor Nasr, the seat is the part where the worker comes in deep contact danger. It is more safe to get the worker spine apart enough of the whole body vibration resulted from the unsuspended seat during operation. A suspended seat was designed and manufactured depending on the maximum value of labor weight (115 kg) for the injured labors with low back pain and also the seat weight itself (30 kg). According to the distance to the middle area vertically under the seat, the length of the suspension units (springs) were designed and manufactured at (18 cm), the stiffness of steel helical coil spring, the steel leaf spring, and the rubber spring values were (710, 1330, 1000 kg/m) respectively that to provide safely and suspended distance between the seat and the tractor block.

Data of vibration measurement parameters for tractor Nasr during measuring time and during twelve hours in primary tillage with a suspended seat by rubber spring illustrated graphically in fig. (9) revealed that the RMS of (0.251 m/s^2), (0.218 m/s^2), and (0.369 m/s^2), were for the x, y, z-direction respectively, it is clear that the RMS is not more than the threshold limit, it was (0.369 m/s^2) in vertical (Z) axis. CF of (3.889), (3.36), and (6.028), were for the x, y, z-direction respectively, it is clear that CF is not more than the threshold limit, it was (6.028) in vertical (Z) axis. MTVV of (0.387 m/s^2), (0.358 m/s^2), and (0.704 m/s^2), were for the x, y, z-direction respectively, it is clear that the MTVV is not more than the threshold limit, it was (0.704 m/s^2) in vertical (Z) axis. VDV of (0.62 $m/s^{1.75}$), (0.533 $m/s^{1.75}$), and (1.136 $m/s^{1.75}$), were for the x, y, z-direction respectively, it is clear that VDV is not more than the threshold limit, it was (1.136 $m/s^{1.75}$) in vertical (Z) axis, this in considerably not in excess of the WBV exposure action value (EAV) and also exposure limit value (ELV) proposed by ISO 2631-1-1997.

Fig. (9b) shows that the A (8) RMS of (0.352 m/s^2), (0.306 m/s^2), and (0.37 m $/s^2$), were for the x, y, z-direction respectively. The VDV of (6.728 $m/s^{1.75}$), (5.78 $m/s^{1.75}$), and (8.8 $m/s^{1.75}$), were for the x, y, z-direction respectively. It is clear that the values not exceeded both of exposure action value and exposure limit value proposed by ISO 2631-1-1997, especially in vertical (Z) axis. Rubber spring is better than helical coil and leaf spring so it is recommended to use it as a suspension spring under the seat.

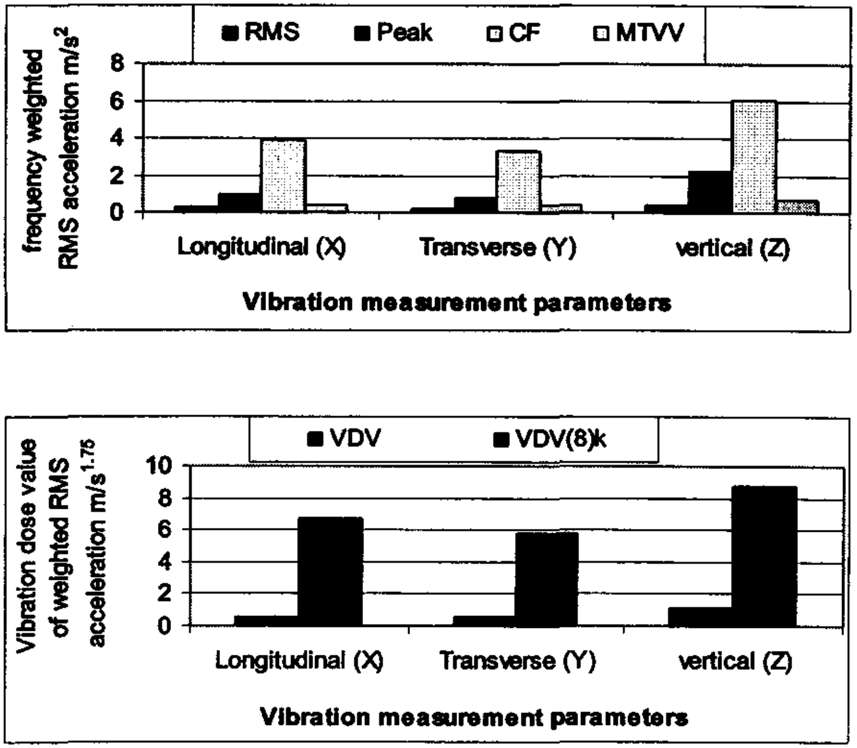
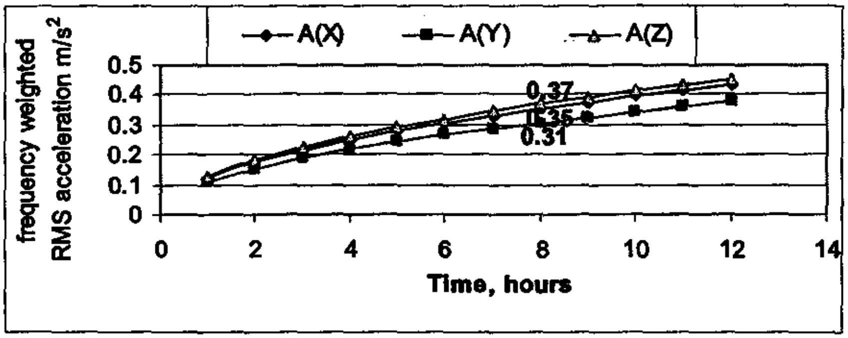


Fig. 9a. Vibration measurement parameters for tractor Nasr during measuring time in primary tillage by using rubber spring.



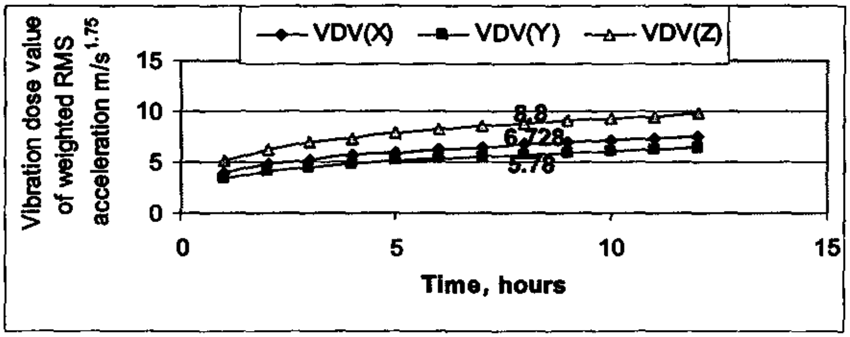


Fig. 9b. Vibration measurement parameters for tractor Nasr during twelve hours in primary tillage by using rubber spring.

SUMMARY AND CONCLUSSION

The aim of this research is to develop the agricultural equipment seat suspension system unit to reduce WBV transmitted to agricultural equipment operators, the results indicated that:-

1- The highest number of labors postures adopt was (65.7%) for other constrained posture where the labors move in every directions randomly, followed by (19.9%) for twisted, and (14.4%) for bent forward.

2- The highest number of tractors distribution by types in the sample was about (26.6 %) for tractor Nasr, followed by (15.6 %) for tractor Kubota, (13.9 %) for tractor UTB, (12.1 %) for tractor John Deere, (11 %) for tractor Fiat new Holland , (8.1 %) for tractor Lamborghini, (6.9 %) for tractor Massy Ferguson, and (5.8 %) for tractor Ford.

3- The tractor (Nasr model) in the sample under study considers the highest equipment gives WBV data the frequency weighted RMS acceleration magnitude of the largest single orthogonal axis is in the vertical axis (Z) and also for VDV of weighted RMS acceleration. This constitutes a high risk on the labor body, followed by UTB tractor and rice combine.

4- A Chi-Square Test was used to determine whether there were any statistically significant relationships between all the whole body vibration factors. The results of significant relationships of chi-square tests revealed that there is a need to provide good suspension for the seat (which get the final transmitted force then to the operator) to ensure operating in safe conditions.

5- The statistical analysis for correlation matrix between all the whole body vibration factors revealed that there are highly significant and significant correlations.

RECOMMENDATION

1- Modify the seat (which gets the final transmitted force then to the operator) and be easy to adjust for the operator's mass and body size, height, fore-aft and backrest adjustments that are especially important. The seat cushions should be ergonomically designed.

2- Use a rubber spring as a suspension spring under the seat.

3- To researchers, it is highly encouraged to perform studies related to the ergonomics, human factors engineering, and human body vibration for the numerous benefits and impact on the safety of workers in order to the increase of productivity of agricultural mechanization units.

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نشرة الآلات والمعدات الزراعية ، ٢٠٠٨ . قطاع الشئون الاقتصادية ، وزارة الزراعة واستصلاح الأراضى ، جمهورية مصر العربية .

الملخص العربي

تطوير وحدة نظام تعليق مقعد المعدات الزراعية لتقليل إهتزاز كامل الجسم المنقول لمشغلى المعدات الزراعية

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يصمم تعليق المقاعد لعزل مشغلى المركبات من المخاطر المحتملة والناتجة من اهتزاز كامل الجسم خاصة فى الاتجاه الرأسى ، ومعظم المركبات الزراعية عرضة للاهتزاز والتصادم بحد كاف لحدوث المخاطر لمشغليها . لذا تهدف هذه الدراسة الى تطوير وحدة نظام تعليق مقعد المعدات الزراعية لتقليل إهتزاز كامل الجسم المنقول لمشغلى المعدات الزراعية من خلال حصر أجرى على ٩ محطات للخدمة الآلية التابعة لوزارة الزراعة الى جانب المشروع المصرى لتحسين انتاجية محاصيل الحبوب الرئيسية والمحطة الاقليمية للبحوث الزراعية بالجميزة والعاملين بالقطاع الخاص فى الميكنة الزراعية من خلال الزيارات الميدانية خلال عامى ٢٠٠٨ ، ٢٠٠٩ .

وقد أظهرت النتائج أن اكثر وضع يتخذه مشغل المعدة فى اتجاهات عشوائية أثناء التشغيل خاصة للجرار الزراعى بنسبة (٦٥,٧%) ، ويليها (١٩,٩%) للتحرك بالتواء ، وتقل عند التحرك للأمام والخلف بنسبة (١٤,٤%) .كما أظهرت النتائج أن الجرار النصر أكثر المعدات الزراعية تسببا في حدوث اهتزاز كامل الجسم خاصة مع عملية الحرث الأولى وبالتالي هناك ضرورة إلى توفيرتعليق مناسب للمقعد ليمتص الاهتزازت أثناء العمل مما يستلزم اجراء التعديلات اللازمة وبناء عليه تم تصميم وتصنيع مقعد للجرار مع ثلاثة نماذج من اليايات (سوستة معدنية حلزونية – سوستة معدنية ورقية – سوستة مطاطية) وتم اختبار الجساءة للنماذج الثلاث وكانت (٧١٠ – ١٣٣٠ – ١٠٠٠كجم / م) لكل من (سوستة معدنية حلزونية – سوستة معدنية ورقية – سوستة مطاطية) على التوالى . وتعتبر السوستة المطاطية هى أفضل الأنواع الثلاثة من اليايات والتى تم استخدامها فى تعليق المقعد لتلافى قيم الاهتزازات المتجاوزة للحدود العتبية الموصى بها

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١ أستاذ الهندسة الزراعية ، كلية الزراعة ، جامعة القاهرة .
٢ أستاذ الهندسة الزراعية المساعد ، كلية الزراعة ، جامعة القاهرة .
٣ باحث أول بقسم بحوث نظم الهندسة الحيوية الزراعية ، معهد بحوث الهندسة الزراعية ، وزارة الزراعة .
٤ مهندس زراعي بقسم بحوث نظم الهندسة الحيوية الزراعية ، معهد بحوث الهندسة الزراعية ، وزارة الزراعة .

وقد أظهرت التجارب الحقلية قبول هذه التعديلات والتي تقلل قيمة جرعة الاهتزاز الى اقل من الحدود العتبية الموصى بها كما أنها لا تؤثر بالسلب على أداء المشغل أو سلامته داخل فى الاعتبار أقصى وزن للعامل فى العينة محل الدراسة وهو (١١٥ كجم) وكذلك وزن المقعد نفسه (٣٠ كجم) وفي يوم حقلي تم تشغيل الجرار النصر في مزرعة المشروع المصرى لتحسين إنتاجية محاصيل الحبوب الرئيسية الكائن بمحافظة كفر الشيخ على عملية حرث أولى بمحراث حفار ٧ سلاح لعدد من المشغلين والمالكين لهذه النوعية من الآلات وثبت معنوية وجدوى تركيب التعديلات الخاصة بها . تم حساب تكاليف كل الأجزاء المعدلة حيث بلغت تكلفة تصنيع المقعد (٨٠٠ جنيه مصرى وقيمة تكلفة التعديلات الملحقة بالمقعد والمتمثلة فى السوستة المطاطية ٧٠ جنيه) . علاوة على أن هذه التعديلات بسيطة وتحتاج الى صيانة ومتابعة بسيطة تقتصر على فحص المسامير والصواميل واللحامات .