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Research Article

Vibration characteristics of tractor seat cushion materials

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ABSTRACT- Operators of agricultural machinery are exposed to an extensive range of indirect vibrations through the seats, which gradually causes chronic damages. One of the ways to reduce the vibrations imposed on the operators is to use appropriate materials in tractor seat cushion. The present study was carried out in order to select appropriate foam or sponge and investigate different factors in reducing vibrations imposed on operator's body so as to promote drivers health and enhance their working efficiency. Vibration experiments were performed at different accelerations on foam and sponge materials at different thicknesses and densities for different occupant masses, and the input and output acceleration signals were recorded and analyzed. Using the analysis of variance, analysis of the mean squares of the input and output acceleration, the type of material used in the seat cushion and the effect of different factors on them were investigated. The results showed that in reducing vibrations, sponge for mass of 90 kg and more and foam for mass of 75 kg and less were more efficient. The sponge was also suitable for acceleration of excitation above 6 ms^{-2}and foam for acceleration of excitation above 3 ms^{-2} and below. Therefore, according to the working conditions of agricultural machines and anthropometric characteristics of Iranian drivers and the appropriate suitable thickness of the seat cushion (6-8 cm), it is recommended that their seat cushion be made of a combination of foam and sponge with high density and thickness of 8 cm.

INTRODUCTION

The ergonomic design of tractor operator seat and workplaces is an effective method for improving operators' comfort. The seat design comprises of static and dynamic characteristics. The vibrations to which the operator of a tractor is subjected are known to be injurious to health and, deleterious to performance. Exposures to vibration for long duration, which does not produce any apparent acute ill effect, might result in chronic injuries. The effect of vibrations on human body causes the muscles to attempt to dampen the vibrations (Chaffin et al., 2006). In addition, the individual's inappropriate posture while driving can affect the amount of the vibration transmitted to him (Demec et al., 2002; Tiemessen et al., 2007). There are reports on an increase in incidence rate of backache and lumbar disorders among drivers of tractors, trucks, cranes, buses and other land vehicles. Most drivers of professional vehicles are suffering from backache. Prolonged exposure to whole body vibration is one of the causes of backache (Lings and Leboeuf, 2000; Azrah et al., 2014).

It is important to study the problems caused by mechanical damages to tractor drivers and when the frequency of vibration transmitted to the driver's body is within the natural frequencies range of his body organs, it is of particular importance. If a strong vibrating stimulator exposes the driver's body with a frequency close to the body resonance frequencies, damage occurs because of resonant oscillations (Maleki and Mohtasebi, 2014). Fairley and Griffin, 1990 studied the vibration values of 0.25, 0.5, 1, and 2 m s^{-2} within the frequency range of 0.2-20 Hz among 8 individuals. They concluded that according to the individual's apparent mass, resonant frequency reduces from 6 to 4 Hz with an increase in vibration size.

In a study, researchers investigated the intensity of backache as a result of vibration among 169 tractor drivers in Punjab, India. Twenty-nine of those drivers backache. The results of the study showed that there was a direct relationship between backache intensity and an increase in the rate of exposure to vibration and age (Koley et al., 2010). The range of damage caused by vibration differs depending on the frequency size, vibration range, and the type of the vehicle (Mansfield and Griffin, 2002). Whole body vibration (WBV) is a generic term used when vibrations (mechanical oscillations) are transferred to the human body. Humans are exposed to vibration through a contact surface that is in a mechanical vibrating state. It is a potential form of occupational hazard, particularly after years of exposure(Mansfield 2004).

A number of studies focused on immediate effects of whole body vibration (McBride et al., 2010; Turner et al., 2011) and some concentrated on effects in long term (Machado et al., 2010; Tsai and Lin, 2011) have reported different and sometimes contradicting results, which can be attributed to the settings of the driver seat (frequency and range), the individuals' situation during exposure to vibration, and the time of vibration exposure (Lamont et al., 2011).

Taking into account the ergonomic aspects and by utilizing some foam materials in the seat of tractors and other off-road vehicles, the risks related to whole body vibration and musculoskeletal disorders can be reduced among drivers (Makhsous et al., 2005). Modifying the foam of seat cushion through polymers is one of the methods to reduce the vibrations imposed on the driver's body. Over the last 4 decades, polymers have had a great effect on the industry. Using such materials has helped the manufacturers achieve significant goals such as insulation of temperature and sound, absorption of vibrations and shocks. Appropriate design of seat can be a determining factor in modifying the loads imposed on the body and reducing discomfort (Mehta and Tewari, 2000).

In general, polymers used in foam production are divided into thermoplastic and thermoset groups, the difference is the type of the polymer and the injected gas. One of the polymers used in seat cushion is polyurethane, which has a good absorption capacity; therefore, it is a good material to reduce the vibrations imposed on drivers (Barikani, 2007). Polyurethanes have very high resistance against vibrations, friction, shock, and crack. Polyurethane foam is a polymeric material having cellular structure. Closed cell structure leads to its dimensional stability and resistance of semi-rigid foam structure against tension and compressive forces. In addition, open cells in the structure of semi-rigid foam leads to reversibility and prevention of structure decline against compressive forces. Polymers have limitations such as weakness at high temperature and moisture. Existence of this condition reduces the foams' performance largely due to their thermoplastic properties (Barikani, 2005).

According to DIN standard (7726 (1982)), foam is a mass that is composed of open- or closed-cellular structure. Its initial density is lower than its cross-linked state. Flexible foams have less resistance against force application compared to rigid foams. Flexible foams are normally composed of polyurethane according to DIN standard number 18159-1 (DIN, 1991) or standard DIN EN 14315-1 (DIN, 2002).

In their study, Cvetanovic et al. (2017) attempted to reduce the vibration levels using various vibration-absorbing components, such as cushions, at driver's seat. The results of their measurements showed that the vibration levels were significantly lower in comparison to original seats. Another study was done to examine the agro technical surface, speed of movement and seat upholstery on operator's whole body vibrations. The vibration measurement for sponge resulted in the highest values on the asphalt surface in the direction of the x axis while the lowest value was recorded in the direction of the y axis. The vibrations recorded on memory foam have the same values on the asphalt surface in the direction of all three axes. The highest vibration value was recorded on the alfalfa field in the direction of the z axis (Barač et al., 2018).

Foam and sponge are materials with cellular structure with density lower than other materials due to presence of spherical bubbles of gas in polymeric matrix. In open-cell foams, cavities are continuous; therefore, particles of water vapor are placed in amidst the solid phase cells, while gas phase is discontinuous in closed-cell foams. Polyurethane with closed cellular structure based on polyol, containing acidic hydrogen, chemically reacts with polyisocyanate in the presence of catalyzers and puff-causing substances. Variable pressure foaming (VPF) is formed by mixing enough water and isocyanate, and presence of carbon dioxide, a process which converts the primary materials into foam (Amiri, 2011).

Polyurethane foams are available in two types; hot and cold foams. Hot foams are rigid and become softer with time, and its elasticity declines gradually. Cold foams have an open-cellular structure, and indirect or low temperature is used to produce it. Low temperature provides more opportunity to form the molecules of this type of foam. As a result, its elasticity is more than hot foam, and is also softer. Open cells cause the air available in the cells to move while pressure is exerted and the foam to return to its first state when the pressure is removed. This quality causes cold foam to be flexible and soft. Compared to hot foam, cold foam has a longer lifespan and does not decline or lose its elasticity; therefore, it is appropriate for vehicles' seat. Sponges are porous materials, in which gas bubbles are encapsulated inside their pores, and they have different applications depending on their softness or rigidness. (Corsaro and Sperling, 1990).

The effect of foam thickness (4, 6, and 7 cm) on maximum contact pressure was examined. With a decrease in thickness, contact pressure first decreased slowly then fast. The effect of density of polyurethane foam with thickness of 7 cm (30, 40 and 50 kg m^{-3}) was also investigated. Results showed that the decreasing of foam density of the seat cushion affected the contact pressure on the occupant and improveed the seat comfort. (Mircheski et al., 2010).

Due to the importance of agricultural tractor seat design (Drakopoulos, 2007), it is necessary to choose polyurethane foam or similar foam in order to reduce the amount of the vibrations imposed on the body and enhance the driver's health and efficiency with appropriate seat.

In this regard, the present study was carried out in order to select appropriate foam for seat cushion as the absorber of vibration and to investigate vibration decrease using foam material and sponge having different qualities. The second objective was to examine the effect of different factors on foam and sponge performance. In so doing, physical and content characteristics of the seat mattress as well as the effect of factors such as thickness, density, driver's mass and acceleration of vehicles in terms of vibration have been considered and analyzed.

MATERIALS AND METHODS

In this study, foam and sponge with different thickness and density were exposed to excited vibration and the mean input and output accelerations were recorded These factors were material type, foam type, thickness and density as affected by various levels of simulated acceleration and the driver's mass at three levels. The appropriate positions to install the accelerometers were chosen using Standard ISO2631 to examine the effective range of transmissibility in seat foam structure (Standard, 1997). Test were carried out in several replicates and the mean output acceleration was recorded and analyzed. Tests were carried out using the shaker machine available at Shahrekord University, Iran (Fig. 1). By installing an unidirectional accelerometer (Table 1) on the shaker platform and another one on the seat foam equivalent at the level of cushion surface, the input and output accelerations were recorded in the form of vibration signals. Afterwards, MATLAB Software was employed to measure the mean of input and output accelerations in frequencies of one-third octave bandwidth through Duncan test.

The first stag, the effect of the thickness and density of the seat cushion mat on the vibration transfer to the occupant was investigated. Polyurethane foam in two types of hot foam (with a density of 40 kg m^{-3}) and cold foam (with a density of 50 kg m^{-3}) with different thicknesses of 6, 8 and 10 cm as seat mat were considered.

In the next stage, the effect of Polyurethane sponges (with a thickness of 12 cm) with having density of 12.5, 20, 30 and 50 kg m^{-3} exposed to vibration as investigated. Each foam and sponge sample were placed separately on the shaker. All samples were exposed to vibration for driver's mass of 75, 90, and 105 kg, in three acceleration of 1, 3, and 6 m s^{-2}. A continuous measurement then was made during 5 min with the 4410 Hz sampling rate. We ruled out making measurements during more prolonged periods in light of previous experiences in which no significant variations (Ferrarin et al., 2000) therefore each tests were repeated twice.

Table 1. Specifications of the instruments

Instrument	Manufacturer	Model	Range (Hz)	Sensitivity
Accelerometer	DYTRAN	3255A2	1 - 10,000	10 mV/ms^{-2}
Data Acquisition	BSWA	MC 3022	20 - 20,000	-
Shaking test rig	-	-	1 - 2000	-

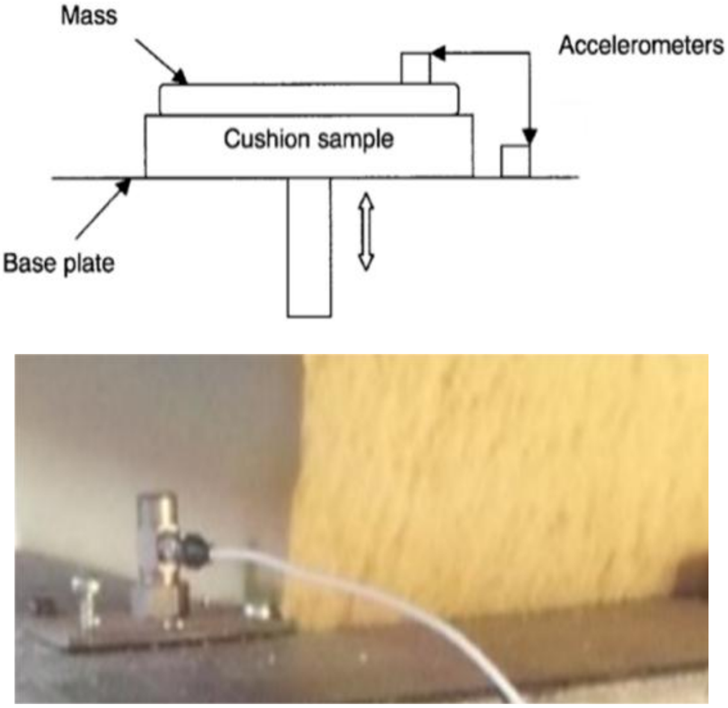


Fig.1. Schematic vibration test rig (top) and the unidirectional accelerometer (bottom)

RESULTS AND DISCUSSION

Frequency analysis and mean square analysis of the input and output accelerations of main factors were carried out using SPSS Software. Mean square of output acceleration in frequencies of one-third octave bandwidth for main factors and the effect of their interaction are indicated in Table 2 for foam and Table 3 for sponge materials. One factor analysis of variance of sponges indicated that mean square of output acceleration in octave bandwidth frequencies was significantly affected by input acceleration, driver’s mass. Two-factor analysis of variance of sponges was significant difference in density & acceleration and also density & driver’s mass but was not significant difference in acceleration & driver’s mass and also density & acceleration & driver’s mass.

The Effects of Driver Mass

Mean squares of input acceleration and output acceleration are indicated in Figs 2 to 5 at frequencies of one-third of octave bandwidth for driver’s mass of 75, 90, and 105 kg for both foam and sponge cushion seats. Decreased output acceleration at all frequencies may be attributed to an increase in damping for higher masses, in other words, a decrease in mass causes a reduction in the force exerted to the seat backrest resulting in slight changes in damping. In examining the mass of 105 kg on foam, the trend of decrease in vibration is almost constant for all frequencies; however, foam is more appropriate for lower weights compared to sponge.

If the sponge can considered as series of springs. The sponge becomes more compressed due to increase of driver mass and assumed springs move less. In addition, its hyper-elastic quality changes and arrangement of sponge cavities becomes similar to foam.

The Effects of Acceleration

The results of the effects of acceleration factors on output frequencies for foam and sponge materials showed that mean square of output acceleration was significantly affected for foam but not for sponge in a significant manner. The results of foam and sponge are presented in Fig. 5 to 7 at three levels of acceleration.

Table 2. Variance analysis of output acceleration in frequencies of octave bandwidth as affected by thickness, stimulation acceleration interaction and drivers’ mass and interaction of the three factors for foam material

Source of Variation	Degree of Freedom	Frequency (Hz)												
		2	4	8	16	32	64	128	256	512	1024	2048	4096	8192
Thickness **(T)**	2	2.218^{ns}	1.743^{ns}	*3.512	0.0^{ns}	0.0^{ns}	**800.0	20.82^{ns}	*100.0	100.0^{ns}	44.92^{ns}	4.25^{ns}	3.388^{ns}	4.008^{ns}
Acceleration **(A)**	2	**0.0	**0.0	**0.0	0.0^{ns}	1100.0^{ns}	**400.0	**300.0	0.0^{ns}	100.0^{ns}	100.0^{ns}	*100.0	*0.0	*0.0
Driver mass **(M)**	2	1.579^{ns}	**5.145	2.128^{ns}	3.862^{ns}	1300.0^{ns}	**400.0	**500.0	0.0^{ns}	**400.0	**600.0	**300.0	**200.0	**100.0
T*A	4	*3.694	**4.226	*3.795	9.003^{ns}	500.0^{ns}	**500.0	**100.0	**100.0	100.0^{ns}	5.418^{ns}	1.991^{ns}	1.907^{ns}	2.402^{ns}
T*M	4	2.739^{ns}	**3.670	2.617^{ns}	0.0^{ns}	900.0^{ns}	**500.0	*0.0	0.0^{ns}	100.0^{ns}	41.8^{ns}	7.736^{ns}	5.643^{ns}	5.355^{ns}
A*M	4	*3.961	**6.113	*2.885	4.052^{ns}	1500.0^{ns}	**500.0	**100.0	0.0^{ns}	100.0^{ns}	100.0^{ns}	*0.0	**100.0	**0.0
T*A*M	8	79.720^{ns}	1.154^{ns}	1.093^{ns}	0.0^{ns}	200.0^{ns}	**500.0	**0.0	*0.0	100.0^{ns}	5.387^{ns}	7.977^{ns}	2.614^{ns}	2.929^{ns}
Error	61	1.15	0.92	1.15	9.52	700.00	0.0	9.43	0.0	0.0	0.0	0.0	0.0	4.11

Table 3. Variance analysis of output acceleration in frequencies of octave bandwidth as affected by density, stimulation acceleration interaction and drivers’ mass and interaction of the three factors for sponge material

Source of Variation	Degree of Freedom	Frequency (Hz)												
		2	4	8	16	32	64	128	256	512	1024	2048	4096	8192
Density **(D)**	3	*833.2	**243.4	617^{ns}.2	**7.035	1300^{ns}	0^{ns}	0.0^{ns}	**800	100^{ns}	5.515^{ns}	1.802^{ns}	1.172^{ns}	0.693^{ns}
Acceleration **(A)**	2	**5.935	**5.363	*4.899	0.0926^{ns}	**42700	**700	100.0^{ns}	**2300	800^{ns}	*100.0	*0.0	**0.0	*3.457
Driver mass **(M)**	2	**5.173	2.059^{ns}	*5.471	3.739^{ns}	**23600	**400	0.0^{ns}	**700	700^{ns}	**100.0	*0.0	**0.0	**8.905
D*A	6	**4.546	*2.0	**6.645	**9.070	**5500	**300	8.509^{ns}	**900	400^{ns}	9.135^{ns}	4.721^{ns}	**8.148	1.962^{ns}
D*M	6	*2.461	1.048^{ns}	*3.415	2.575^{ns}	**5000	**300	0.0^{ns}	**400	400^{ns}	0.0^{ns}	4.140^{ns}	**9.307	*3.540
A*M	3	*2.843	2.167^{ns}	*3.318	1.715^{ns}	**20600	**400	0.0^{ns}	**500	400^{ns}	0.0^{ns}	4.040^{ns}	3.429^{ns}	32.470^{ns}
D*A*M	6	**2.693	1.130^{ns}	*3.349	*4.138	**5100	**300	0.0^{ns}	**300	300^{ns}	6.235^{ns}	90.09^{ns}	1.603^{ns}	32.30^{ns}
Error	65	100	100	100	100	51400	2900	2200	6100	19500	800	200	100	100

Fig. 5 suggests that in vehicles with more vibration acceleration is more appropriate to use sponge in seat cushion rather than foam. Figure 6, indicates better performance of foam for low-acceleration. Foam and sponge have contrary results in accordance with acceleration factor. For instance, for acceleration of 6 ms^{-2}, sponge reduced vibration more, and for acceleration of 3 ms^{-2}, foam is more appropriate. As observed in Fig. 7, for lower accelerations, foam and sponge showed similar performance. The trend of diagram changes shows that foam is more suitable for higher masses, and sponge performs better than foam for higher acceleration. The cells of internal structure of foams are close to one another, and they can almost be considered more solid than those of sponges.

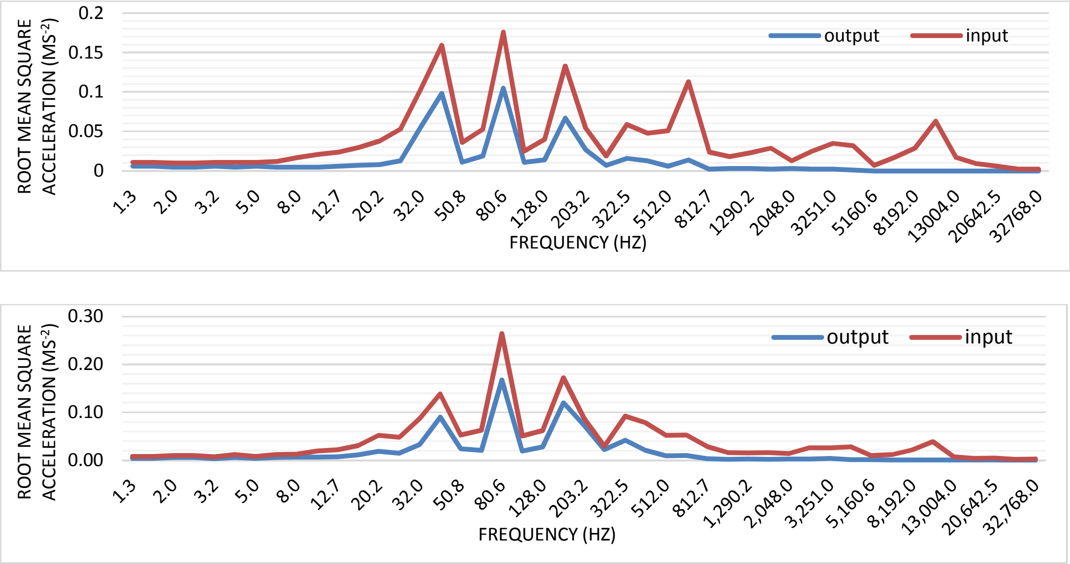


Fig. 2. Mean input and output accelerations for mass of 105 kg at different frequencies of one-third octave spectrum for the two materials of sponge (top) and foam (bottom)

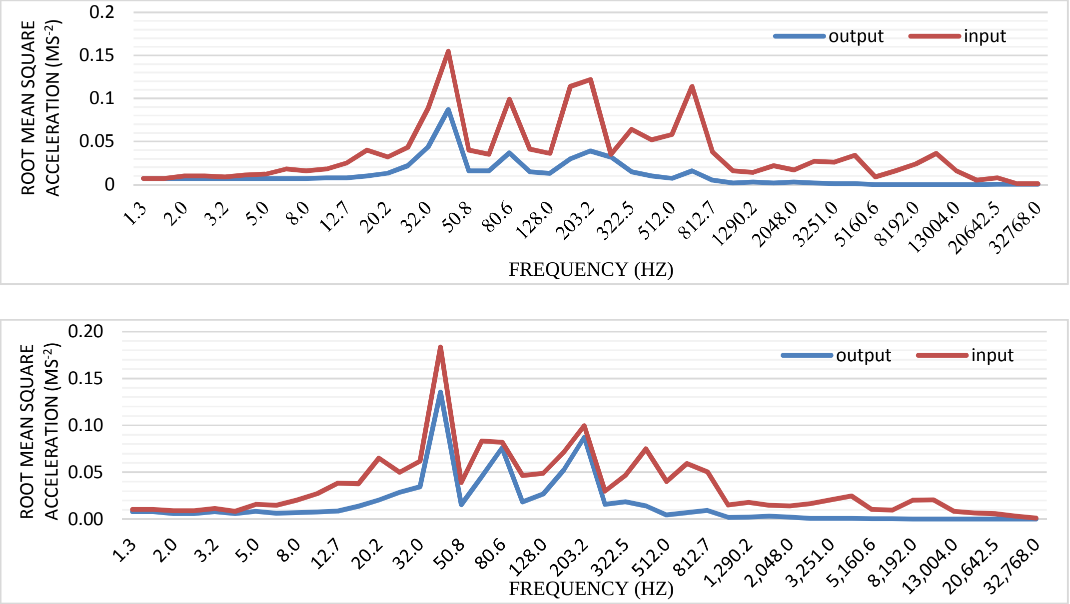


Fig. 3. Mean input and output accelerations for mass of 90 kg at different frequencies of one-third octave spectrum for the two materials of sponge (top) and foam (bottom)

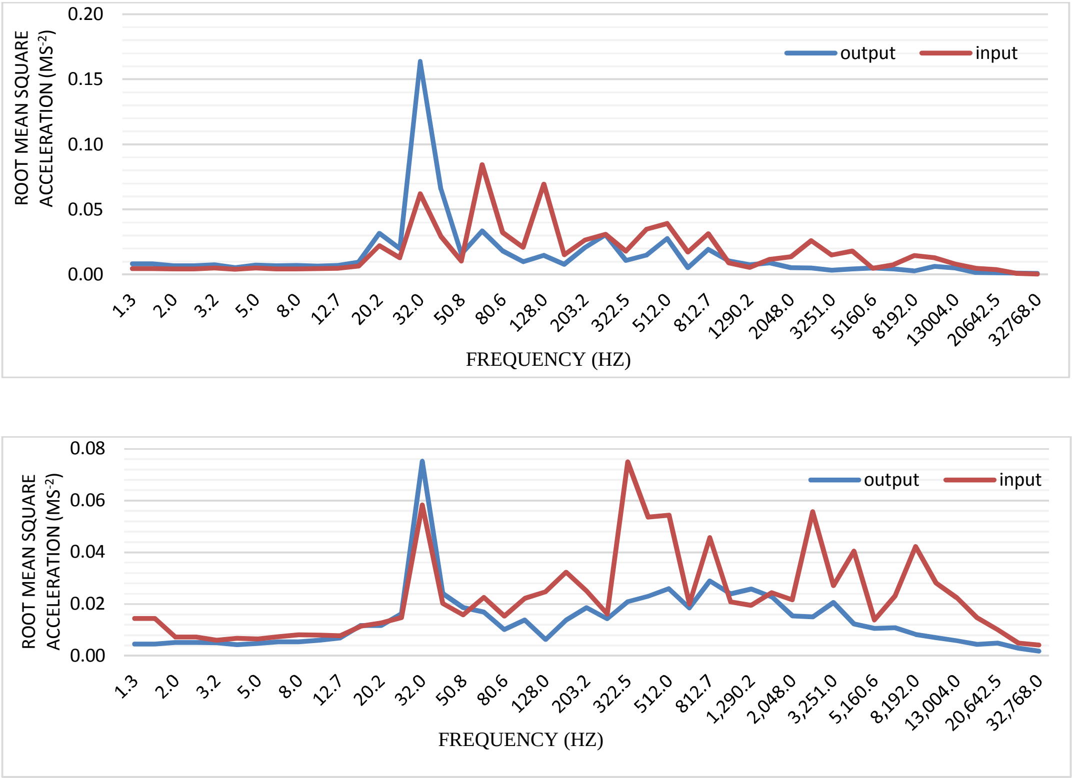


Fig. 4. Mean input and output accelerations for mass of 75 kg at different frequencies of one-third octave spectrum for the two materials of sponge (top) and foam (bottom)

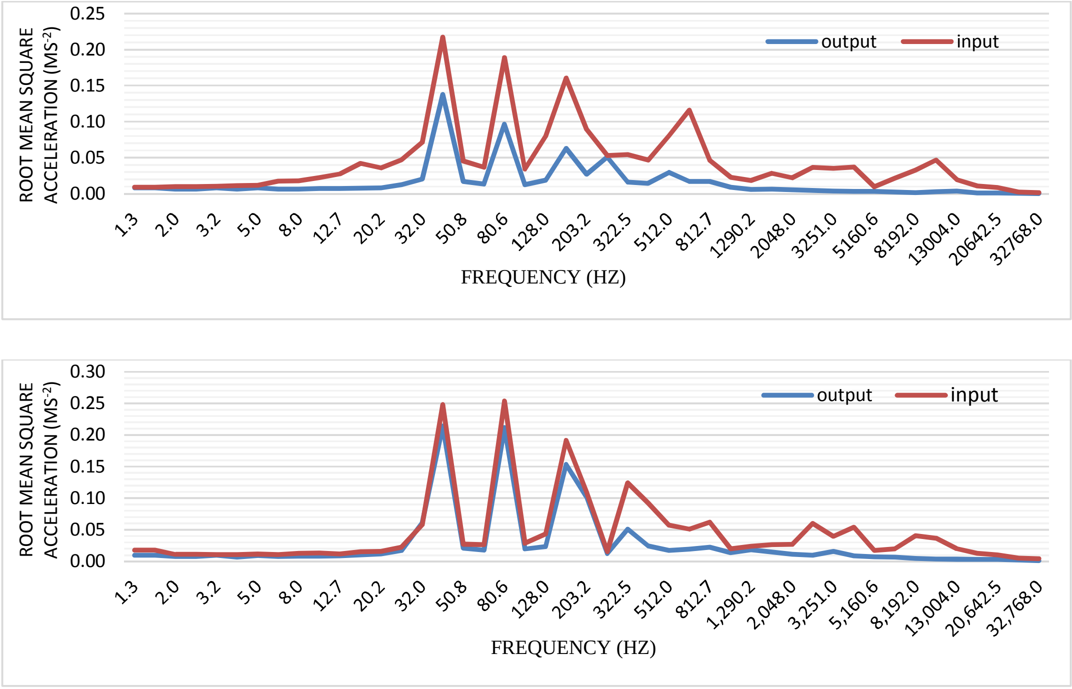


Fig. 5. Mean input and output accelerations for acceleration of 6 ms^{-2} at different frequencies for sponge (top) and foam (bottom)

The structure of the internal pores of sponges become closer to one another at higher accelerations and become similar to foam structure. Therefore, sponge and foam can be equally used for vehicles with acceleration of 6 ms-^{2} and higher but foam should necessarily be used for lower accelerations to provide equal performance.

The Effects of Density

Analysis of variance of density of the sponge materials shows that there was no significant difference in output acceleration at frequencies of one-third octave bandwidth within sponge samples. Fig. 8 presents the effect of frequencies of one-third octave bandwidth on output acceleration at four levels of 12.5, 20, 30, and 50 kg m^{-3} sponge densities.

According to figures, for sponges with density of 50 kg m^{-3}, the mean output acceleration compared to the input acceleration had a higher decrease. Sponges with density of 30 and 50 kg m^{-3} showed acceptable results; therefore, it can be concluded that the amount of vibration absorption of sponges with higher density is higher. Higher density is due to the heavier weight of the raw material per unit volume and the shorter the distance between the sponge cavities. Therefore, considering the arrangement of the holes in the sponge with higher density, the results are reasonable.

Fig. 9 shows effect of frequencies of one-third octave bandwidth on output acceleration according to density factor at two levels of 40 kg m^{-3}for hot foam and 50 kg m^{-3} for cold foam. Although foams with densities of 40 and 50 kg m^{-3} have acceptable performance, the level of vibration is higher in foams with higher density. The results showed that for different frequencies, the trend of decrease in foam with density of 40 kg m^{-3} is almost the same.

The Effect of Thickness at Different Frequencies for Hot Foam

Analysis of variance of thickness of the hot foam materials shows that there was no significant difference in output acceleration at frequencies of one-third octave bandwidth within hot foam samples. Fig. 10 shows effect of frequencies of one-third octave bandwidth on output acceleration according to thickness of hot foam at three levels of 6, 8, and 10 cm. Results showed that the amount of vibration absorption in the foam with a thickness of 10 cm is less, while the performance of foam with thickness of 6 and 8 cm was almost the same.

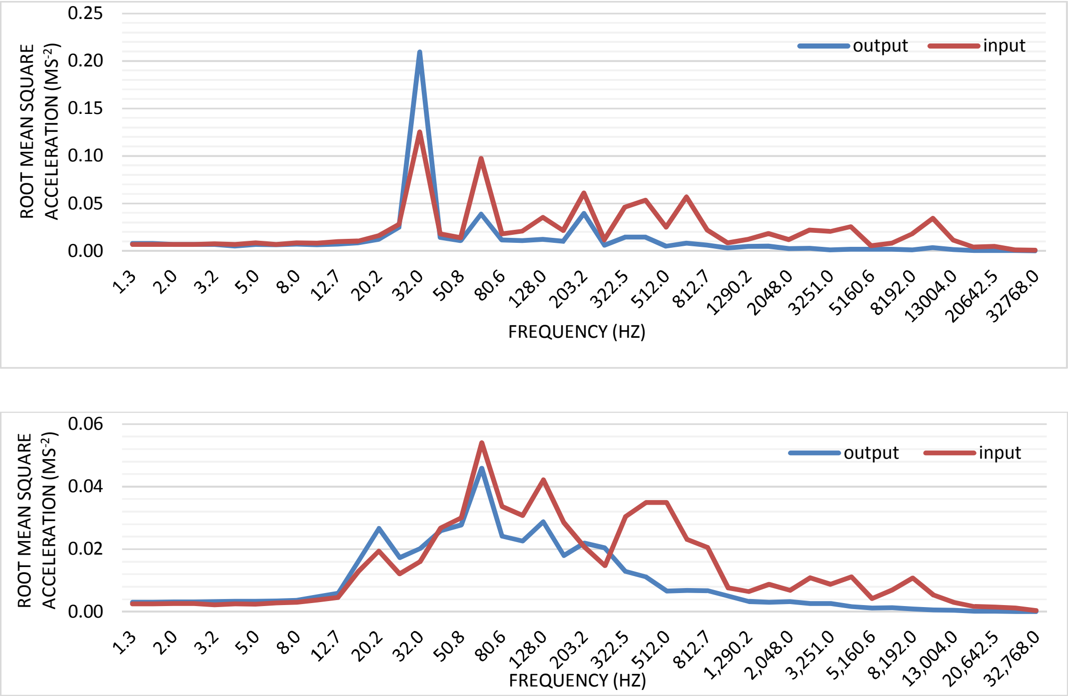
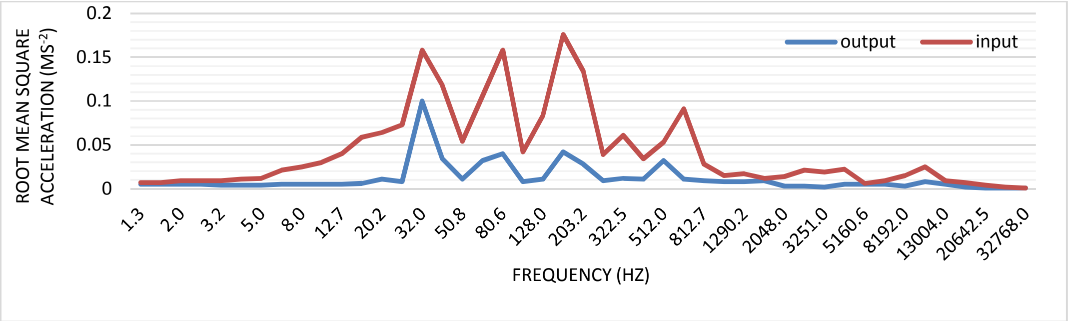


Fig. 7. Mean input and output accelerations for acceleration of 2 ms^{-2} at different frequencies for sponge (top) and foam (bottom)



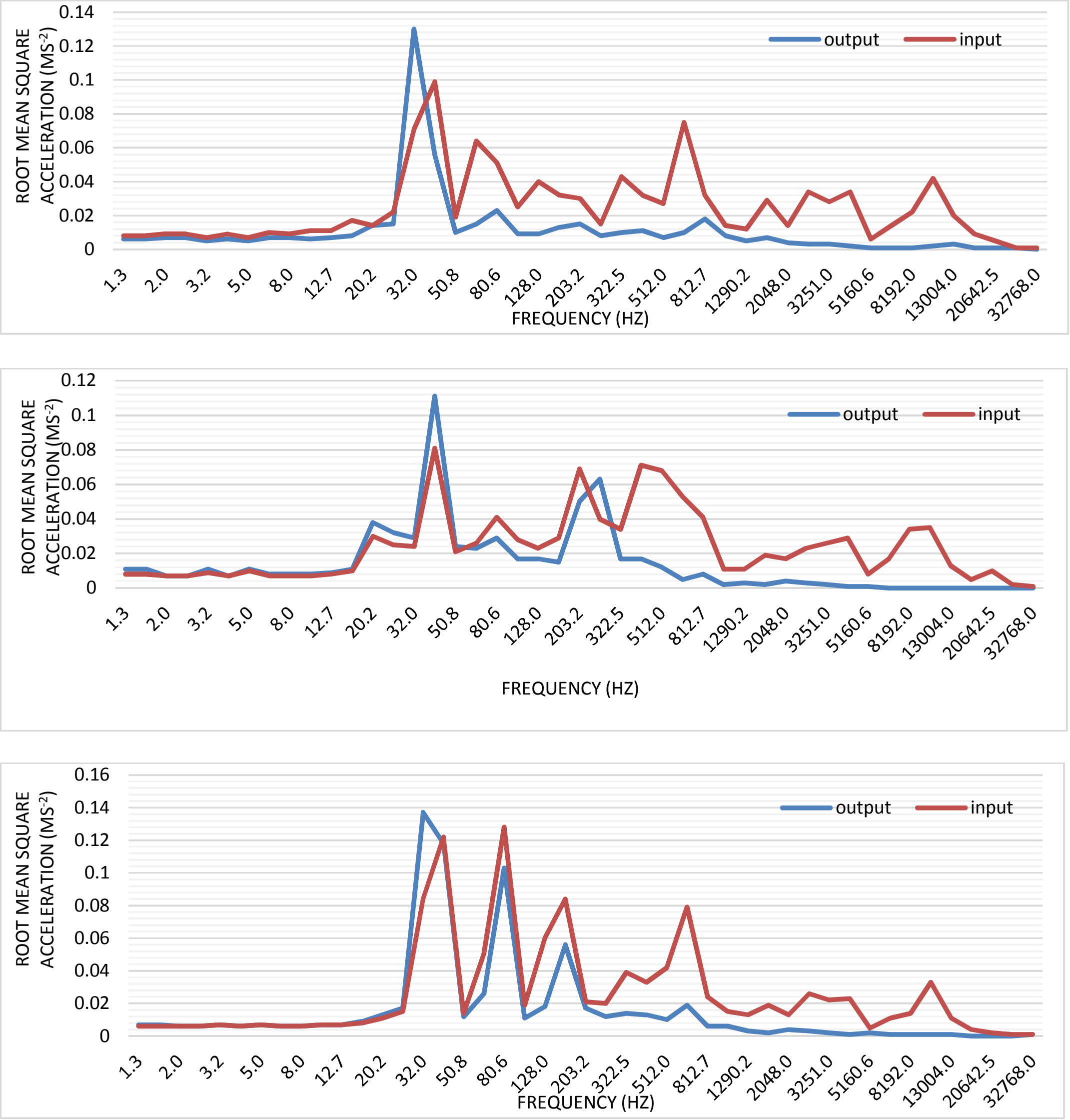
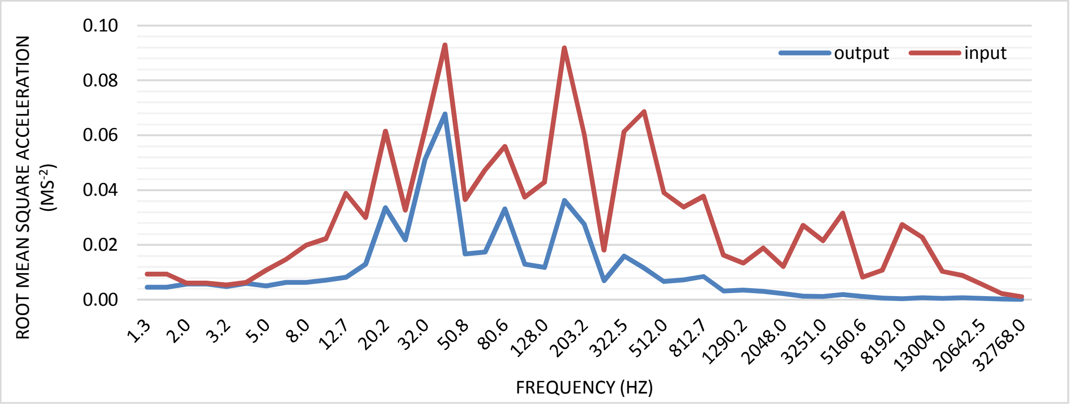


Fig. 8. Mean input and output acceleration for sponge with density of 50, 30, 20 and 12.5 kg m^{-3} (from top to bottom, respectively) at different frequencies



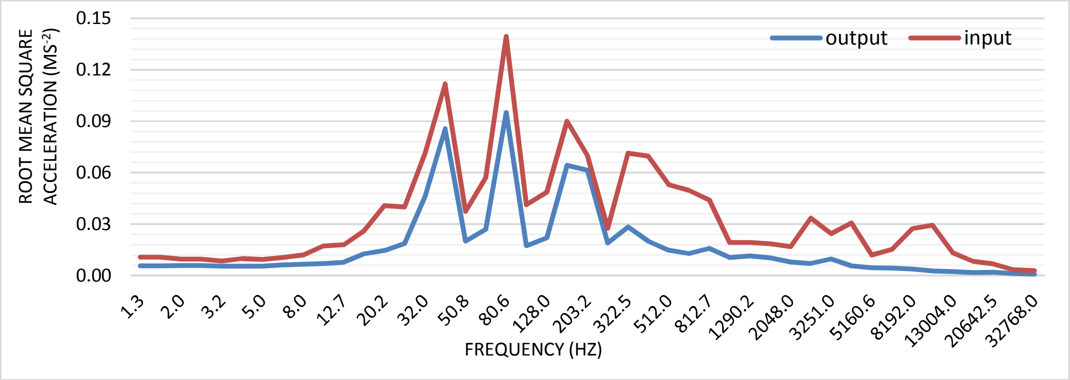


Fig. 9. Mean input and output acceleration for foam with density of 50 kg m^{-3} (top) and 40 kg m^{-3} (bottom) at different frequencies

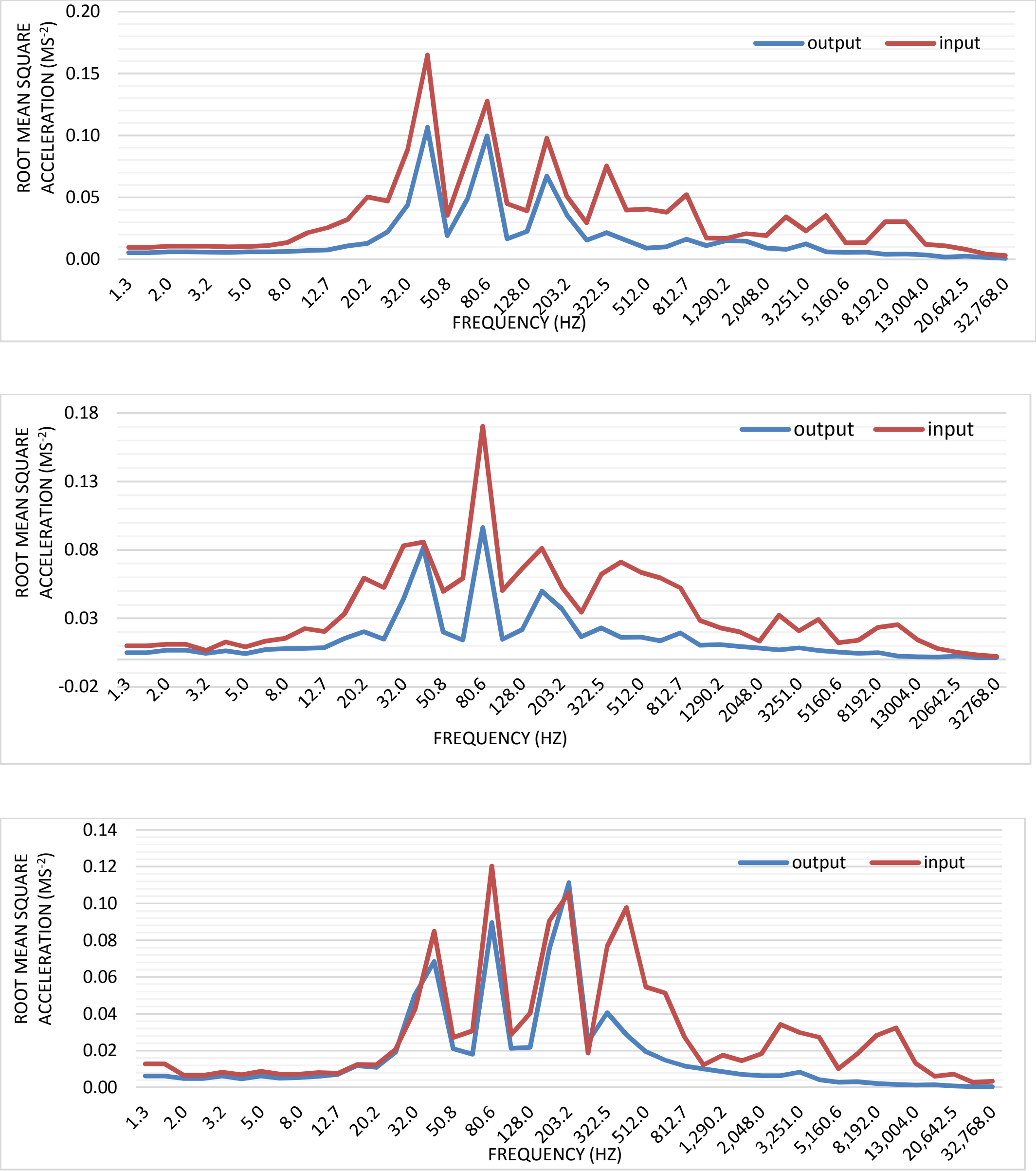


Fig. 10. Mean input and output accelerations for hot foam of 6 (top), 8 (center) and 10 (bottom) cm at different frequencies

CONCLUSIONS

In general, the results of the present study showed that polyurethanes play an effective role in damping vibration. Using appropriate foam or sponge material in seat cushion can help reducing vibrations exerted to the driver. Due to the anthropometric conditions of the drivers, for driver with a mass of 90 kg (and higher), use of sponges is recommended, while for drivers with a mass of 75 kg (and less), foam is recommended.

Due to acceleration factor, the sponge showed better performance for higher acceleration and foam for lower acceleration.

Another factor influencing the reduction of vibrations transmitted to the driver is the density of the seat cushion, which according to the results obtained for both foam and sponge materials, the selection of materials with higher densities (above 40 kgm^{-3}) has a higher priority.

Therefore, according to the working condition of agricultural tractors and anthropometric characteristics of Iranian drivers and the appropriate suitable thickness of the seat cushion (6-8 cm), in order to reduce the vibrations transmitted to the drivers' bodies, It is suggested that the tractor seat cushion be made of a combination of high density foam and sponge with a thickness of 8 cm to be more efficient in different operating conditions.

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تحلیل ارتعاشی مواد بالشتک صندلی تراکتور

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چکیده- رانندگان ماشین‌های کشاورزی در معرض محدوده وسیعی از ارتعاشات غیرمستقیم، از طریق صندلی آن هستند و به مرور زمان آسیب‌های دائمی برای آن‌ها به‌وجود می‌آید. یکی از راه‌های کاهش ارتعاشات منتقل شده، استفاده از مواد مناسب برای نشستگاه صندلی تراکتور است. مطالعه حاضر به منظور انتخاب فوم یا اسفنج مناسب و بررسی عوامل مختلف در کاهش لرزشهای وارد شده به بدن اپراتور به منظور ارتقاء سلامت رانندگان و افزایش کارآیی کار آنها انجام شده است. آزمایش‌های ارتعاشی در شتاب‌های مختلف روی دو ماده فوم و اسفنج در ضخامت‌ها و دانسیته‌های مختلف برای جرم‌های متفاوت سرنشین انجام شد و سیگنال‌های شتاب‌های ورودی و خروجی ثبت و تجزیه و تحلیل شدند. با استفاده از آنالیز تحلیل واریانس میانگین مربعات شتاب ورودی و خروجی، نوع ماده مورد استفاده در نشستگاه صندلی و اثر عوامل مختلف بر آن‌ها بررسی‌شد. نتایج نشان داد که در کاهش ارتعاشات اسفنج برای جرم ۹۰ کیلوگرم و بیشتر و فوم برای جرم ۷۵ کیلوگرم و کمتر، کارایی بالاتری داشتند. همچنین اسفنج، برای شتاب تحریک بالاتر از ۶ متر بر مجذورثانیه و فوم، برای شتاب تحریک ۳ متر بر مجذورثانیه و پایین‌تر مناسب بود. لذا با توجه به شرایط کاری ماشین‌های کشاورزی و خصوصیات انتروپومتریکی راننده‌های ایرانی و محدود مناسب ضخامت کوسن صندلی (۶-۸ سانتیمتر)، پیشنهاد می‌شود کوسن صندلی آن‌ها به صورت ترکیبی از فوم و اسفنج با دانسیته بالا و ضخامت ۸ سانتیمتر ساخته شود.